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Postharvest Handling of Tropical Fruits

Proceedings of an International Conference held at Chiang Mai, Thailand, 19–23 July 1993

Editors: **B.R. Champ, E. Highley, and G.I. Johnson**

Sponsors:
Department of Agriculture, Thailand
Chiang Mai University
ASEAN Food Handling Bureau
Australian Centre for International Agricultural Research

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Address of Welcome

IT is an honour and pleasure for me to welcome you, on behalf of all the sponsors, to this International Conference on Postharvest Handling of Tropical Fruit, at which you will consider ways to improve the postharvest handling of tropical fruits for the benefit of producers and consumers around the world.

As you know it is much more difficult to export fresh fruit than fruit in the can or otherwise processed. To look at means for overcoming problems in postharvest handling of tropical fruit, the organisers have been able to assemble here an impressive array of invited speakers supported by contributed paper presenters from many parts of the world.

I see from the conference handbook that some 25 countries are represented at our meeting and that participants have come from not just academic institutions, research organisations, and government agencies, but also fruit traders and the wider commercial sector. That we have representatives of the private sector here is gratifying because it indicates that they see the potential for innovation and progress possible by further adoption of the results of research and development work.

Ladies and gentlemen, though you have a very full conference program this week, I hope that you will be able to find some time to sample some of Thailand's unique culture and food, and perhaps to shop for some mementos of your visit to Chiang Mai.

You will have seen just outside this conference room the veritable orchestra of fruits brought together in a display by the Department of Agriculture. This is the season for many kinds of fruit here in Thailand. You can enjoy longan, melon, lychee, sweet apples, durian, and many other fruits. I hope that you will try them as you tour the city of Chiang Mai.

Well, my last words: Welcome to Thailand. I hope your stay will be enjoyable, and the conference stimulating and productive for you. Thank you for your attention.

Professor Dr Choti Theetranont
President
Chiang Mai University
Thailand

Objectives of the Conference

LADIES and gentlemen I have the honour to present to you the objectives of this conference. These are as follows.

- To review key technical information relevant to the postharvest handling of tropical fruits.
- To define the impediments and pitfalls in successful handling, transportation, storage, and marketing of tropical fruit, both for export and domestic markets, and to review possible solutions.
- To provide a platform for the communication of current research, and to foster professional contacts that will minimise duplication and maximise collaboration in future research.
- To publish and disseminate the content and ideas generated at the conference.

Given the planning and commitment by the various cosponsors of this conference, I feel confident that we can meet these objectives over the next few days and in the months ahead. The conference has been at least two years in the planning and, during that period, we have given great thought to what topics the meeting should cover and who should be invited to speak. As it turns out, we have been able, we believe, to arrange something approaching the best of all possible worlds regarding speakers: we have been able to enlist not only key international speakers, but also, through an exceptionally strong program of contributed poster papers, those working on most aspects of tropical fruit handling in the Asian region and elsewhere.

Ladies and gentlemen, I again commend the objectives of our conference to you. I am personally looking forward to a lively and productive meeting, and I take this opportunity to thank in advance all those who will be making presentations. Thank you.

Dr Sonthat Nanthachai
Chief of Postharvest Group
Horticulture Research Institute
Department of Agriculture
Thailand

Collaborative Research and Development — ACIAR's View

On behalf of ACIAR, one of the cosponsors of this meeting, I would like to welcome you all here. I must say how pleased we are to see such a broad representation of interests: a wide range of countries; a wide range of agencies; and a very strong involvement of the private sector.

This level of interest reflects not only the importance of the topic of tropical and subtropical fruit and its handling, but also the extent to which there needs to be close, open, and meaningful collaboration in research and development and, ultimately, in transferring the results of the research that you will discuss this week.

This to some extent reflects the mandate of my own organisation, ACIAR, which is part of the Australian technical assistance program. One of the more unusual things about ACIAR is that it is located in a country which grows many of the crops that we will be talking about this next week. We have tropics and subtropics, and we go right through to cool temperate climates. So we are exposed to a wider range of problems in this area than many other technical assistance donor agencies. This means, of course, that we have many of the same problems in Australia as our developing country partners, and 'partnership' is the hallmark — indeed our motto — for the sorts of activities we engage in. There is no question of visiting experts coming to one country or another; we are equals and we are sharing experiences.

While research will remain a major part of what we support in terms of our funding activities, we have recently had a rebirth as an organisation following a 'sunset' review by a committee of the Australian Parliament. Before that we were an organisation with a sword hanging over us. We had been given an initial life of 12 years, and it certainly sharpens your focus and clarifies your thinking if you know you might cease to exist after such a period.

We have come through a rigorous process of review. One of the most pleasing aspects of this was the very strong representation made by our developing country partners to the Parliament, in some instances in person, which helped our parliamentarians to recognise the importance of research in development. Those of you who have to deal with politicians, will know that is no easy matter.

The fact that ACIAR had a new life also enabled us to broaden our mandate in response to criticisms that research in isolation is of no value at all. We needed to have a strong process whereby the results of research could be translated into usable technologies and then transferred to potential beneficiaries. In our new 'sunrise' period we have been given increased resources from government to assist in positioning the results of research in such a way that they can be picked up by others and of course, activities such as this workshop, which have a mix of people including, very often, policymakers and industry, are an important step in that direction.

One of the dilemmas that all funding organisations face is the issue of private vs. public sector interests and fundings. There are the critics who say that the private sector virtually only comes in very near the market end of research and doesn't like funding research that's further upstream, even though it may eventually benefit from that research.

I think that view is often not well founded. One of the elements in the sorts of partnerships that we have been talking about is the close involvement of the private sector. Clearly, in what's called the pre-competitive stage of research it is often understandable that the private sector feels it cannot be involved because it cannot always capture what it believes is a fair share of the benefits of that sort of activity to recoup its investment and

realise reasonable profit. It remains a question which perhaps may be interesting to explore in some of your workshop sessions or corridor discussions. This is a very important area of funding and at the end of the day, funds are what make it all happen.

I've raised this issue in the context of my own organisation, because one of our objectives, particularly in terms of our developing country partners, has always been to do research which is of relevance to the poor in the rural sector — poor rural consumers, poor rural producers, and also of growing importance because of increased urbanisation in the developing world, poor urban consumers. The issue of who pays and who captures the benefits of research, is critical here.

We often find that with proposals coming to us on, for example, issues relating to the containerised storage of perishables such as fruit and vegetables, it is stated that this research is likely to benefit primarily the businesses concerned with containerisation, marketing, and so on. While there are times when that argument is meaningful, it is no longer always true, because one of the more important consequences of research that we do is to generate income. The only way that one can alleviate poverty in the developing world is to generate income and of those who generate income in some cases it may be off-farm income, but in other cases the only way is to produce cash crops such as tropical fruits. This means reliable markets and reliable receival centres where produce can be stored over a longer period. Thus issues of supply and demand are important and, of course, these impact very much on those poor rural producers who are growing the commodities. That's why I'm really pleased to see the emphasis on marketing and agribusiness in this meeting because, at the end of the day, no matter how poor rural producers are, there has to be a market for whatever they produce if it's a marketable commodity. This is, of course, aside from subsistence production of food to maintain basic needs.

A good example which I have just seen while I have been looking at a range of ACIAR projects is one — not conducted by our agency — with the hill tribes on the Burmese border. As part of the anti-narcotics programs, a number of hill tribes have grown cut flowers with simple but very appropriate technologies, including enhanced lighting, and so on. Appropriate containerisation of these cut flowers and in-container chemical treatments have allowed them to be shipped by truck from the Burmese border, at the northern most tip of Thailand, right through to Bangkok. Thus small producers were able to find a suitable market and it is one of the approaches one might envisage for higher value fruits for which there may ultimately of course also be export markets.

In terms of the relevance of this particular conference to ACIAR's activities, I can say that the postharvest area has been a high priority for ACIAR. One of the important elements of our programs, I believe, has been the need to link production and post product aspects. I think there has often been a tendency, and I see it reflected not only in some ministries in developing countries but also in developed countries, to draw a line, indeed a barrier, between postharvest and preharvest issues. I think all of you know far better than I do, that it is absolutely crucial to link the two. In other words, vertical integration of the whole process is important, whether it's in a developing or developed world context. In this regard we also see, particularly in terms of our partner country activities but also in Australia, the need to consider everything that is done in a socioeconomic context.

Those involved in life science work tend only to bring in the social scientist after the event to do economic analyses of projects as salvage operations, so to speak, to determine whether the research really has a good cost–benefit equation. I think, using today's jargon, that ex ante work is seen to be of equally great importance to such ex post studies, not only in terms of, if you like, dry economics, but also in terms of socioeconomics. We believe this requires a multidisciplinary approach and again it is pleasing to see that reflected in the subject matter at this conference.

In terms of specifics and what Dr Sonthat has already identified as the general objectives for your meeting, there have been three issues that are seen as important for our organisation. One of those is the need for consensus on the development of generic protocols for disinfestation treatments of tropical fruits. One of the features one sees very often is the need to do individual pieces of research for each country within the region if those countries wish to trade with one another in perishable commodities. There is scope for rationalisation and generation of what could be called generic protocols and more strategic research is required to achieve this. This would still be done to satisfy the quarantine requirements in international trade, but would simplify the process.

The other thing of course is to ensure that there is very strong collaboration between countries in regions where there are trade advantages and complementarities in the production of commodities. A good example in the Australian context would be the fact that our seasons are the opposite as a southern hemisphere country. In Thailand, in the northern hemisphere, and where you have products produced over a limited period, we can complement each other in the markets we are targeting and have those products available for a longer period even a year-long period of supply. The year round complementarity means also that collaboration in research can provide for a considerable acceleration in opportunities to complete specific investigations.

The third area and the last that I will mention is that we see it appropriate in the context of perishable commodities to go beyond fruit to vegetables, tropical vegetables are of great importance as you can see when you go to the markets.

In conclusion, I wish you a most successful meeting. Thank you.

G.H.L. Rothschild
Director, ACIAR

Keynote Address

LET me begin by again welcoming, on behalf of the Department of Agriculture, all participants in this International Conference on the Postharvest Handling of Tropical Fruit. I am delighted to see so many people here from so many parts of the world, which surely reflects the importance of the topic of our conference.

Tropical fruits, ladies and gentlemen, are exciting products with exciting market prospects. I believe — if you'll excuse the hint of a pun — that the time is ripe for tropical fruits to fulfil their untapped potential on world markets.

In this part of the world, we have, for the most part, overcome problems in staple food supply and there are food surpluses. Domestic consumers are widening their food horizons. Farmers and traders are looking for crops that will yield extra cash and further improve their standards of living. Fruit is one such crop.

In other parts of the world, disposable incomes are also rising and consumers are becoming more sophisticated, adventurous, and discriminatory in their food preferences. They are now much more likely to want to savour the delights of a rambutan or mangosteen than they were 20 years ago. It is true that the current worldwide recession and other factors have affected global trade in agriculture, but I believe this is a temporary setback and we need to be ready to go when the world economy starts to grow again.

So, in tropical fruit we have a product with enormous market potential. You will see as you preview the next few days' events in your conference handbook, that most of the 70 or so papers to be presented at this meeting will be addressing the technical problems that impede the fulfilment of the untapped potential of tropical fruits on world markets.

The postharvest handling of tropical fruit presents many technical problems, most of them deriving from the inherent attributes of the commodity. There are fundamental differences between temperate and tropical fruits. Temperate fruits such as apples and oranges are relatively easy to store and transport. Indeed, nature designed them for storage insofar as they have usually evolved as structures to protect overwintering seeds. Tropical fruits, in contrast, have evolved to decompose quickly after maturity in an environment where there is generally no impediment to immediate seed germination.

Thus, to be able to use economical means of surface transport to get tropical fruit to distant markets — say to Europe from Thailand or Australia — we need some technical tricks if the end consumer is to receive a good quality product and value for money. We need to remember at all times that export tropical fruit is a high value, high price commodity. For a citizen of, say, Glasgow, Scotland, buying a piece of fresh tropical fruit is likely a very significant purchasing decision. If the product does not fulfil our Glaswegian's expectations, it may be a decision never again entertained.

If we are to fulfil untapped markets for tropical fruit we must focus on a capacity in our handling systems to reliably deliver a quality product that meets market expectations. You will encounter this theme of quality and reliability in many of the papers presented at this conference.

The technical knowledge that we need for successful postharvest handling of tropical fruits spans many disciplines — chemistry, pathology, biochemistry and physiology, engineering and, most recently, molecular biology. So this is very definitely a multidisciplinary endeavour. All of these disciplines are covered in the papers we are to hear over the next few days. First, however, the scene will be set in a series of presentations examining social, economic, and political issues, the importance of quality, and regulatory aspects of international trade in tropical fruit. We will also have an assessment of the returns that we can expect from investment in postharvest tropical fruit research. These

papers are being given by specialists from many different parts of the world, and will give us, I am sure, a broader perspective on the challenges in this field.

Before closing I want to mention a point that is perhaps so obvious that it is liable to be overlooked. This is the comparative advantage that we tropical countries have in marketing our fruit products. Unlike many other agricultural commodities, we are usually not competing with European or American farmers in selling our fruit, or with governments protecting their farmers.

We must continue to capitalise on this advantage. We must also continue to capitalise on the mutual benefits of collaboration in postharvest research and development on tropical fruits. As I have already mentioned, there are fundamental differences between tropical and temperate fruits, such that we cannot simply transpose to our commodities temperate fruit research results. So we have had to start from scratch in determining the characteristics of our commodities.

The collaborative research programs involving my Department and other institutes in Thailand and research groups in Australia, for example, are of great assistance in accelerating our progress up a steep learning curve. They are founded on a recognition of mutual scientific and trade benefits, and we are working together to deliver products of reliable quality that will build consumer confidence and promote wider markets. In collaborative research between my country and Australia, there are few commercial conflicts because our seasons are staggered. Indeed, our collaboration opens up opportunities, through commercial agreements, to provide near year round supplies of fruit to distant markets such as Europe.

Quarantine regulations, principally against various fruit flies, are an impediment to the growth of world trade in tropical fruits. This issue is being tackled on a number of fronts. On the technical side, recent research has shown that all fruit fly species respond similarly to disinfestation treatments, raising the possibility of a generic approach to postharvest quarantine disinfestation requirements. This would seem to be a worthy topic for further international research collaboration. The acceptance of generic quarantine schedules would bring significant benefits, not the least of which would be the possibility for harmonisation of quarantine procedures relating to fruit flies in horticultural produce and, consequently, a further freeing up of trade.

Ladies and gentlemen, I wish you a very successful and productive conference on a topic that you can see has strong economic and commercial aspects as well as technical ones. The full program before you indicates that the conference will certainly be a busy one. Thank you.

Dr Montri Rumakom
Director-General
Department of Agriculture
Thailand

Conference Summary and Recommendations

THESE proceedings publish the 31 invited and 53 contributed poster papers presented at the International Conference on Postharvest Handling of Tropical Fruits, held in Chiang Mai, Thailand on 19–23 July 1993. They also include summaries of the various conference sessions, and of a number of workshops on specialist topics, organised as part of the conference program.

The conference was sponsored by the Department of Agriculture (Thailand), Chiang Mai University, the ASEAN Food Handling Bureau (Kuala Lumpur), and the Australian Centre for International Agricultural Research. It attracted some 260 participants from 23 countries.

Conference objectives were:

- to review key technical information relevant to the postharvest handling of tropical fruits;
- to define the impediments and pitfalls in successful handling, transportation, and marketing of tropical fruits, both for export and domestic markets, and to review possible solutions;
- to provide a platform for the communication of current research, and to foster professional contacts that will minimise duplication and maximise collaboration in future research; and
- to publish and disseminate the content and ideas generated at the conference.

Attainment of the first three of these objectives was assured by the comprehensiveness of the conference program, the range and quality of the presentations made, and the enthusiasm with which participants contributed to discussion sessions. These proceedings fulfil the final objective.

In the final session of the conference, following presentation of workshop reports and general discussion, the following recommendations were adopted.

1. That a multi-sectoral approach to R&D be adopted, so that research agencies together with the private sector are involved in jointly funded studies.
2. That a multidisciplinary approach to tropical fruits R&D be adopted.
3. That the commodity focus of R&D be on high-value fruit, and the marketing focus be on sea movement of tropical fruits.
4. That work be initiated to develop generic disinfestation procedures to meet the requirements of major fruit-importing countries.
5. That a mechanism for continuing and enhanced exchange of information on technical issues and market development be established.
6. That sustainability in R&D work be a matter of concern in developing countries. If trends in other countries are mirrored in Asia, the amount of government funds for horticultural research will decline. To offset this decline, the private sector will need to be financially involved and mechanisms for such involvement need to be developed.

Participants contracted to vigorously pursue these objectives on return to their respective countries, institutes, agencies, and companies.

Overview of the Problems

Tropical Fruits: the Social, Political, and Economic Issues

Alex Buchanan*

Abstract

Most tropical fruits, apart from bananas and pineapples, used to be grown mainly in home gardens and smallholdings for local consumption. Recently, many new tropical fruit export markets have been developed through large-scale production in plantations, improved technologies, longer storage life, improved marketing, improved prices for tropical fruit, and changing food habits.

This has been stimulated by government support in many prosperous, newly independent tropical countries.

Processing technologies have enabled the development of new markets for fruit juices and improved postharvest technologies are allowing new markets for fresh tropical fruit to be developed.

New outlets for tropical fruit are being stimulated by tourism in tropical countries, increasing incomes and a trend towards healthy eating.

The growing demand for 'clean' food free of additives and pesticide residues, creates a marketing opportunity which should be considered by tropical fruit producers.

UNTIL recently, most tropical fruits were grown primarily in home gardens and smallholdings for local consumption. This has changed in recent years because improved processing technologies, longer storage life, better storage facilities, and better transport systems have allowed more distant markets to be developed. With this has come the development of large-scale production in plantations, improved marketing, increased exports and various forms of government support for tropical fruit production, marketing, and research and development.

Improved technologies which have been developed in recent years have had an important role in enabling these changes to take place. These technologies will be discussed in more detail by other speakers at this conference, but it should be acknowledged at the outset how important has been the contribution of technological development in triggering the social and economic changes. The technological advances have included those in:

- identifying the optimum conditions for postharvest handling of different types of tropical fruits;
- refrigeration for cooling and chilling fresh fruit as well as for chilling and freezing processed fruit and juices;
- modified atmosphere packaging (MAP) and controlled atmosphere packaging (CAP), for prolonging storage life;
- airfreight, albeit high in cost and of limited capacity;
- packaging developments;
- irradiation, pesticides, integrated pest management, and other methods of pest control and improving quality and postharvest storage life.
- ultrahigh temperature (UHT) processing, aseptic packaging, and 'bag-in-box' technology, particularly for fruit juice and concentrates;
- fruit drying; and
- development of purees, extracts, and essences for use in other processed foods.

The impact of these technological advances has been limited by tariffs and non-tariff barriers to trade, particularly quarantine barriers.

Processing

In the early twentieth century, pineapple was the only tropical fruit used for large-scale commercial processing. Large-scale, efficient canning facilities were developed in Australia, Malaysia, Philippines, Thailand, and other countries. Large-scale plantations were established to serve these canneries.

Canning technology, also used for the large-scale canning of temperate fruits such as peaches, pears, and cherries, was easily extended to the canning of lychees, rambutans, mangoes, and other tropical fruits. In 1990 in

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Thailand, 90% of canned fruit production was pineapple and the rest longan, rambutan, lychee and others. Output grew from 215 452 t in 1985 to roughly 420 000 t in 1989 then dropped to 404 000 t in 1990 (Bhumiratana et al. 1993).

The largest canned fruit market in the region is Japan, where the demand has remained stable over recent years. However, domestic fruit production declined 34% between 1980 and 1990, so imports have increased (Table 1).

Japan also imports preserved mangoes, guavas, mangosteens, avocados, bananas, and fruit juices and markets for these are expected to continue to expand.

However, fruit canners will need to be aware of the strict quality control operating in Japan. Even the quality of the can itself is important in the Japanese market. One supermarket chain refuses to handle cans with paper labels because cans with torn labels are rejected by consumers as defective products, as are dented cans.

Fruit Juices

More recently, new technology has allowed the development of widespread markets for fruit juices. The market for orange juice has led to the development of markets for a wide variety of other juices, including tropical fruit juices and purees, each with their special problems in marketing and technology. For example, Chan and Ramanajaneya (1992) at the United States Department of Agriculture (USDA) Tropical Fruit and Vegetable Research Laboratory in Hawaii improved the quality of aseptically processed 'bag-in-box' packaged papaya puree but could not inhibit the browning reaction. Soponronnarit et al. (1992) refined the method of drying papaya glacé in a cabinet dryer. Hodgson et al. (1990) developed a simplified process to produce guava juice concentrate.

World trade in tropical fruit juices, concentrates, and pulp has expanded rapidly in recent years, with world trade in fruit juices increasing fourfold between 1977 and 1988. A sophisticated passionfruit juice concentrate plant was recently established in Sabah (Anon. 1993d).

Kortbech (1990) expected the increase in world trade in fruit juices to continue. The major exporters are Brazil, Mexico, Morocco, Philippines, Thailand, Belize, Chile, Kenya, and Turkey. The five largest import markets for fruit and vegetable juices and concentrates in 1988 were the USA, Germany, the U.K., the Netherlands, and Canada.

Changing consumer preferences are having an impact on the market, as increased awareness of health issues leads to increased consumption of fruit juices and other 'natural' products. The main outlets are in beverages and dairy products. Other outlets include bakery products, baby food and jelly. Kortbech (1990) considered the prospects for the industry to be good, particularly in the light of current health consciousness.

In Thailand, fruit juice consumption is still increasing at about 20% per annum (Table 2) The Thai fruit juice market is valued at US$39–47 million a year and is expected to grow by some US$780 000 annually and mature in 2–3 years according to Simon (1993) He attributes the expansion to changing lifestyles and growing health awareness in the country. Nevertheless, the current level of 1.64 litres per head per annum is still way below the 5.7 litres in France and a massive 32 litres in West Germany (Brunet and Porter 1991).

Table 2. Fruit juice consumption in Thailand

	1989	1990	1991	1992
Sales volume (million L)	54.0	66.4	77.8	95.6
Population (millions)	55.4	56.3	57.0	58.0
Per capita consumption	0.97	1.18	1.37	1.64
Consumption rate growth		+21%	+16%	+20%

Source: Distribution and Production Control Division, Ministry of Finance, Thailand, in Bhumiratana et al. (1993).

Social Issues

The market for tropical fruit is increasing rapidly in many countries because of increasing tourism and incomes and the trend towards healthy eating.

The rapid growth in air travel and tourism in recent years has seen many potential customers becoming

Table 1. Imports (t) of canned fruit into Japan

Fruit	1986	1987	1988	1989	1990	1991	1992
Pineapple	18 424	19 847	21 627	24 941	53 283	66 515	60 934
Peaches	38 510	39 866	46 626	47 075	37 545	54 737	52 900
Pears	4 751	5 929	6 046	5 726	6 243	6 819	7 669
Apricots	2 609	2 800	3 542	3 085	3 228	3 000	3 602
Cherries	1 339	1 401	2 945	4 065	3 558	3 228	5 164
Mixed	7 481	7 507	9 802	9 401	9 155	11 834	13 380
Total	73 114	77 350	90 588	94 293	113 299	146 133	143 649

Sources: Tradescope (1992a b) and Japan Statistical Yearbook (1992)

familiar with tropical fruits. European, American, Australasian and Japanese tourists are being introduced to the joys of fresh tropical fruits. When they return to their traditional breakfasts of rice porridge, oat porridge, corn flakes, or even muesli with dried tropical fruit in it, they become nostalgic for the exotic and delicious fruits they experienced on their visits to the tropics.

Others are finding that Cavendish is not the only variety of banana. This is leading to increasing markets in Hong Kong, Japan, and other countries for more delicious varieties such as the one known as 'pisang mas' in Malaysia, 'senorita' in the Philippines, or 'monkey' banana in Japan. Esquerra et al. (1992, 1993) have shown that some of the more exotic varieties can be exported to distant markets with a reasonable shelf life with improved eating quality.

In Europe, the consumption of tropical fruits increased from 7.8 to 10.8 kg per capita between 1983 and 1986 according to Arope (1992). He noted the same trends in Malaysia where papaya consumption increased from 2.7 to 3.8 kg per capita from 1985 to 1988 whilst carambola consumption doubled from 0.2 to 0.4 kg per capita over the same period.

Throughout the world there is a dramatic trend towards healthier eating. Consumers around the world are far more conscious and knowledgeable about healthy diets and are substantially changing their diets. Fruits in general are accepted as being rich in vitamins, minerals, and dietary fibre and therefore as essential ingredients of a healthy diet. This image is good for the industry and has the advantage of being true. Most would agree with Proctor (1990) that the wide interest in healthier eating will lead to increased consumption of all fruit and that an increasing proportion of this will be tropical fruit.

Integrated Pest Management

In many markets there is scope for the marketing of fruit which is considered to be organically produced (Marte 1989), or at least free of pesticide residues. This is a marketing opportunity for the producers of tropical fruit. The biological control of pests and 'integrated pest management' (IPM) should be viewed as not only a method of controlling costs of production and postharvest handling of tropical fruit. It should also be seen as a marketing tool to gain a premium from environmentally conscious customers.

Marketers of tropical fruit could find that it is feasible to develop IPM programs and an IPM certification system to capitalise on this growing market, not just in Europe and the USA, but also in Asia, where food industry leaders are predicting there will soon be a big rise in consumerism and awareness of environmental considerations (Buchanan 1993).

The more prosperous countries of Asia are expected to leapfrog the rest of the world with their growing consciousness of environmental matters. Thus there could be a marketing advantage in developing an internationally recognised IPM certification system. Consider the parallel case of the American Earth Island Institute (EII) which certifies companies for dolphin-friendly fishing methods. Due to consumer demand, this certification has become, in practice, a requirement for the marketing of tuna (Anon. 1993b).

Quality Control

The Queensland Department of Primary Industries identified high priorities for future research and development as the development of quality management systems, identification of causes for consumer satisfaction with internal quality, and development of cost-effective systems for long distance sea transport. Education of growers in postharvest handling and marketing was regarded as essential for the results of R and D to be effectively utilised (Ledger 1991). Even for the very tolerant local market in Australia, they found fruit quality was a limiting factor to market expansion. For example, over 40% of avocado consumers surveyed could recall a bad purchase and 53% reported that avocados were unsatisfactory when served. Less than 2% of Australia's avocado production is exported but market opportunities were identified in Europe from April to November if freight costs could be contained and quality assured.

In summary, marketing opportunities for fresh tropical fruit are available but quality must be improved and costs must be controlled.

Political Issues

Until recently, pineapples and bananas were regarded as the only tropical fruits with potential for export and large-scale development. Other tropical fruit were grown primarily in home gardens and in smallholdings for local consumption.

Governments regarded other tropical fruits as useful in the local diet and a source of supplementary income for smallholders (Arope 1992) but not as having serious potential for developing export income. This has now changed.

The Malaysian Government now encourages the large-scale cultivation of fruits through various tax incentives and special loans (Basri 1989). They are planning to increase the cultivated area for fruits in Peninsular Malaysia from 121 529 ha in 1986 to 263 000 ha by the year 2000 (Punan et al. 1991)

Arope (1992) claimed that the government-owned Malaysian Airlines has a special commodity rate for fruit consignments, lower then the rate applying to textiles and footwear, resulting in a subsidy of M$3.9 million p.a.

In Thailand, the government is cooperating with the private sector in promoting expansion in exports of fruit, which has been considerable in recent times (Subhadrabandhu 1992).

Economic Issues

Agricultural commodity prices have generally been steadily declining, relative to other prices, for the past 20 years, but over the same period, tropical fruit prices have been rising. So with improved prices and improved technologies we have seen big plantation companies diversifying into the fruit industry. In Malaysia, for example, Guthrie, Golden Hope, Asiatic Development, Perlis Plantation, Sime Darby, and scores of government agencies such as the State Economic Development Corporations have gone into large-scale planting of mangosteens and bananas (Arope 1992).

Large scale cultivation of carambola has developed over recent years with new markets being developed in Europe and the Middle East, supplementing Malaysia's traditional export markets in Singapore and Hong Kong. Exports of 13 022 tonnes in 1988 were expected to increase to 20 000 tonnes in 1992 (Wahab et al, 1989). The Malaysian Ministry of Agriculture recently identified 15 types of fruit as suitable for large-scale production, including durian, mango, rambutan, mangosteen, papaya, banana, and carambola.

In Indonesia, 2000 ha in West Java have been allocated this year for a tropical fruit plantation, to expand cultivation of durian, rambutan, pineapple, orange, mango, banana, mangosteen, and lanseh (Anon. 1993a).

Fruit production in Thailand increased from 58.8 million tonnes in 1981 to 75.1 million tonnes in 1987, with export value increasing over the same period from 29.75 to 63.9 billion baht.

Tables 3–5 show that the overall production of the large-volume tropical fruits (bananas, mangoes, and pineapples) has increased steadily for the past decade but there have been no dramatic increases in production. India and the Philippines have maintained their positions as the dominant producers of bananas. India continues to produce about 60% of the world's mangoes, but the Philippines is the leading exporter. In Thailand, pineapple production has decreased, but that country still dominates pineapple production in Asia. Thailand produces as much pineapple as Latin America and more than all of Africa.

Trade with Japan

The largest food importer in this region is Japan. The Japanese market is 35% larger than the nine next largest food import markets in the region put together (Table 6).

Table 3. Production of bananas in the Asia–Pacific region ('000 t)

	1979–81	1990	1991	1992
Australia	126	165	203	198
China	296	1 657	2 177	2 200[a]
India	4 403	6 734	6 400[a]	6 649[a]
Indonesia	1 886	2 411	2 472	2 530[a]
Malaysia	452	505	509[a]	510[a]
Philippines	4 006	2 913	2 951	3 900[a]
Thailand	1 550	1 613[a]	1 620[a]	1 630[a]
Oceania	1 083	1 419	1 459	1 490
PNG	904	1 200[a]	1 200[a]	1 242[a]
USA	2	5	5	5[a]
World	37 087	47 013	47 953	49 672

Source: FAO (1993)
[a] FAO estimate

Table 4. Production of mangoes in the Asia–Pacific region ('000 t)

	1979–81	1990	1991	1992
Australia	2	12	13[a]	14[a]
China	291	463[a]	595[a]	630[a]
India	8 365	9 500[a]	9 700[a]	9 890[a]
Philippines	369	338	306	308[a]
Thailand	509	614[a]	614[a]	615[a]
Oceania	10	19	21	22
USA	6	9	13	9[a]
World	13 597	16 045	16 592	16 844

Source: FAO (1993)
[a] FAO estimate

Table 5. Production of pineapples ('000 t)

	1979–81	1990	1991	1992
Australia	124	126	142	145[a]
China	299	697	923[a]	1 008[a]
India	548	787	800[a]	820[a]
Philippines	861	1 156	1 171	1 170
Thailand	2 857	1 865	1 931	1 900[a]
USA	597	522	504	500[a]
Latin America	1 584	2 254	2 144	2 200
Africa	854	988	997	1 040
World	8 978	9 980	10 183	10 384

Source: FAO (1993)
[a] FAO estimate

The demand for fresh fruit in Japan is not growing on a volume basis. The same is true of fresh fruit imports. Although demand for some tropical fruit is growing rapidly, consumption volumes remain so small that overall demand for tropical fruit is not affected. The

major tropical fruit imports are bananas (84%) and pineapples (14%), for which the demand remains unchanged (Tradescope 1991).

However, the Japanese like delicious and exotic tropical fruit very much (Kitagawa et al. 1990; Kitagawa, these proceedings). In the early twentieth century, fruits were purchased by wealthy people as ornaments or gifts, like flowers, rather than as food. This custom continues in Japan. The gift market covers both fresh and canned fruit, as it does in other parts of Asia.

Table 6. Food imports in 1990 (US$billion)

Japan	28.2
Hong Kong	4.6
Taiwan	4.2[a]
South Korea	3.2
Singapore	2.4
Malaysia	1.7
Australia	1.4
Thailand	1.3
Indonesia	1.0[b]
Philippines	0.7[c]

Source: White (1992)
[a] processed food only; [b] 1989 only; [c] 1988 only

In Japan, you will see various kinds of fruit in gift baskets and beautifully decorated boxes being sent to respected persons, friends and sick people. For this purpose, fruits should be excellent in external appearance, and this is why size, colour, and overall fruit quality are so important to the fruit trade in Japan. The custom persists and, as such, the Japanese buy disproportionately expensive fruit relative to their income. They distinguish fruit from other foods.

To the Japanese, eating fruit is a luxury similar to the consumption of alcoholic drinks. Kitagawa et al (1990) describe it as quite common for one family to divide a single apple after dinner, peeling and cutting the fruit. So an apple should be large and of good appearance besides having good eating quality. Rare and exotic fruit can be sold for very high prices, but if the fruit has lost its rarity, the price goes down and consumption may even decrease.

So the demand for tropical fruit other than banana and pineapple is expected to increase as the diversification of eating habits progresses and interest among restaurants and up-market fruit shops grows, according to Tradescope (1991).

The imports of the main tropical fruits are shown in Table 7. Almost all the pineapples and most of the bananas and mangoes come from the Philippines. Their papaya comes from the USA, all from Hawaii. The USA and Mexico supply all Japan's avocado requirements.

European Community Market

The European Community (E.C.) market for tropical fruit has more than doubled since 1983 especially for pineapple, avocado, mango, and papaya. There is also considerable interest in what Proctor (1990) calls the minor tropical fruit such as lychee, carambola, passionfruit, guava, mangosteen, and physalis. These minor

Table 7. Imports of tropical fruits into Japan ('000 t)

	1986	1987	1988	1989	1990	1991	1992
Bananas	765	775	760	774	758	803	777
Philippines	620	570	600	620	585	587	547
Ecuador	57	80	70	85	125	135	152
Taiwan	82	108	85	62	33	54	66
Others	5	17	5	7	14	27	12
Pineapples	145	145	138	135	128	137	127
Philippines	140	136	130	130	124	135	125
Papayas	4.0	4.3	5.2	5.7	5.4	5.3	5.2
USA	4.0	4.3	5.2	5.7	5.4	5.3	5.2
Mangoes	3.7	5.6	5.3	6.0	5.5	6.9	8.1
Philippines	2.8	4.3	4.2	4.7	4.3	5.8	7.3
Mexico	0.1	1.2	1.0	1.2	1.2	1.0	0.7
Avocados	2.9	5.2	3.4	2.7	2.2	2.7	3.6
USA	1.8	4.7	2.5	1.7	0.9	1.0	2.2
Mexico	1.1	0.5	0.9	1.0	1.3	1.6	1.4
Total	920	935	912	924	899	955	921

Source: Japan Statistical Yearbooks (1986–1992)

tropical fruit are a subject of increased consumer interest and curiosity; and for many the market is expected to increase rapidly over the next few years. Proctor (1990) suggested that the characteristics which should be taken into account when evaluating alternative tropical fruit for U.K. markets are:

- small to medium size or weight;
- long season of supply, preferably all year;
- easy to eat and prepare;
- multipurpose culinary usage;
- interesting colour or shape characteristics;
- long storage life; and
- ease of post-ripening handling.

Factors influencing the demand include increased consumer purchasing power, product promotion, consumer education and above all, the increased availability and access to, well-presented quality fruit.

Iso and Hamilton (1990) identified 10 tropical fruits and nuts with the potential to increase their share of the market as carambola, durian, lansone, mangosteen, peach palm, pili nut, pulasan, rambutan, sapodilla, and soursop.

In many E.C. countries, particularly in the U.K., the share of the fruit trade held by the supermarkets has risen spectacularly (Table 8)

Table 8. Distribution channels for fruit in the U.K.

	1976	1987
	% share	
Supermarkets	22	49
Greengrocers	37	28
Market stalls	25	17
Others	16	6

Source: Henderson (1989)

Chilvers (1987) noted that the U.K. market for exotic (tropical) fruits was expanding rapidly when the fresh fruit market as a whole was showing very limited growth. Exotics have become the main hope for further expansion and diversification. He analysed the demand and prospects for 32 individual exotics through to 1995, outlining opportunities arising from seasonal gaps in supply and from market growth, then advised on market opportunities for suppliers of exotic fruits.

Verhaegh (1991) showed that Dutch imports of fresh tropical fruit increased strongly in the 1980s and concluded that the market remains a promising one. French imports increased slightly in 1989 because of increases in avocado, mango and pawpaw shipments (Guinchard 1990), maintaining the 25% increase in consumption of tropical fruits between 1980 and 1988 (Durand 1989).

The trend is the same in the newly emerging countries of Southeast and East Asia, with supermarkets becoming important distributors of all fruits.

Transport Costs

Ahrens (1990) pointed out that in many export markets, the transport of the product accounts for over half of the retail price. Appropriate transportation may not be available at all for tropical fruit with high respiration rates, rapid deterioration, and susceptibility to chilling injury. Air freight is expensive but also is often not available during the peak of the season. The airlines will quote much reduced prices for quantities over 500 kg and will negotiate cheaper rates to destinations where there is spare capacity. For example Parkes (1987) quoted Qantas rates of A$6/kg from the U.S. west coast to Australia but only A$1.50/kg for primary produce in the opposite direction. As a result, fresh fruit and vegetables comprise Australia's main export items by air.

Subhadrabandhu (1992) reported that most Thai fruit exports are shipped by passenger aircraft but the space is limited and available only from a few airline companies. The freight charges were described as 'high', but the prospects for export expansion as 'bright'.

Nevertheless, improved technologies have enabled producers to extend the limits of their export markets (Bagshaw 1991; Chaplin et al. 1991; Esquerra and Lizada 1990; FAO 1990; Jordan 1989; Newell 1989; O'Connor et al. 1992; Onnop et al. 1988; Sankat and Balkisson 1992; Seow et al. 1991; Tjiptono 1993; Tongdee et al. 1990; Tongdee and Suwanagul 1989; Wills 1990; Wills et al. 1988; Yuen et al. 1993; Yuniarti 1993; Yuniarti and Suhardi 1992). For the ASEAN countries, the traditional markets in Hong Kong, Singapore and Malaysia have been extended to include Japan, Brunei, the Middle East, Europe and North America.

Taiwan

Lin (1992) reported fruit production in Taiwan steadily increased between 1945 and 1988, from 6.4% to 35.5% of total agricultural crops, with planting increasing from 18 220 ha to 214 025 ha. In recent times, production has shifted away from bananas and pineapples to high unit value crops such as wax apples, grapes, and oriental pears. They also grow guavas, carambola and mangoes.

Taiwan fruit exporters are now set to enter the U.S. market, following the U.S. Department of Agriculture's recent approval of the first shipment to pass its quarantine inspection, after solving their problems with fruit fly and other diseases. The first five tonnes of mangoes are to be exported in July and will probably be followed by consignments of peach, papaya, lychee and wax fruit (Anon. 1993c)

Korea

South Korea has the potential to be a significant market for tropical fruit exporters but they will not be pleased

that for the first 10 months of 1992, banana imports were cut by about 60% compared to the previous year, to US$76.5 million (Anon. 1993c)

North America

Sood (1989) reported on a detailed study of the U.S. market for bananas and other fresh fruit for the period 1980–87. There was an increase in consumption of fresh as well as processed fruit during the period. Even then, interest in nutritious food was a contributing factor, as was the ageing of the population. Although imports doubled in five years, they represented only a small percentage of the U.S. fruit market. The main opportunities for fruit imports occurred outside the seasons for locally grown fruit, or when the climate prevented a good harvest of local fruits. The distribution of fresh fruit in the USA was found to be very efficient. Sood (1989) found only about half the final cost due to transport, storage and marketing.

Figueroa and Echeverri (1990) surveyed North American produce importers in the autumn of 1988. They expect demand to increase and found that more information regarding nutrition and culinary uses of tropical fruit would enhance that demand. Price and advertising can also affect the demand.

Ledger (1989) found that in the U.S. market, fresh fruit and vegetables are the number one reason why consumers select a particular grocery shop. They are interested in a diverse range of products, which has spurred the growth of 'exotics'. The rise in demand for 'exotics' is a result of the growing popularity of ethnic cooking, consumer desire for greater variety of fruit and vegetables, the growth in Hispanic and Asian populations, as well as strong promotion of 'exotics'.

The retail industry is dominated by grocery chains (with more than ten outlets) but about 40% of fruit and vegetables in the U.S. are used by the food service industry.

In the U.S. and Canadian markets, Caplan (1990) attributed her company's success in marketing tropical fruit to: (1) the variety of items available; (2) branding; and (3) aggressive marketing. However, she attributed the overall success of tropical fruit in general in the North American market to the growing health consciousness of adventurous consumers, for whom price is no longer a barrier to *moderate* volume. 'Tasty, high quality tropicals are just the hook that many retailers in the United States feel they need to "bait" sought after customers'.

Morton (1990) listed jackfruit, breadfruit, plantain banana, egg fruit, and akee as tree fruits important in certain areas of the world but under-exploited or totally unknown elsewhere, for which further markets could be developed. Durian is another obvious possibility in this category (Mohamed 1990). Herein is an opportunity for innovative food processing and market development.

Finally, the primary influence in expanding world trade has undoubtedly been the availability of quality produce and improved shelf life, with the extension of the time for which that quality can be maintained, so essential for the distant premium markets being targeted.

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Quality Assurance: a Total Approach

C. Bunt and M. Piccone*

Abstract

Commercial fruit production is part of the food manufacturing industry. For protagonists in this industry to be profitable and continue to be viable they must satisfy several objectives. These include the following.

- Ensuring that the end customer is satisfied in terms of service, product price, and quality. Producers and marketers must continually respond to — and meet — their end customers' expectations.
- Business operations need to be run efficiently and cost-effectively. The market will only ever pay a certain price for fresh or processed produce, dependent on supply and demand. To maximise profit, a business must be as cost-effective and non-wasteful as possible. Production and handling cost reductions in a static market-place can often be the difference between making a profit or a loss.

In order to meet these and other objectives, quality assurance (QA) as a management and marketing tool has become an integral part of commercial fruit production in a wide range of crops. The emphasis in this paper is that a QA program, to be truly successful, must incorporate all facets of a production and distribution chain. To not do so means running the risk of having dissatisfied customers, as well as incurring unnecessary costs and wastage.

THE horticultural industry has unique characteristics, including susceptibility to weather and, often, seasonal production. The evolution of QA in horticulture has been in response to the apparent need for greater control of both production and marketing activities. As such, QA can be seen as a catalyst for change. However, it is critical that this change be carefully managed.

QA involves the product, services, processes, and people. It is a planned and systematic integration of *all* these business components (Fig. 1).

This paper examines the effect of variability in horticulture and the industry's role as a food manufacturer. The paper looks at the evolution of quality assurance (QA) and the role of quality standards. It assesses the critical elements necessary to successfully implement quality programs and pitfalls that must be avoided.

Quality Assurance and Its Relevance to Commercial Horticulture

QA had its origins in the heavy industrial manufacturing sector, most visibly successful in Japan after World War II. It began with the use of statistical techniques to measure and therefore control variability in production.

It is the term *variability* that is the key to understanding QA. QA practitioners accept that variation is present in all aspects of our lives and work. This concept is particularly true in horticulture. The vagaries of nature, differences in growing techniques, and the likely

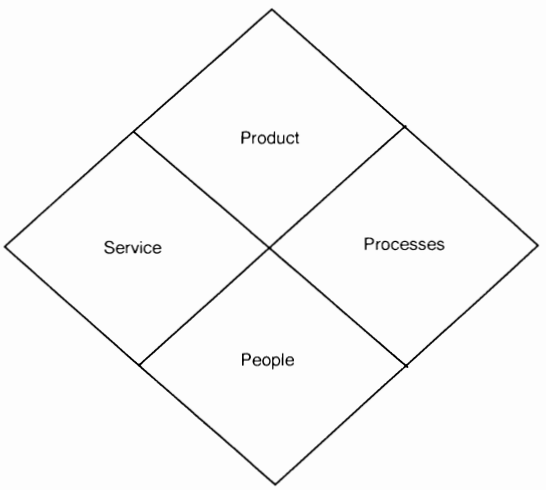

Figure 1. Quality assurance: a planned and systematic integration

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range of postharvest handling conditions create equal variation in the quality of the product, i.e. the packaged fruit or vegetable. Additionally, given that horticultural production and marketing are often loosely structured and seasonal there is also wide variability in people performance, product knowledge and, essentially, commitment to a business or product's commercial success.

In a *marketing* sense, QA assures customers that they can purchase a product with confidence, knowing that it will meet *all* their expectations for that product. QA is concerned with building and maintaining a product's *reputation.*

In a *production* or *manufacturing* sense, it is concerned with ensuring that the marketing goals are achieved in the most *consistent, cost-effective,* and *efficient* manner possible.

QA systems are designed to consistently satisfy customer expectations by *defining objectives, planning activities,* and *controlling variability.*

Commercial Fruit Production as Part of the Food Manufacturing Industry

Having said that QA is a management tool with its origins in the manufacturing and industrial sector, how can we measure its worth or relevance to horticulture?

Let's look at the similarities between commercial horticulture and manufacturing in a general sense.

Firstly, *commercial* horticulture, in this instance tropical fruit postharvest handling, is above all else a *business* activity. Many of the people at this conference may not always see themselves as commercial operators, but the harsh reality is that commercial horticulture in all its components must concern itself with *sustainable profit* — that yardstick needs to permeate all horticultural activities, including research and development. Sustainable profit is very much tied to customer satisfaction, so horticulture and manufacturing do share the same marketing goals inherent in QA.

What about production issues?

One would assume that any commercial producer wishes to be as cost-effective and efficient as possible. What are his chances though of *controlling variability,* say in comparison to a car manufacturer or producer of electrical goods? My point is that the commercial fruit producer or postharvest handler faces far greater hurdles than producers of 'hard' commodities. Yes, we are manufacturers — we take the raw materials (i.e. the fruit) and handle, treat, and modify, that is, *manufacture* a product. But our key raw materials and our products are alive! The potential for variability is enormous and therefore exceedingly difficult to *measure* and *control.*

The evolution of horticultural quality assurance

QA in Australian horticulture is being developed very much with the aim of compliance to international standards — specifically the International Standards Organisation (ISO) 9000 series. These are *manufacturing* standards that evolved mainly from the aeronautical industry.

There is a move worldwide for horticultural industries to develop quality systems that comply with ISO 9002 — this is a trend where we believe further thought is warranted.

On one hand, compliance with an ISO standard imposes *discipline* on an organisation. This discipline increases the confidence of a purchaser in the quality of suppliers' products — hence the push for suppliers to become accredited to a standard often comes from the market-place or governmental agencies. However, with many seasonal tropical crops the *inherent variability of production* makes accreditation in itself misleading from a customer's point of view.

Accreditation to an internationally recognised standard such as ISO 9002 is ideal for industries such as appliance manufacturers producing the same products in the same way, day in, day out, all year long. Their systems operate consistently because their inputs and outputs are measurable and reliable. They are also far more likely to have a stable, permanent staff operating their systems than many horticultural businesses, such as seasonally operated packhouses for instance.

An accreditation compliance audit of a packing house, for example, is likely to give an atypical impression of the overall performance of that packing house because of this inherent variability of fruit production. 'Acts of God' such as hailstorms or continuous rain will place enormous pressure on packing house systems. Staff will often be casual labour who will have far less real commitment than most permanent staff and they will have accrued less experience and skill. The 'raw materials', i.e. the harvested fruit, may vary widely from one grower or orchard block to the next. Regardless, the packer is expected to cope equally well — despite the stop–start nature of postharvest fruit handling, despite the often high staff turnover, and despite the possibly wide variations in fruit quality and characteristics.

We believe that horticulture needs to take the *discipline* aspects of the standards being used as *models* for accreditation and modify those standards and accreditation requirements to suit the peculiarities of horticultural industries.

Yes, we *are* manufacturers, but horticultural industries are unique and this 'uniqueness' should be reflected in design and implementation of our QA systems.

Where Does a QA System Begin and End?

QA systems are *documented* as they are *planned* and *deliberate*. They must encompass the products produced, services rendered, processes employed, and human component of an organisation or business.

In essence they begin with the customer and end with the customer, because a QA system documents all the interactions necessary to satisfy the customer's requirements. Although they are formal and written down, QA systems are 'alive' and dynamic. They must be designed so as to never take the customer for granted and always consider improvements that can be made to current practices. Really 'living out' this philosophy is a major cultural change or challenge for any business. This is especially so for a basically conservative industry such as commercial fruit production, where inherent business practices may go back generations.

We find the easiest and most effective way to visualise and therefore develop a QA system is not to start at the beginning, but to start at the end, i.e. by looking at what is required in the market-place. What we are suggesting is that *QA programs should be structured to satisfy marketing objectives in the most reliable and cost-effective manner.* They should therefore expand the potential profit margin for a product by not only maximising returns, but by minimising production and post-harvest handling costs.

Traditional *quality control* (QC) programs have been very much *inspection* orientated. They utilised a set of product specifications or standards, inspected product against those standards and segregated defects. There are many so-called QA or quality management programs being promoted currently in horticultural circles that we believe are really only basic QC programs. That is because they do not get to the *root causes* of quality issues as they exist or as they arise. They rely on inspection rather than *objective information gathering and problem solving.*

QA programs need to be *process orientated.* They should look at the *method* employed, not simply the end result. Therefore they are concerned with *management practices* with quick, early, and accurate identification of actual or potential problems and deviations a key factor — if the *system* is working effectively, you cannot help but get the proper end-result.

Getting to the root cause of quality issues means asking questions and making judgments based on the answers. Let's take a hypothetical but not uncommon example:

The problem:	Bruised fruit are being found in packed trays.
Question:	Why are these fruit bruised?
Answer:	Because they were damaged on the sizer.
Question:	Why were they damaged on the sizer?
Answer:	The bruised fruit appear to be soft.
Question:	Why are they soft?
Answer:	Their flesh temperature is high.
Question:	Why is it high?
Answer:	Bins of fruit were marshalled in the sun.
Question:	Why were they marshalled in the sun?
Answer:	Because the shaded area was full.
Question:	Why was it full?
Answer:	Because the packing house staff member responsible neglected to inform the pickers that stockpiles were becoming over-loaded.

How many quality risks and potential solutions can you identify in this chain of events? What was the *real* cause or causes of the bruised fruit? How could these problems be solved?

Each time a process occurs, *value is added* to the end-product or service. Each time something goes wrong cost is accrued, stress levels rise, and a company's performance and/or reputation declines. *Why should this be tolerated?*

QA was developed by industries such as car manufacturers where mistakes are not accepted. As food manufacturers in an increasingly competitive and customer-conscious world can we afford to be any less diligent?

QA as the Planned Interaction of Products, Services, Processes, and People — a Total Approach

In our experience of horticultural quality systems we have seen four very common 'pitfalls' repeated many times, especially in the development phase.

- The first of these mistakes is what we call the 'paint by numbers' approach. This is when an organisation takes a theoretical type quality system and attempts to impose it on their own activities. Invariably this doesn't work, or at best doesn't lead to a sustained QA program. To be truly sustainable and successful QA programs must be driven and understood by the management of a company. This commitment must be encouraged in everyone associated with the business. This means that the QA program being implemented must reflect the *specific goals* and the *particular strengths and weaknesses of the company* — only then will its participants realise the relevance to them and its worth.
- In the early stages especially, designing and implementing QA programs requires a great deal of effort, open-mindedness, and plain hard work. For that energy and momentum to be sustained, the com-

pany's *total commitment* to the program, especially that of management, is absolutely vital. A lack of genuine commitment is the second common pitfall.

- A third very common pitfall is confusing QA or quality management with *product maintenance*. The maintenance of a product's physical quality and characteristics during growing, postharvest handling and marketing is absolutely vital. *It is not what QA is all about, however.* Product maintenance is just *part* of a 'big picture'. QA is concerned with the *management* of *all* the components of the activities of a business. You might have the most attractive, long-lasting fruit in the world, but if your people management is poor, product servicing is inadequate, your supply capability erratic, or your production costs excessive, then sooner or later you will fail.
- The fourth and most 'human' pitfall to be avoided is *complacency*. Companies embarking on a QA program will soon begin to see improvements in their business operations and will likely receive kudos from the market-place and peers for their improved performance. Don't fool yourself now that you've 'made it'. If a primary goal of QA is to maintain a competitive edge in terms of product reputation and production efficiency then a company must be prepared to continually and self critically strive for improvements. If you don't, your competitors will!

In stating that QA is a total management approach and philosophy it follows that *people embarking on a QA program must be prepared to change*. Embracing change is often one of the most difficult things in life for us to accept. Adopting a quality approach to business means taking a hard critical look at the way we currently function and finding out why we function that way — not only as a business or industry but also as individuals. That analysis takes courage and honesty. It takes courage because the limitations of our industry, of our business, and particularly of our own limitations as managers will become patently obvious and impossible to ignore. The plus side of the equation is that particular strengths we have available to us will also come into focus.

In either instance, actively pursuing a total QA approach provides both companies and individuals with *opportunities*. Once weaknesses have been identified work can begin on correcting those weaknesses. Conversely, full advantage can be taken of defined strengths.

Adopting QA in a Fragmented and Imperfect World

Dealing with a number of fruit producers, packers, coolstore operators, distributors, and marketers highlights that, despite their own unique roles in the fruit industry, they all share common dilemmas. Often they believe that adopting a quality program is first, too expensive and second, futile, because they are not 'big' or influential enough to achieve control and improvement overall. This reasoning is often because they lack confidence in the performance of their own suppliers or in operators downstream in the distribution and marketing chain.

This quandary can arise through unrealistic expectations. Even very large companies have difficulty in either demanding or achieving control of a product or service through an entire production/marketing system.

Often a way to rectify this dilemma is to seek out relationships and alliances, formal or otherwise, with companies and organisations whose functions and attitude complement your own.

'Relational marketing' is a concept gaining credence. This refers to the conscious *bonding* between suppliers and receivers of products through the deliberate nurturing of those relationships. The emphasis is on creating a win/win situation where both parties interact for their mutual and continued benefit. It could be said that there is, or should be, a large element of this already in all business relationships.

QA programs, however, provide an opportunity to strengthen these relationships by structuring very clearly the activities and responsibilities necessary for both parties to fully benefit from the association. They create trust and therefore greater mutual confidence through better practice and clearer two-way communication.

Future Directions

Personally, we have absolutely no doubt whatsoever that a fundamental key to the success of the Australian fruit industry in the future lies in the appropriate adoption of *true* quality programs by its participants. What we do not see currently, however, is a great deal of tangible progress. We have very few positive role models in Australia. We believe this is happening due to a *lack of focus*, *industry politics*, and *low levels of understanding and commitment*. The four common pitfalls we've nominated — complacency, lack of commitment, too great an emphasis on product maintenance rather than total management, and a 'paint by numbers' approach — need to be avoided at all cost. Unfortunately, it is these pitfalls that are currently limiting the progress of QA in Australian horticulture. 'Experts' are appearing everywhere. Often they are overconfident and as yet do not have the skills, experience, and vision to truly contribute, and we'd suggest a number of false starts have been and are being made.

Many of us in Australian horticulture suffer from a tendency to look for and accept the 'quick fix'. We see ourselves as practical people in a practical industry and are sceptical of theory and ideas. This trait is a definite

limitation in terms of quality systems development, as a lot of the hard work necessary to get such programs up and running involves far more brain power and inspiration than physical labour and perspiration!

We believe real progress can and will be made — it has to be. Horticultural producers and postharvest handlers have traditionally been production orientated rather than customer driven, but this is slowly changing. This evolution towards a greater customer orientation in our work will be the catalyst for change that will instigate true QA in horticulture — that and a conscious effort to fight complacency. The 'near enough is good enough' practitioners in our industry will go the way of the dinosaurs and the dodo!

One thing we do not lack in this part of the world is opportunity. *Quality* in its truest sense — in our products, our services, and the way we work — can convert some of these opportunities into success stories. What is required is the desire and commitment to succeed and a genuine willingness to change.

The acknowledgment that the adoption of QA is as much about *open-mindedness* and *a quality attitude*, both towards the people with whom we work and the people with whom we trade is the first and perhaps most critical step that must be taken.

An Economic Evaluation of Postharvest Tropical Fruit Research: Some Preliminary Results

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Abstract

Over the last decade, a significant amount of postharvest research has been undertaken. Concurrently techniques for research evaluation have been developed for the assessment of postharvest research. While some of the techniques have been applied in the evaluation of postharvest research related to other commodities, they have not been applied to tropical fruit postharvest research. This paper reviews methods for the economic evaluation of postharvest research; illustrates the use of these postharvest evaluation methods using six postharvest tropical research projects as examples, and provides preliminary results on the potential gains from postharvest tropical fruit research. The six research projects were funded by ACIAR and collaborating institutions in Australia and Southeast Asia. These preliminary evaluations indicate that over a 30-year time horizon and with a discount rate of 8 per cent per annum, the six collaborative research projects have the following potential economic benefits (valued in 1991 Australian dollars).

Project activity	Total benefits	Research cost	Net present value	Internal rate of return
	$A millions 1991	$A millions 1991	$A millions 1991	(%)
Non-chemical control of fruit disease	80.1	1.2	78.9	38
Postharvest technology for banana	51.4	0.8	50.6	48
Edible coatings for shelf life extension	43.2	1.2	42.0	34
Chemical control of fruit disease	37.6	1.0	36.6	41
Cool storage, controlled atmospheres and chemical controls	19.9	1.2	18.7	27
Vacuum infiltration of fruit with calcium	3.2	0.5	2.7	21
Total (6 projects)	235.4	5.9	229.5	n.a.

n.a. = not applicable

These results are preliminary and indicative only and are dependent on the assumptions and data described in the paper. The paper ends with a discussion of data constraints in the evaluation of projects in this area.

As most economies develop there is an important trend to specialisation in most production activities. Associated with this trend is the increased importance of trade. This trade usually starts within a country but eventually becomes international as well. In most economies, the agricultural sector plays a major role in the early stages of the development process. As domestic and international trade in agricultural products expands, increased importance is placed on the postharvest sector, in the form of, for example, assembly, transport, storage, grading, and processing of produce.

As the demand for postharvest sector products and services expands, there are increased incentives to improve the technologies available in this sector. Research is an important source of these improved technologies. Since many postharvest activities are undertaken by private businesses, and many of the technologies used in this sector can be patented, the private

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sector often plays an important role in providing this postharvest research effort. However, there are still many production constraints that are likely to be resolved through public-sector supported research. The results from these types of research are not appropriable by those undertaking the research and, therefore, the private sector may under-invest in these areas. This paper assumes a case has been established for public sector funding of tropical fruit postharvest research; the question is: how do decision-makers ensure that these funds are allocated effectively?

With the growth of economies in tropical regions of the world has come an increase in the demand for a range of fruits grown in these regions. Increased trade within and between countries has created an incentive for improvements in many aspects of the postharvest activities associated with these fruits. During the last decade or so there have been increased public sector research efforts focusing on postharvest activities for tropical fruit.

Increasingly, public research institutions are placing more importance on efforts to evaluate the impact of the research they fund. The information generated by these evaluations has been found to make several important contributions. It provides a useful basis for supporting cases for continued and increased government funding of research. It provides information which can support decision-making within research institutions. If undertaken with constructive interaction between economists and technical scientists, it can improve the nature and focus of the research projects. Evaluation of farm-level research was first undertaken in the 1950s and a now considerable set of these evaluations has been completed for a range of commodities and countries. Evaluation of postharvest research has received attention only during the last 10 years. As far as we are aware there have been no published studies which have focused on economic evaluation of postharvest tropical fruit research.

Given the growing interest in postharvest tropical fruit research, as is evidenced by the papers included in these proceedings, it seems important to devote some effort to determining what the impact of this type of research has been or is likely to be. This paper is a preliminary foray into this area. It provides a brief review of methods for evaluation of agricultural research, especially postharvest research. A summary of some of the past attempts to evaluate postharvest research is presented and briefly discussed. None of the studies has considered projects which focus on tropical fruit. In the rest of the paper the results of a preliminary analysis of six collaborative postharvest tropical fruit research projects are discussed. A model which suits evaluation of the postharvest tropical fruit research projects is chosen and the implications of the preliminary results from its application are discussed.

Methods for Evaluating Postharvest Research and Some Past Applications

Methods for evaluation of research

Development of methods for the evaluation of agricultural research began with work by Schultz (1953) and Griliches (1958). This work focused on farm-level research activity and projects, and was reviewed by Norton and Davis (1981). The returns from research estimated by some of the studies were summarised by Ruttan (1982, 242–246). Many of the early evaluations were undertaken by economists outside the research organisation where the research was undertaken. Recently there has been an increased emphasis by research institutions to generate these evaluations to support decision-making. Examples are Davis and Ryan (1993), GRDC (1992), and Johnston et al. (1992).

It was not until the early 1980s that attention was focused on the need to consider postharvest separately from farm-level research. Freebairn et al. (1982) first raised the issue of the need to consider a revised, although theoretically related, form of methodology to estimate the returns to postharvest research, or as they called it, market service sector research. Their paper generated significant interest in this area. Although the model Freebairn et al. (1982) developed was an important improvement on the temptation to simply use the retail value of the increase in output as the benefits to research, it was soon found that the question of the impact of, and benefits from, postharvest research can be quite complex. Developments by Alston and Scobie (1983), Freebairn et al. (1983), and Holloway (1989) have been important. Alston (1991) provides a comprehensive review of research evaluation methodology which includes, and places in perspective, postharvest research.

Perhaps one of the more critical implications of these developments is the potential importance of the distribution of the gains from postharvest research. With farm-level research it is generally accepted that if the results of research are applicable to a farmer or group of farmers and they adopt the resultant technology then those farmers, at least, will always gain from the research. This is not to say that some farmers will not lose from research. The farm-level analyses have shown that if the technologies are not appropriate to a group or groups of farmers, and if the research impact causes a fall in the product price (which is likely to occur in most circumstances), then these farmers can be worse off with the research rather than if it had not been undertaken. On the other hand, the above studies have shown that it is sometimes possible for all farmers to lose from the impact of postharvest research on the commodity they produce. In summary: while society

generally will gain from most successful farm-level and postharvest research, in some cases some groups (especially farmers) might be worse-off due to the research.

Past applications of postharvest research evaluation methods

The early postharvest research evaluation papers concentrated on developing the methodology. When applications were included they were generally hypothetical rather than relating to a specific research project or outcome. Several subsequent studies have applied the methodology to specific research issues and, in some cases, projects. Table 1 provides a brief summary of 14 of these studies, which will not be discussed in detail here. One important feature is the considerable variability in both the evaluation method used and the types of results reported. Only 5 out of the 14 provided a complete assessment which included an assessment of the lags from the commencement of the research and the adoption levels and patterns as well as the annual welfare impacts of the research. These five are listed at the top of Table 1, in the order of the highest to lowest internal rate of return (IRR). The rates of return reported range from 29 to 143% which are similar to the types of returns reported for farm-level research. The other studies have reported estimates of the annual welfare gains to the countries indicated from the research. Some of these are estimates of the potential gains rather than those to a specific completed project. There are some very large estimates reported, especially for the livestock sectors. One of the 14 studies reported negative returns to the project and two found it difficult to apply the available methods to the research project considered.

Care is required in drawing general conclusions from the studies, since the methods and format for presentation are not necessarily comparable. Literature reviews (e.g. Alston 1991) have been very useful in guiding the choice of methods for evaluating research. However, so far the classification has been based on the economic characteristics only. During the process of applying research evaluation methods at a project level at ACIAR (and this experience has been confirmed by other institutions) it has been found that it is important to be able to select an evaluation method that suits the type of research being undertaken as well as the economic characteristics facing the production of the commodity the research will eventually influence. This is especially important as there appears to be a gap in the literature regarding the most appropriate procedures for estimating the research impact parameters included in the economic models. The nature of these parameters will depend on the type of research. Davis (1992) and Davis and Lubulwa (1993) have discussed this issue and suggested several possible research classification areas. They related the methodology classifications suggested by Alston (1991) to these research area classifications. A summary of the research classifications (Alston 1991) relevant to postharvest research is provided in Table 2. This emphasises that the type of model is likely to vary with the type of postharvest research.

Davis (1992) allocated ACIAR's postharvest research projects to these groups and found that the majority fell in the wastage reduction group. The last column of Table 2 compares the areas considered in this conference with these research area groups. Again it appears that major emphasis or interest is on wastage reduction research.

Recent versions of the multiregional vertical market models (Alston 1991) are becoming relatively complex, especially from an economic perspective. Yet procedures for estimating the research impact parameters included in them are not very well developed. Davis (1993) discusses this and suggests a simpler model which focuses on waste reduction at the postharvest level as an alternative for this subset of research projects.

This section has briefly reviewed research evaluation methods and their application to postharvest research. There have been no evaluations of tropical fruit research projects, or indeed of any fruit research. Many of the (tropical fruit) postharvest research projects focus on what might be regarded as wastage reduction issues. A wastage reduction evaluation model (Davis 1993) is used in the evaluation of a set of six postharvest tropical fruit projects to illustrate its application and draw some preliminary conclusions about the possible returns from this area of research.

Overview of ACIAR's Postharvest Tropical Fruit Research Program

Four completed ACIAR projects and two projects in progress at the time of writing are assessed in the paper. Table 3 summarises the commodity coverage of, and the solutions explored under the six projects. A brief summary of each project (PN = project number) is given below.

Use of calcium to inhibit ripening and senescence of fruits (PN8319; 1983–1987)

This project investigated whether the process of postharvest application of calcium by vacuum infiltration could be used in Indonesia and Australia to extend storage life of mango, avocado, papaya, guava, melon, rambutan, mangosteen, longas, and lychee at storage temperatures ranging from 25–30°C. While Hass avocadoes did not respond well to calcium infusion, data on

Table 1. Summary of some postharvest research evaluation studies

Description	Commodity	Country	Research type	Net present value ($M)	Internal rate of return (%)	Benefit–cost ratio	Comments	Source
• Suppression of Grain Dust	Wheat	Australia	Wastage	14.5	143	54:1		GRDC (1992)
• Integrated Pesticide Use in Grain Storage	Rice	Malaysia/Philippines/ Australia	Wastage–storage	24.3	43			Chudleigh (1991)
• Stored Grain Under Plastic	Rice	Southeast Asia/Australia	Wastage–storage	9.2	38			Ryland (1991)
• Reduced Amylose in Rice	Rice	Indonesia	Quality	117.0	37		Only annual benefits reported	Unnevehr (1986)
• Reduced Amylose in Rice	Rice	Philippines	Quality	227.0	29		Only annual benefits reported	Unnevehr (1986)
• Pigmeat Fat Reduction	Pigs	USA	Quality	977.5			Present value of year 5 benefits no research costs	Lemieux and Wohlgenant (1989)
• Reduction in Dark-Cutting in Beef	Beef	Australia	Quality	905.0			Potential benefits no research costs	Voon and Edwards (1990a)
• Boxed to Tray Ready Beef	Beef	USA	Processing	845.6			Annual impact no research costs included	Mullen et al. (1988)
• Increased Protein Content in Wheat	Wheat	Australia	Quality	447.0			Potential benefits no research costs	Voon and Edwards (1990b)
• Reduced Backfat Depth in Pigs	Pigs	Australia	Quality	66.0			Potential benefits no research costs	Voon and Edwards (1990c)
• Wool Carding Improvement (Sirocard)	Wool	Australia	Processing	21.9			Benefits only no research costs included	Mullen and Alston (1990)
• Component Pricing and Grading	Soybeans	USA	Grading–quality	–12.6			Annual impact no research costs included	Updaw (1980)
• Wheat Quality for Middle East	Wheat	Australia/Middle East	Quality	Not estimated			Qualitative assessment only	GRDC (1992)
• Safe Storage of Oilseeds	Rapeseed	Australia	Wastage –storage	$5/t			Impact per tonne only assessed	GRDC (1992)

Table 2. Possible postharvest research area classifications

Research classification area	Type of evaluation model (based on Alston 1991)	Comments	Matching themes in these proceedings
Post-farm-gate			
Wastage reduction	Multi-regional vertical market model	Wastage reduction version can be useful simplification	• Harvesting • Diseases and disorders • Storage • Ripening • Disinfestation
Processing methods	Multi-regional vertical market, probably factor-biased, model	Private sector relevance could be important since most research gains are appropriable.	Processing
Transport	Multi-regional vertical market model	Private sector relevance could be important because most research gains are appropriable.	Transportation
Farm and off-farm			
Product quality	Multi-commodity, related in consumption, vertical market model	Care is required if a simple increase in price model is used.	Harvesting
New product	Single or multi-regional, multi-commodity supply shift model	Quantity associated with minimum TAC[a] required. Care is required as estimates are subject to more error.	
Policy/regulation	Value of information with saving in dead weight loss model.	Model not well developed and few applications.	Regulation
Environmental issues	Single or multi-regional, multi-commodity supply shift model	Other areas also involve environmental issues.	
Human health	Labour supply shift, demand for health services	Models not well developed or applied.	
Institutional analysis	Value of information with saving in dead weight loss model.	Model not well developed and few applications	Marketing

[a] TAC = Total Average Cost.

Australian Fuerté avocados showed that calcium treatments led to an average shelf life extension of about 3–5 days or 32–55% over the average shelf life of 9 days for Fuerté without the treatments. However, ACIAR (1986) noted that :

> In Australia, Fuerté is an early variety for which growers get a good price before the better varieties become available. They are therefore interested in faster ripening using ethylene but are not likely to be interested in delaying ripening with calcium infusion.

The project demonstrated that calcium infiltration could delay ripening in some varieties of avocado and papaya in Australia and Indonesia. However, for the treatment to have commercial application it was considered that improved control of rotting was necessary.

Postharvest physiology of, and technology for, bananas in Southeast Asia (PN8355; 1983–1987)

This project was confined to bananas. Research was conducted in Malaysia, Philippines, Thailand, and Australia. Commercially viable handling technology for banana was successfully developed (Lizada et al. 1987). This technology involved better control of ethylene to delay ripening of bananas under modified atmosphere storage, and use of fungicides to control stem-end rots.

Table 3. Commodity coverage in ACIAR's postharvest tropical fruit research

Project number	8319	8355	8356	8844	9313	9105
Solutions explored	Vacuum infiltration of fruit with calcium	Postharvest technology for bananas	Chemical controls to fruit disease	Cool storage, CA[a] and chemical controls	Non-chemical controls of fruit disease	Edible coatings for shelf life extension
Country focus	Indonesia, Australia	Malaysia, Philippines, Australia	Malaysia, Philippines, Thailand, Australia	Thailand, Australia	Thailand, Australia	Thailand, Australia
Mango	✓		✓	✓	✓	✓
Avocado	✓[b]			✓	✓	✓
Longan			✓	✓	✓	
Lychee			✓	✓	✓	✓
Rambutan				✓	✓	
Mangosteen			✓	✓	✓	
Durian				✓		
Green coconut			✓	✓		
Papaya	✓					
Banana	✓	✓				

[a] CA stands for controlled atmospheres

[b] A tick indicates that the fruit in question was studied as part of the project, but it does not necessarily imply that the study led to some useful technology for postharvest handling of the fruit. The commodities are not equally applicable to all countries. Details about the fruits on which different countries focused on are given in Tables 8–13.

Four handling trials had proven the technology feasible for the export of bananas from Malaysia and the Philippines by sea to Hong Kong and Japan.[1] ACIAR (1986, p 43) reached similar conclusions but noted that there was still a need for research on banana pathology problems, on response to modified atmospheres, and on low-cost ethylene absorbents.

Chemical controls of fruit disease (PN8356; 1983–1987)

This project investigated postharvest characteristics of mango, longan, lychee, and mangosteen in Australia and the Southeast Asian region. The project demonstrated that, during controlled atmosphere storage, a dual treatment of hot water followed by prochloraz was required to control stem-end rot, anthracnose, and alternaria rot. The project also verified the efficacy of hot benomyl and prochloraz sprays for the control of anthracnose with negligible impact on fruit quality, and demonstrated that hot benomyl controlled some types of stem-end rot. Postharvest research into other tropical fruits in Thailand under PN8356 produced results indicating that sulfur dioxide fumigation increased the storage life of lychees to at least 90 days. For mangosteen, storage at 5°C in 5% carbon dioxide and 5% oxygen gave one month storage.

Cool storage, controlled atmospheres, and chemical controls (PN8844; 1989–1992)

This project focused on mango, lychee, longan, rambutan, mangosteen, and durian. A 1991 reviewer of the project concluded that it had achieved major results in the following areas:

- new technologies with early commercial application, particularly in relation to export marketing of longan, lychee, mango, and durian;
- results of scientific merit, particularly in relation to controlled atmosphere storage of different varieties of mangosteen, rambutan, mango, lychee, and longan; the development of harvesting indices for lychee, durian, longan, rambutan, and mango; the biology and control of mango stem-end rot and other postharvest diseases; and mango sapburn.
- the development of sulfur dioxide fumigation technology for the control of postharvest disease in exotic tropical fruits, and external browning in trimmed green coconuts, and measures to limit lychee and rambutan skin colour loss in storage.

Non-chemical controls of fruit disease (PN9313; in progress)

While PN8356 and PN8844 focused on the use of fungicides in the control of tropical fruit disease, PN9313 will study the mechanisms of tropical fruit resistance to disease, and develop strategies that minimise the use of chemicals in the control of tropical fruit diseases and pathogens. This is partly in response to increasing market pressure for the reduction in the use of postharvest chemicals on fruit. The project aims, in part, to build on pioneering discoveries (Johnson et al. 1992) made within ACIAR PN8844 regarding the infection processes of stem-end rot fungi. Potential benefits from this project include the following. Watering regimes suitable for stimulation of flowering and reduction in stem-end rot losses in tropical fruit (mango, lychee) may be developed. Screening procedures for the selection of stem-end rot resistant cultivars may be developed. The results could underpin development of control recommendations for stem-end rot of avocado, carambola, mangosteen, and rambutan, commodities for which there are no satisfactory stem-end rot control measures at present, and alleviate reliance on postharvest fungicides in mango.

Development of simple, edible coatings for the postharvest life extension of fruit (PN9105; in progress)

This project aims to develop edible coatings that will extend the postharvest life and maintain the quality of fresh fruits handled under ambient or low temperature conditions in Thailand and Australia. The coatings — which serve to modify atmospheres within the produce — are simple to apply, non-toxic, and accessible and affordable to the user. Produce dipped in the coatings, which are water soluble, is coated with a natural microfilm, which is odourless, tasteless, and invisible. The coatings can be applied at any stage, can be washed off with water later and are compatible with the commonly used fungicides. The project will involve further research and development on properties of the films, including mechanical (e.g. thickness and strength) and barrier attributes (e.g. permeability to water vapour, oxygen, and carbon dioxide). The coatings will be tested under a range of climates and handling conditions to optimise the effectiveness and commercial suitability of different coatings on different produce. The project will also investigate disease control in tropical fruit which is a major constraint to the commercial application of coating and film technologies, particularly in the tropics.

[1] See ASEAN Food Handling Newsletter, April 1987, 11.

Factors that Influence the Levels of the Potential Impacts of Research

The potential impacts of postharvest tropical fruit research depend on the following factors:

- the size of the tropical fruit industry in the countries included in the research projects and the proportion of that industry that is likely to be affected by results from the research project;
- whether the project has led or is likely to lead to changes in commercial practice or in new applicable technology; and
- the adoption pattern.

Industry size

As an indication of industry size, Tables 4 and 5 show the amounts of farm-level quantities produced and the farmgate prices of tropical fruits in the five countries covered in this paper. The list of fruits is not exhaustive, covering only those fruits that were included in the projects under assessment.

Practices 'before research'

The adoption pattern for any technology depends on the type, level, cost, and effectiveness of technology used before research. Recent reviews (ASEAN 1989; FAO 1990) of tropical fruit postharvest practices in the five countries in this study give an indication of the types of technology being used in these countries.

Indonesia. FAO (1990,123) concluded that, in Indonesia, postharvest measures are not applied in a systematic way, storage and packaging are limited to traditional

Table 4: Tropical fruit (t, 1991) produced in Southeast Asian countries and Australia

Fruit	Indonesia[a]	Malaysia[b]	Philippines[c]	Thailand[d]	Australia[e]
Mango	640 457	15 014	346 000	894 266	11 918
Avocado	91 420	na	22 000	na	12 005
Longan	na	na	na	86 563	na
Lychee	na	na	na	24 357	635
Rambutan	355 792	37 193	na	577 790	29
Mangosteen	na	7 026	na	90 263	na
Durian	205 389	118 313	21 380	539 133	na
Green coconut	na	na	124 818	97 783	na
Papaya	352 651	71 918	100 000	408 038	4 472
Banana	2 471 925	134 940	3 545 000	43 487	165 057

Sources:

[a] Based on data held by the Indonesian Statistical Centre, the Department of Agriculture, Indonesia.

[b] Federal Agriculture Marketing Authority, Malaysia (1992)

[c] Food and Agriculture Organisation of the United Nations (1991) and Philippine (National) Statistical Coordination Board (1992)

[d] Based on data held by the Department of Agriculture Extension, Thailand and the Department of Export Promotion, Thailand.

[e] Australian Bureau of Statistics(1992)

na: not available.

Table 5. Farmgate prices ($Aust/t) for selected tropical fruits in Southeast Asian Countries and Australia

Fruit	Indonesia	Malaysia	Philippines	Thailand	Australia
Mango	590	719	834	1153	1611
Avocado	324	na	459	na	1170
Longan	na	na	na	1499	na
Lychee	na	na	na	1845	na
Rambutan	528	528	na	519	1150
Mangosteen	na	618	na	1153	na
Durian	1017	1305	1216	1009	na
Green coconut	na	na	519	519	na
Papaya	251	270	410	519	598
Banana	339	337	159	433	904

Sources: as for Table 4, except for Australia. Australian prices were estimated using data supplied by the Queensland Department of Primary Industries.

na: not available.

methods, harvesting is not based on maturity indices and, in many areas, fruits are given no special treatment during transportation. However, valuable fruits for export and inter-island trade are stored in cool storage facilities during transportation and storage. The handbook on the postharvest handling of fruit in ASEAN countries (ASEAN 1989) notes that benomyl or prochloraz dips are recommended for controlling fungal disease in banana and mango in Indonesia.

Malaysia. A large proportion of farmers in Malaysia produce mangoes and other fruit primarily for family consumption. Only 3% of farmers produce fruit solely as a source of income (Tjiptono et al. 1984). FAO (1990,129) concludes that Malaysia is still a net importer of fruits. With respect to the type of technology discussed in this paper, ASEAN data (ASEAN 1989) indicates that benomyl dips are used to control fungal disease in banana and mango in Malaysia for export produce.

Thailand. FAO (1990,152) states that refrigerated storage rooms are in common use for many types of fruits in Thailand. However, the same study suggests that growers are inadequately trained in preharvest techniques, and that poor postharvest handling of fruit and incorrect handling of fruit reduces shelf life in Thailand, resulting in high losses. Thompson (1990) observed that hydro-cooling is used in Thailand for longan and lychee. Hot-water treatment of fruit and benomyl dips are used to control fungal disease in banana and mango in Thailand (ASEAN 1989).

Philippines. Mendoza (1981, 44) reports that, in the Philippines:

- storage and transport facilities with appropriate temperature and relative humidity controls are virtually non-existent in the production areas;
- there is little provision for temperature, humidity, and decay controls under traditional ripening practices;
- harvesting indices for fruit are not used by farmers thus the time and method of harvesting usually favour mechanical injuries, occurrence of physiological disorders, and other blemishes; and
- use of unsuitable containers brings about large wastage due to abrasion, compression, and heat injuries.

However, ASEAN (1989) indicates that dipping fruit in benomyl and other fungicides, and polyethylene bags, are used to control fungus diseases in bananas. Lizada (these proceedings) outlines recent improvements in postharvest handling practices for bananas in the Philippines. There are indirect signs that ACIAR-sponsored research has influenced commercial practice in some Southeast Asian countries. For example, ASEAN (1989) cited Lizada et al. (1984), a research output of PN8356, as a basis for the recommendation on control measures for chilling injury in mango in the Philippines.

Adoption patterns

The general picture which emerges is that the technologies arising from ACIAR projects are used in Southeast Asia in handling produce for distant markets. Distant markets could be regional, national, or export. Table 6 summarises the different projects in terms of the projects' impacts on commercial practice.

Table 7 summarises estimates of the percentages of fruits that are sold in distant markets and might benefit from the types of technologies developed in the 6 projects discussed in this paper.

Quantification of the Impacts of New Postharvest Technology

The impacts of the technologies developed by the tropical fruit postharvest research projects could include:

i. reductions in total wastage of fruit which, in turn, lead to increases in the retail supply of fruit — this is the aim of all the projects discussed here;
ii. changes in postharvest costs as a result of adopting the research results; for example, a technology may increase costs because it requires greater postharvest inputs (more fungicides or increased labour or new machinery); on the other hand postharvest costs may be reduced by making it feasible to reduce the dependence by fruit shippers on expensive rapid transport (mostly air) and shift to slower but cheaper modes (sea and road) in the transportation of fruit to distant markets;
iii. decreases in retail prices of fruit: the research extends the shelf life of fruit which leads to an increase in the quantity of fruit available at retail, which in turn leads to a fall in the retail price of fruit;
iv. increases in retail returns: due to disease reduction extending the maximum consumer-appeal period;
v. increases in the total demand for fruit: the assumption is that as retail prices of tropical fruits fall, these fruits become affordable to more and more consumers;
vi. under some conditions, favourable impacts on farmgate prices and farm-level production;
vii. scientific research capacity building in both Australia and the collaborating countries which is achieved during the life of the project through the exchange of skills and knowledge between Australian scientists and scientists in the Southeast Asian region; and
viii. the enhancement of the nutritional value of fruit. This benefit is reduced to the extent that postharvest fruit handling technologies may require the use of chemicals which have potentially negative, but to date unquantified human health effects.

Table 6. Six ACIAR projects and tropical fruit postharvest technology

Project no.	PN8319	PN8355	PN8356	PN8844	PN9313	PN9105
Solution devised	Vacuum infiltration of calcium	Postharvest technology for bananas	Chemical controls of fruit disease	Cool storage, CA, and chemical controls	Non-chemical control of fruit disease	Edible coatings for shelf life extension
When did the project finish?	1987	1987	1987	1991	1996[a]	1994[a]
Has the research solution been translated into a technology in Southeast Asia ?	Not yet	Yes	Yes	Yes	Not yet	Not yet
Basis for the assessment Personal communication	Dr C. Yuen, Department of Food Science and Technology, University of New South Wales (pers. comm.)	Thompson (1990, 14)	Thompson (1990, 12) ASEAN (1989)	Thompson (1990, 15) ASEAN (1989)	Not applicable	Not applicable
Comments	Still needs a machine embodying the technology	Used mainly for banana exports	Used to control disease in mango and banana	Used extensively in transport-ation of fruit over long distances	Research in progress	Research in progress

[a] Planned completion date.

Table 7. Fruit sold in distant markets for countries involved in the projects (percent of national fruit production)

Fruit	Indonesia	Malaysia	Philippines	Thailand	Australia
Mango	15–20[a]	16[b]	3.8[c]	13 (0.36% export)[d]	93 (6% export)[f]
Avocado	10–15[f]	na	0[c]	na	90 (1% export)[f]
Longan	5[e]	na	na	8.8 (8.8% export)[d]	na
Lychee	5[e]	na	na	2.0 (2.0% export)[d]	na
Rambutan	10[e]	6[b]	na	6 (0.04% export)[d]	100
Mangosteen	10–15[e]	19[b]	na	19 (0.23% export)[d]	na
Durian	25–30[e]	31[b]	0[c]	23 (0.52% export)[d]	na
Papaya	10–15[e]	38[b]	0[c]	27 (4.05% export)[d]	90
Banana	10–15[e]	25[b]	20[c]	20 (22% export)[d]	90 (0% export)[f]

Sources:
[a] Tjipono et al. (1984, p3)
[b] Federal Agriculture Marketing Authority (1992)
[c] Philippines Bureau of Agricultural Statistics (1989)
[d] The figures in brackets are based on data supplied by Dr Sonthat Nanthachai based on information held by Department of Agriculture and Extension, Thailand and Department of Export Promotion, Thailand. The other figures in this column are averages of the entries for the other 3 Asian countries.
[e] Dr Chris Yuen, Department of Food Science Technology, University of New South Wales
[f] Export figures are from Industry Commission (1993).
na Data not available.

Table 8. Impacts of the research projects on fruit wastage rates[a] (percent of fruit produced at farm-level) in Australia

Commodities	Wastage before research	Wastage after PN8319	Wastage after PN8355	Wastage after PN8356	Wastage after PN8844	Wastage after PN9313	Wastage after PN9105
Mango	16			16→9.2	9.2→7.8	16→6.6	9.2→8.5
Avocado	55	55→40				30→10	30→15
Lychee	50			50→40	40→20	20→10	30→10
Rambutan	40				40→30	30→20	
Banana	30		30→10				

[a] Rates are based on estimates provided by project scientists.

Note: Blanks in the table indicate that the commodity was not affected by the research project. From column 3, the number to the left of the arrow is the estimated wastage rate before research while the one to the right of the arrow is the estimated wastage rate after research.

Table 9. Impacts of the research projects on fruit wastage rates (percent of fruit produced at farm-level) in Indonesia, Philippines, and Malaysia

Commodities	Indonesia Wastage rate PN8319	Philippines Wastage rate PN8355	Philippines Wastage rate PN8356	Malaysia Wastage rate PN8355	Malaysia Wastage rate PN8356
Mango			24[b]→14[a]		24[b]→14[a]
Avocado	56→36[a]				
Rambutan					36[b]→16[a]
Banana		33[b]→13[a]		33[b]→13[a]	

[a] Based on estimates provided by project scientists.

[b] Mendoza (1981, page 58, Table 3).

Note: Blanks in the table indicate that the commodity was not affected by the research project. From column 2, the number to the left of the arrow is the estimated wastage rate before research while the one to the right of the arrow is the estimated wastage rate after research.

Reductions in total wastage of fruit

Most of the tropical fruit postharvest research projects affect the wastage rate of fruits. Tables 8, 9, and 10 summarise the estimated impact of research as a result of research in the 6 projects. Only those commodities for which research has had an impact or it is expected to have one are included in the tables. Three projects are linked since PN9313 is designed to replace some of the chemical controls developed under projects PN8356 and PN8844. The 'before research' wastage rates for PN9313 are thus the rates that would apply if the chemical controls from PN8356 and PN8844 were not available. This is equivalent to setting the 'before research' wastage rates to the pre-PN8356 rates. The 'before research' rates for PN9313 may not be identical to the pre-PN8356 rates if non chemical control methods were developed for a fruit under either PN8356 or PN8844.

Changes in postharvest costs as a result of changes

In order to realise the impacts indicated in Tables 8, 9 and 10, changes in postharvest inputs are often necessary. This leads to changes in postharvest costs. Tables 11–13 summarise the changes in input costs that have been estimated as applying to the technology developed in the 6 projects.

Other assumptions

Three other sets of assumptions have been made in the analysis. These relate to the patterns of adoption of tropical fruit postharvest technology, the elasticity of demand and supply, and the discount rate.

Little is known about the pattern of adoption of fruit postharvest technology. For example, in an annotated bibliography of 719 studies on worldwide adoption of innovations (CAB 1981), there was no study of adoption patterns of fruit postharvest technology. In this paper it is assumed that the process and pattern of adoption for tropical fruit postharvest technology are likely to be similar to those commonly observed for farm-level technologies (see Davis et al. 1987, 35). Most of these research projects take 3 years. It is assumed that after the research is completed, about 7 years are needed to develop the research results into a commercially appli-

Table 10. Impacts of the research projects on fruit wastage rates (percent of fruit produced at farm-level) in Thailand

Commodities	Wastage rates PN8356	Wastage rates PN8844	Wastage rates PN9313[i]	Wastage rates PN9105[j]
Mango	30→20[a]	20→15[d]	30→10	20→15
Longan	50→40[b]	40→20[e]	20→10	
Lychee	50→40[b]	40→20[e]	20→10	30→20
Rambutan		40→30[f]	30→20	
Mangosteen	50→40[c]	40→30[g]	30→20	
Durian		30→20[h]		

Notes:
Blanks in the table indicate that the commodity was not affected by the research project. From column 2, the number to the left of the arrow is the estimated wastage rate before research while the number to the right of the arrow is the estimated wastage rate after research.

[a] Dip in hot benomyl. However, because benomyl is used as a preharvest spray in Thailand, some resistance to the fungicide has been observed.

[b] Sulfur dioxide fumigation used to control disease, but there were still problems due to SO_2 injury to the pericarp and development of off-flavours during storage.

[c] The project developed a better harvesting index.

[d] The project led to the recommendation of an optimal cool storage temperature for mangoes and, by disease control treatments, to reductions in damage to fruit.

[e] Optimum conditions for sulfur dioxide fumigation were established.

[f] Use of plastic over wrapped punnets were recommended to reduce moisture loss and shrinkage at the recommended storage temperature.

[g] An optimal storage temperature was recommended.

[h] A waxing treatment was developed which delayed ripening and cracking of fruit during transport to distant markets.

[i] The project commenced in July 1993. Improved control measures for stem-end rot may be developed, which could lead to reduced losses in stem-end losses in fruit.

[j] The project is developing edible coatings to extend shelf life of fruit.

cable technology. From then on, the technology is adopted by a small proportion of producers or traders. The technology then diffuses to other producers slowly until adoption peaks at a maximum level of adoption. This maximum level of adoption varies depending on the fruit, the country in question, and the characteristics of the technology.

The literature on the empirical estimation of elasticities of demand and supply for tropical fruit is limited. The elasticity of demand with respect to own price of fruit has been assumed to be –1.5. This is consistent with the estimate of –1.6 by Santoso and Wahyunindyawati (1992) for the own price demand elasticity of mangoes. However, Stuckey and Anderson (1974) estimated the demand elasticity for bananas in Sydney at –0.8. In the sensitivity analysis, a value of –0.6 has been used to describe a scenario when demand for tropical fruit is inelastic. A relatively inelastic supply curve with an own supply price elasticity of 0.1 is assumed in the analysis.

The discount rate is assumed to be 8%/year. This rate is used to discount both the costs incurred and benefits received over a 30-year time horizon. The research costs which were incurred before 1991 are adjusted to their 1991 values by using inflation deflators between 1983 and 1991.

An Evaluation of Six Tropical Fruit Postharvest Research Projects

This section presents results from a preliminary evaluation of the ACIAR-funded tropical fruit postharvest research projects. Table 14 describes results of the assessments using information and parameter values in Tables 4–13. These tables describe what is referred to below as the base case research impacts.

Results from the base case analysis

In Table 14 the projects are arranged in descending order of their net present values (NPV). The NPV (column 7 of the table) is the difference between the monetary value of benefits and the research costs of a project, over a 30-year period, discounted at a rate of 8%/year. The internal rate of return (column 8 of Table 14) is the rate which would be required to equate the discounted benefits flowing from the project to the discounted research costs. These results depend on a number of factors including:

- the farm-level quantities of fruit produced (Table 4) — the larger the volume of fruit produced the larger the potential benefits;
- the proportion of the fruit produced which is likely to be affected by the new technology (Table 7) and the pattern of adoption of the technology;

Table 11. Impacts of the research projects on fruit postharvest costs in Australia

Commodities	Farmgate price	Postharvest costs	Change in postharvest costs after PN8319	Change in postharvest costs after PN8355	Change in postharvest costs after PN8356	Change in postharvest costs after PN88844	Change in preharvest costs after PN9313	Change postharvest costs after PN9105
	$A/t (1991)[a]	$A/t (1991)[b]	$A/t (1991)	$A/t (1991)	$A/t (1991)	$A/t (1991)	$A/t (1991)[i]	$A/t (1991)[j]
Mango	1611	2449			+11[c]	+6[f]	+72	+9
Avocado	1170	1778	[c]				+72	+9
Lychee	1104	1678				+0[g]	+72	+9
Rambutan	1150	1748				+100[h]	+62	
Banana	904	1374		+85[d]				

Notes: Blanks in the table indicate that the commodity was not affected by the research project.

[a] From Table 5 of this paper.
[b] Estimates based on Industry Commission (1993, 97).
[c] Not estimated. Despite the potential delayed ripening benefits in Table 8, the technology is not likely to be adopted in Australia because it works best on an early variety of avocados, Fuerté, for which growers get a good price before the better varieties come on the market. For this variety farmers would like to speed up, not delay, ripening (see ACIAR 1986)
[d] This change in postharvest costs is due to: (i) the cost of 50 sealed polyethylene bags and ethylene absorbents = $A47; (ii) the cost of benomyl = $A4; and (iii) labour = $A34. Labour costs are estimated using relativities in Industry Commission (1993).
[e] The cost of benomyl on the assumption that 1.33 kilograms of benomyl is needed with 'top up' and 1 litre of non-recirculated prochloraz for about 2750 trays (7 kg each). Cost of benomyl = $A59/kg and cost of prochloraz = $A129/L.
[f] Cost of detergent (e.g. Agral) to control sapburn.
[g] A more accurate harvesting index was developed and an optimal storage temperature was recommended replacing haphazard practices in existence before research.
[h] This is made up of $A60, the cost of 1000, plastic overwrapped small baskets (punnets) to reduce moisture loss and shrinkage of fruit at the recommended temperature plus $A40 of additional labour costs.
[i] The cost of replacing existing trees with new stem-end rot resistant cultivars less the savings in costs of fungicides. The cost of growing trees is based on Industry Commission (1993, 323).
[j] The cost of edible coatings is estimated to be about $A4/t. The application of these coatings to fruit is estimated to add another $A5/t in labour costs.

- the impact of research on wastage rates (Tables 8–10) — the larger the reduction in wastage rates as a result of research, the larger the potential gain; and
- the change in postharvest costs (Tables 11–13) — the higher the increase in postharvest costs relative to the before research level of postharvest costs, the lower the potential gains.

Though generally all the projects increased both producer and consumer benefits, consumers gained more than the producers. The main source of the gains to consumer is the decrease in prices of fruit as the retail supply of fruit increases. The share of the gains to producers is influenced by the elasticity of demand for fruit. In the base case it is assumed that demand is elastic (own price elasticity of demand of –1.5). However, if demand is inelastic, producers may lose as a result of technologies developed under the projects covered in this preliminary evaluation.

Sensitivity tests

Sensitivity analysis was undertaken to assess how the preliminary base case results in Table 14 would change if the variables in Tables 4–13 took on different values.

- Wastage rate reductions

In order to assess the sensitivity of the results in Table 14 to the estimated change in wastage rates, the analysis was repeated using the assumption that research leads to twice the reduction in wastage rates used in the base case. Generally, doubling the wastage rate reduction led to a doubling of total discounted benefits but increased the internal rate of return by only about 7%.

- Elasticity of demand

When the demand elasticity was reduced from –1.5 to –0.6, the NPVs tended to decrease marginally and the IRRs were slightly lower than in the base case. More significantly, the model indicates that producers of fruit under conditions of inelastic demand (–0.6) may as a result of research incur net losses in economic surplus.

- Change in postharvest costs

The analysis was repeated with the assumption that research leads to a doubling of the base case change in postharvest costs. Generally, doubling of the research-induced change in postharvest costs leads to a small decrease in consumer benefits, a comparatively larger reduction in producer benefits, and a reduction in IRR.

Table 12. Impacts of the research projects on fruit postharvest costs in Indonesia, Philippines and Malaysia.

Commodity	Indonesia Farmgate price	Indonesia Postharvest costs	Indonesia Change in postharvest costs after PN8319	Philippines Farmgate price	Philippines Postharvest costs	Philippines Change in postharvest costs after PN8355 and PN8356	Malaysia Farmgate price	Malaysia Postharvest costs	Malaysia Change in postharvest costs after PN8355 and PN8356
	$Aust/t (1991)[a]	$Aust/t (1991)[b]	$Aust/t (1991)	$Aust/t (1991)[a]	$Aust/t (1991)[b]	$Aust/t (1991)	$Aust/t (1991)[a]	$Aust/t (1991)[b]	$Aust/t (1991)[b]
Mango				834	717	+11[d]	719	618	+11[d]
Avocado	324	279	+18[c]						
Rambutan							528	454	50[f]
Banana				159	137	+8[e]	337	290	+18[e]

Notes:
Blanks in the table indicate that the commodity was not affected by the research project.
[a] From Table 5 of this paper.
[b] This is estimated to equal 86% of farmgate price. This estimate is developed from Santoso et al. (1990) for Indonesia and Malaysia, Torres et al. (1984) for the Philippines, and using information in Tables 5 and 10 in this paper.
[c] The estimate is based on the assumption that this technology is likely to be used by small producers of avocado in Indonesia, producing about 4 t/year of avocado. Calcium is estimated to cost about $A30/25 kg bag. The technology requires 4% calcium solution, reusable. Thus a 25 kg bag of calcium is estimated to be enough for about 10 t of avocados. The cost in the table comprises (i) 10% depreciation on a $A400 simple calcium infiltration machine ($A10/t) plus (ii) $A3/t for the cost of calcium, plus (iii) $A5/t added labour costs.
[d] See note (e) in Table 11.
[e] This estimate is derived from Table 11 where it is estimated that the technology developed under PN8355 is likely to increase postharvest costs by 6.2%.
[f] See note (h) in Table 11. This estimate comprises $A45 for plastic overwrapped punnets and $A5 for added labour.

Table 13. Impacts of the research projects on fruit postharvest costs in Thailand

Commodities	Farmgate price	Postharvest costs	Change in postharvest costs after PN8356	Change in postharvest costs after PN8844	Change in preharvest costs after PN9313	Change in postharvest costs after PN9105
	$Aust/t (1991)[a]	$Aust/t (1991)[b]	$Aust/t (1991)	$Aust/t (1991)	$Aust/t (1991)[k]	$Aust/t (1991)[l]
Mango	1153	992	+11[c]	0[f]	+72	+9
Longan	1499	1287	+129[d]	0[g]	+44	
Lychee	1845	1587	+129[d]	0[g]	+44	+9
Rambutan	519	446		26[h]	+16	
Mangosteen	1153	992	0[e]	0[i]	+44	
Durian	1009	868		9[j]		

Notes:
Blanks in the table indicate that the commodity was not affected by the research project.
[a] From Table 5 of this paper.
[b] This is estimated to equal 86% of farmgate price, based on Santoso et al. (1990).
[c] Cost of fungicide estimated as indicated in note (e) in Table 11.
[d] Cost of sulfur dioxide.
[e] There are no added postharvest costs for adopting a better harvesting and maturity index.
[f] Since cool storage equipment is assumed to be in use already, there are no added postharvest costs for adopting an optimal cool storage temperature.
[g] Zero added postharvest costs for adopting optimum conditions for sulfur dioxide fumigation.
[h] This is made up of $A21, the estimated cost of 1000 plastic overwrapped small baskets (punnets) to reduce moisture loss and shrinkage of fruit at the recommended temperature, plus $A5 of additional labour costs.
[i] Zero added cost for adopting optimum cool storage temperature for fruit.
[j] Added cost of waxing fruit is estimated at $A4/t for wax and $A5/t for added labour.
[k] Cost of replacing existing trees with stem-end rot resistant cultivars, based on estimates in Industry Commission (1993, 323) and Buangsuwon (1993: Table 5).
[l] Added cost of edible coatings technology is estimated to be $A4/t for the coatings plus $A5/t for labour.

Table 14. Results from a preliminary evaluation of six tropical fruit postharvest research projects: the base case. Costs and benefits are given in $Aust'000 (1991).

Project number	Project title	Consumer benefits	Producer benefits	Total benefits	Total research costs	Net present value	Internal rate of return
PN9313	Non-chemical control of fruit disease	74 945	5 182	80 127	1 235	78 892	38
PN8355	Postharvest technology for bananas	49 367	2 060	51 427	801	50 627	48
PN9105	Edible coatings for fruit shelf life extension	35 820	7 425	43 246	1 235	42 010	34
PN8356	Chemical control of fruit disease	33 079	4 500	37 579	1 001	36 578	41
PN8844	Cool storage controlled atmospheres and chemical control	17 729	2 243	19 970	1 235	18 735	27
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	3 120	71	3 191	458	2 733	21

The distribution of benefits between fruits and collaborating countries

Table 15 shows the distribution of benefits between the different fruits. This rank ordering according to potential benefits of research is similar to the ranking of production levels of the different fruits. For example, the top two fruits in terms of potential benefits are also the top two in terms of production levels in the 5 countries in the study. The fruit with the least potential to generate research benefits is also the one produced in the smallest quantities in the five countries.

Finally, Table 16 shows that all countries collaborating in the research projects gain. The relative sizes of the benefits accruing to the different countries are dependent on the relative shares in production of the mix of fruit covered under the given project. The results on the distribution of benefits between different countries

Table 15. The distribution of gross benefits ($Aust'000, 1991) according to fruits covered by ACIAR research projects

Project number	Project title	Mango	Avocado	Longan	Lychee	Rambutan	Mango-steen	Durian	Banana	Total
PN9313	Non-chemical control of fruit disease	46 068	15 638	3 317	618	8 098	6 388	0	0	80 127
PN8355	Postharvest technology for bananas	0	0	0	0	0	0	0	51 427	51 427
PN9105	Edible coatings for fruit shelf life extension	39 074	3 555	0	616	0	0	0	0	43 246
PN8356	Chemical control of fruit disease	29 531	0	1 753	183	2 087	4 025	0	0	37 579
PN8844	Cool storage, controlled atmospheres and chemical control	2 569	0	10 926	2 293	2 860	122	1 200	0	19 970
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	0	3 191	0	0	0	0	0	0	3 191

Table 16. The distribution of benefits ($Aust'000 1991) between countries collaborating in ACIAR projects

Project number	Project title	Indonesia	Malaysia	Philippines	Thailand	Australia	Total
PN9313	Non-chemical control of fruit disease	0	0	0	54 378	25 749	80 127
PN8355	Postharvest technology for bananas	0	4 075	40 679	0	6 673	51 427
PN9105	Edible coatings for fruit shelf life extension	0	0	0	39 320	3 926	43 246
PN8356	Chemical control of fruit disease	0	2 676	15 899	15 443	3 561	37 579
PN8844	Cool storage, controlled atmospheres and chemical control	0	0	0	13 893	6 077	19 970
PN8319	Vacuum infiltration of fruit with calcium to delay ripening	3 191	0	0	0	0	3 191

reflect the countries which collaborated in the different projects. In the recent past, projects in the tropical fruit postharvest area have focused on Thailand. This explains the larger share of benefits accruing to Thailand. Similarly, Indonesia has collaborated in one tropical fruit postharvest project to date. Thus, the zero entries for Indonesia have no significance other than indicating that Indonesia has not collaborated in 5 of the 6 projects assessed in this paper.

At this stage the potential spillovers to other countries have been ignored. This is due largely to the preliminary nature of the results. Since it has not yet been possible to collect reliable, verified estimates for the collaborating countries especially regarding adoption levels, to estimate spillovers to non-collaborating countries is unjustifiable at this stage. Nevertheless, it is important to note that these benefits are potentially available.

Concluding Remarks

This paper has reviewed methods for the economic evaluation of research and their application to postharvest research. A summary of past applications indicated that there have been no evaluations of postharvest fruit research projects.

The paper has also illustrated an application of a wastage model in the evaluation of six ACIAR tropical fruit postharvest research projects, and it provides some preliminary estimates of the potential benefits of tropical fruit postharvest research.

The basic data required for the analysis are given in Tables 1–13. Data on production and price levels are more readily available for the fruits that are produced in large quantities, than for the minor fruits. Even for the major tropical fruits, it was not possible to get a data set on prices at the different stages in the marketing chain (farm-level, wholesale and retail, at least). Without this type of data, it is not possible to use econometric techniques to estimate own price demand and supply elasticity of the different fruits, let alone determine the changes in demand of one fruit when prices of other fruits change. Cross price elasticities of demand for fruit may be important, for example, when consumers have a fixed budget share for fruit. Thus, when prices of tropical fruit decline, consumers may reduce consumption of other fruit as they increase their consumption of tropical fruit.

Data on wastage rates and postharvest costs before research were obtained from postharvest research scientists who worked on the 6 projects. These data could

be collected in the research development stages as part of the justification for funding. This would ensure that projects address issues which are both scientifically interesting and economically significant. Estimates of wastage rates and postharvest costs after research could also be collected in the trialing of technologies for commercial use.

While there are many studies of adoption of technology in the agricultural and manufacturing sectors (CAB 1981), the study of adoption, and of the factors that affect the level of adoption of fruit postharvest technology has been neglected. Results from such studies would improve the quality of data used in economic evaluations of fruit postharvest research projects.

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Regulations and Quarantine in International Trade

Nathan Ganapathi*

Abstract

The international trade community (import and export) often considers the restrictions and non-tariff barriers imposed on them by plant quarantine regulations as impediments to trade. The prevention of huge economic losses to a country because of the introduction of noxious or dangerous pests is the responsibility of the plant quarantine service, and if it is to achieve its objectives of preventing the entry and spread of these economically injurious pests then restrictions are inevitable.

The three major areas emphasised in this paper are harmonisation of phytosanitary principles; plant quarantine procedures; and pest risk assessment (PRA). The first two areas deal with plant quarantine principles and procedures, while the third deals directly with the quarantine pests and their interception. A proper understanding and management of the pests can assist in the facilitation of trade.

PLANT quarantine (PQ) regulations which most countries have gazetted into laws give the Department of Agriculture or other appropriate agency authority to regulate plant importation in order to exclude plant pests of quarantine significance without restricting commercial trade or preventing the exchange of valuable germplasm. Some of these plant quarantine regulations clearly mention the requirements and the standards that plant materials have to meet before they can be imported into the respective countries. The relevant agencies in each country have been assigned the responsibility for developing and implementing regulations to exclude pests of quarantine significance. By law, all important plant pests not occurring or not widely distributed in the respective countries are considered pests of quarantine significance (also sometimes referred to as 'exotic pests') and may be the subject of plant quarantine agency regulations.

The international trade community (import and export) often considers the restrictions and non-tariff barriers imposed on them by the plant quarantine regulations as impediments to their trading. The prevention of huge economic losses to a country due to the introduction of noxious or dangerous pests is the responsibility of the plant quarantine service, and if it is to achieve its objectives of preventing the entry and spread of economically injurious pests, then restrictions are inevitable. Some of these barriers and restrictions to trade can be removed or reduced by developing appropriate skills and information systems. This would enable the plant quarantine service to deal with the present increase in traffic of products and people. With a better understanding of, and assistance to plant quarantine regulations and services by commercial and trading groups, a number of obstacles and restrictions could be overcome.

FAO and the various plant protection organisations [European Plant Protection Organization (EPPO), North American Plant Protection Organization (NAPPO), ASEAN Plant Quarantine Centre and Training Institute (ASEAN PLANTI), Asia–Pacific Plant Protection Committee (APPPC)] have devised recommendations and guidelines for developing technically sound plant quarantine procedures that will avoid unjustifiable barriers between trading partners. The three major areas emphasised are:

- harmonisation of phytosanitary principles;
- plant quarantine procedures; and
- pest risk assessment (PRA).

The first two of these areas deal with principles and procedures of plant quarantine, while the third deals directly with the quarantine pests and their interception. A proper understanding and management of the pests can assist in the facilitation of trade.

Minimising the Interference of Plant Quarantine Pests in Trade and Traffic

The restrictions, barriers, and costs encountered in operational PQ occur at:

- inspection and pest interception;
- treatment or post-entry quarantine (PEQ); and

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- emergency action programs (EAP) to control exotic pest outbreaks or infestations due to negligent or accidental introduction of the pest.

These are often an economic cost involving millions of dollars to the country. Consignments with acceptable phytosanitary standards are cleared. However, if pests are intercepted, recommendations are made for treatment or post-entry quarantine, or for rejection or destruction of the commodity.

Rejection or Destruction of Consignment

PQ services have directed their efforts to overcoming some of these barriers. Like other plant protection organisations, PLANTI has compiled its own list of PQ pests, categorised as ASEAN A1 and A2 pests so that only these pests are intercepted and the presence of common or cosmopolitan pests in consignments is of little concern. Inclusion of pests on the list was based on the potential economic impact of these pests on the major crops grown or traded in the ASEAN region.

To validate listings of PQ pests of various countries, FAO and plant protection organisations have recommended that, in future, pest risk assessments (PRA) of the pests be carried out. The PRA methods rely on biological and economic evidence to justify the inclusion of PQ pests on the quarantine lists. Application of the many factors involved in the PRA concept is incomplete in ASEAN and many other parts of the world. ASEAN PLANTI, however, has taken the first steps to acquaint and instil in PQ services the concept of PRA in decision-making on PQ pest status. A proper understanding and application of PRA would alleviate some of the restrictions placed on the movement of commodities. At present, there is zero tolerance for PQ pests. With proper PRA, a maximum pest tolerance level could be determined for the PQ pests, leading to greater flexibility and reduced incidence of rejection of commodities. Furthermore, better pest detection methods and more efficient diagnostic and identification services would increase the speed of movement of goods in trade.

The second line of defence against pests are the treatments recommended to ensure consignments are pest free. Although treatment methods and schedules are constantly updated for appropriate and effective results, several problems have emerged regarding treatment:

- health risks and environmental effects involved in the use of chemicals, e.g. the fumigant EDB (ethylene dibromide);
- pesticide residues which exceed the MRL (maximum residue level); and
- development of pest resistance to pesticides.

One or more of these problems may be eliminated if there is preclearance before export, thereby reducing pest treatments at ports of entry. Pre- and postharvest pest control strategies, storage sanitation, etc. will reduce pest infestations and make exports acceptable. Some countries, such as in the European Community (E.C.) want neither chemical treatment of consignments nor pesticide residues. Their tolerance of pesticides (abiotic factors) is zero. They are more tolerant to pests (biotic factors) in their imports and are better able to deal with biotic factors than with abiotic factors. The reduction in pesticides used will also reduce the incidence of pesticide resistance in insects in international trade and traffic. Specific bilateral trade agreements between countries can help deal with some of these issues and, in the process, eliminate some obstacles.

The development of emergency action programs as a safety measure to eradicate or contain outbreaks or infestations of quarantine pests, together with proper surveillance and in-country monitoring, will help to reduce the total reliance on PQ inspection, and pest interception and treatments, and thus allow for greater freedom in trade and travel. International cooperation between PQ services and plant protection organisations will help to remove some of the barriers and facilitate trade in many ways.

An outline the 'Proposed Standards and Export Certification Procedures' follows. If these are adhered to, movement of fruits in international trade will be facilitated.

Proposed Standards for Procedures

This set of standards illustrates the considerable number of areas of quarantine procedures that will require standards. The incorporation of the projected standards into a framework will assist their systematic development. Discussion of a framework for standards should also indicate to all trading nations that standards will be a great help in clarifying issues and justifying phytosanitary measures.

- *Import specifications standards*
  - Pest risk assessment
  - Publication
- *Export certification procedure standards*
  - Certification administration
  - Training and accreditation
  - General inspection procedures
  - Specific inspection procedures
- *Compliance procedures standards*
  - Quarantine procedures at entry points
  - Cargo, baggage, postal inspection, and audit
  - Response to non-compliance
- *Pest and disease surveillance standards*
  - Pest and disease lists
  - Regional pest-free status
  - National pest-free status
- *Exotic pest and disease response standards*
- *Standards for pest management methods* (including disinfestation procedures)

- *Post-entry quarantine standards*
  - Site and/or facility requirements
  - Inspection methods and screening tests employed
  - Documentation of procedures

Import Specifications

Import restrictions are of great concern to trading partners. Because they are trade barriers, it is essential that they be justified and supported by sound scientific risk assessments. Also, details of the restrictions should be made readily available to trading partners. Hence, there need to be standards or guidelines for:

- the development of the specifications and entry conditions and their documentation;
- dissemination of this information and, if necessary, details of the means of creating the specifications and entry conditions, to trading partners.

The pest risk assessment process (and the pest management process) produces the specification and entry conditions. The standard procedures used for this by quarantine agencies will, it is hoped, be documented and give details including how risk assessment is undertaken, what level of acceptable risk is used, the quarantine pests identified to date that are of concern to the importing country, the pest tolerances, and a standard describing how the PRA is documented. The use of such standards will allow import specifications to be discussed (and presumably justified) when disputes arise.

Standards also need to be developed to publicise entry condition data. These might refer to:

- the availability of the data; and
- the costs, if any, of supplying details of existing entry conditions.

Export Certification Procedures

Ideally, plant quarantine procedures should cover the following areas:

- import specifications
- export certification procedures
- compliance procedures
- pest and disease surveillance
- exotic pest and disease response
- pest management methods (including disinfestation procedures)
- post-entry quarantine.

A great deal of work has yet to be done to derive a set of procedures that meets the certification requirements of importing countries. In the past, much of the treatment of imported products had to be carried out at the port of arrival when products did not meet specifications. This is no longer an acceptable practice. If treatments are required to make the pest status of a product meet the specifications of the importing country, that treatment should be applied in the country of origin.

To bring about change to current practices, countries must make the decision that non-compliance with specifications is no longer acceptable, and they must begin the use of non-compliance measures. This whole process requires standards for non-compliance action.

With regard to certification for export, in the past the phytosanitary certificate had little value. The systems that should be used to inspect and certify conformance to specifications are either absent or not used properly. Basically, this is the reason emphasis is placed on the compliance inspection at the port of entry. Quarantine agencies have to inspect and treat imported produce because it frequently does not meet specification because of inadequate certification practices.

This area is one where cost savings must be possible. If standards for export certification are devised, then countries that adhere to them could perhaps gain some form of accreditation that would have their products subject to a lower level of compliance inspection on arrival at the country of import.

It is convenient to divide a phytosanitary certification system into four component areas. These are: certification administration; training and accreditation of inspectors; general inspection practice; and specific inspection schedules. Standards should be constructed for subjects within each of these components, since trading partners will be interested in all of them if the certification system is to warrant special recognition or accreditation. Standards could involve:

- certification administration, including certificate issue and recording,
- training and accreditation of inspectors/auditors, including proficiency records of an inspector's duties,
- general inspection practice, with sampling plans relating to the required confidence levels for pest tolerance levels,
- specific inspection schedules for certain pests and diseases of high potential significance, such as potato wart, fruit flies, citrus canker.

There are, of course, many standards that could be included in the last-mentioned subject area. Each type of pest, from insects to vector-transmitted viruses, to soilborne fungi will require specific certification procedures.

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Overview of the Problems — Session Summary

Chairman: Dr G. Johnson, CSIRO, Australia
Rapporteur: Mrs Sing Ching Tongdee, Thailand Institute for Scientific and Technological Research

IN this plenary session, four speakers provided overviews of the issues to be addressed at the conference.

Dr Alex Buchanan from Australia discussed the social, political, and economic issues affecting the industry. Changes in workforce size and structure, population demography, transport and technology, disposable incomes, leisure activity, political systems, education, media and advertising, all affect future prospects.

Mr Colin Bunt and Ms Maria Piccone from Australia reviewed the significance of quality assurance (QA), a system developed in post-war manufacturing industries in Japan, and the challenges and benefits of its implementation in all phases of commercial fruit production (including research). The authors reminded us that fruit production was part of the food manufacturing industry, and recommended the introduction of QA systems in the development of our industries.

Dr Godfrey Lubulwa and Dr Jeff Davis of ACIAR reviewed assessments of the economic value of research on postharvest handling of tropical fruit. The authors used examples from ACIAR-supported tropical fruit research to assess their economic impact, and concluded that, in general, investment in postharvest research had high economic benefits. Dr Lubulwa concluded with a call for annual data on fruit production and prices which could be used to reform assessment procedures, and suggested that economic evaluation can strengthen rather than weaken the case for our research proposals.

Dr Nathan Ganapathi from ASEAN PLANTI, Malaysia presented the final paper on regulation and quarantine in international trade, reviewing some of the issues of concern to traders, and the threats to production that quarantine barriers help contain. Dr Ganapathi emphasised three major areas: harmonisation of phytosanitary principles; plant quarantine procedures; and pest risk assessment.

A vigorous discussion followed, especially in relation to assessment of the economic impact of research by funding agencies, and to diseases that threatened regional production.

Marketing of Tropical Fruit

Prospects for Marketing Tropical Fruits in Asia

D.C. Minnis*

Abstract

A wide range of tropical fruit has been grown in Asia to satisfy traditional local and nearby regional demand.

With the exception of banana and pineapple, the international trade in these fruit has been slow to develop. There are many reasons for this, including the quarantine restrictions that apply to fruit imports.

This paper analyses and assesses the existing international trade in tropical fruit in Asia in some detail, including the potentially lucrative markets of North Asia where the climate restricts the production of such fruit and makes importation necessary. New development in postharvest treatments, packaging, and disinfestation are looked at from a commercial viewpoint, and strategies to assist the development of the trade in tropical fruit are discussed.

WHILE a wide range of tropical fruit is grown in Asia, with the exception of bananas and pineapples there has been no substantial world trade in tropical fruit.

While banana and pineapple are available year round, and are cheaply produced on large plantations, many of the other tropicals are seasonal in supply and until recently have been almost entirely grown on smallholdings.

The Food Market in Asia

There have been many reports written on the potential markets for food products in Asia including fresh fruit.

In a recent report entitled 'Capturing Opportunities in Asian Food Markets', published in Australia by the McKinsey Global Institute, there are some interesting comparisons given on market size, population, and per capita food consumption in Asia. They are worthy of reproduction in order to quickly compare the Asian markets (Fig. 1).

The report highlights the fact that in many countries throughout Asia per capita food consumption and food imports are increasing rapidly as a result of continued growth in disposable incomes.

The McKinsey analysis of various countries' statistics indicates that in 1988 about 40 million people in East/Southeast Asian countries (not including China and Japan) were living in households with incomes of more than US$10 000. By the year 2000, this is likely to have increased to over 80 million people, with Korea and Taiwan accounting for more than 60 million.

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While this paper focuses chiefly on the opportunities for processed foods, the main message for those involved in the international trade in fresh and processed tropical fruits is that there will be enormous opportunities for a whole range of food products over the next decade.

Reviewing the Markets for Fresh Tropical Fruit

The markets of Singapore, Hong Kong, Taiwan, Japan, and Korea represent perhaps the full spectrum that exists in Asia.

Singapore and Hong Kong are duty–free markets for the entire range of tropical fruits. The Japan market is slowly opening up to the importation of tropical fruit which may, unless properly treated, represent a quarantine risk. Taiwan, which produces a wide range of tropical fruits, has severely limited imports. This is as much a reflection of the politics of the country rather than undue concern about quarantine issues. Taiwan's policy with respect to the importation of temperate fruit, for instance, is much more liberal than that of Japan's. Finally, there is South Korea which is on the threshold of deciding whether to further liberalise the importation of fresh and processed horticultural products including tropical fruit.

While fruit fly and codling moth are pests of major quarantine concern to South Korea as they are with Japan and Taiwan, the approach that the Government of South Korea takes to quarantine will be critical. It may allow internationally acceptable quarantine treatments to be used by exporters and so enable immediate trade, or it may require the verification of every treatment on every fruit product that is wanted by importers. This

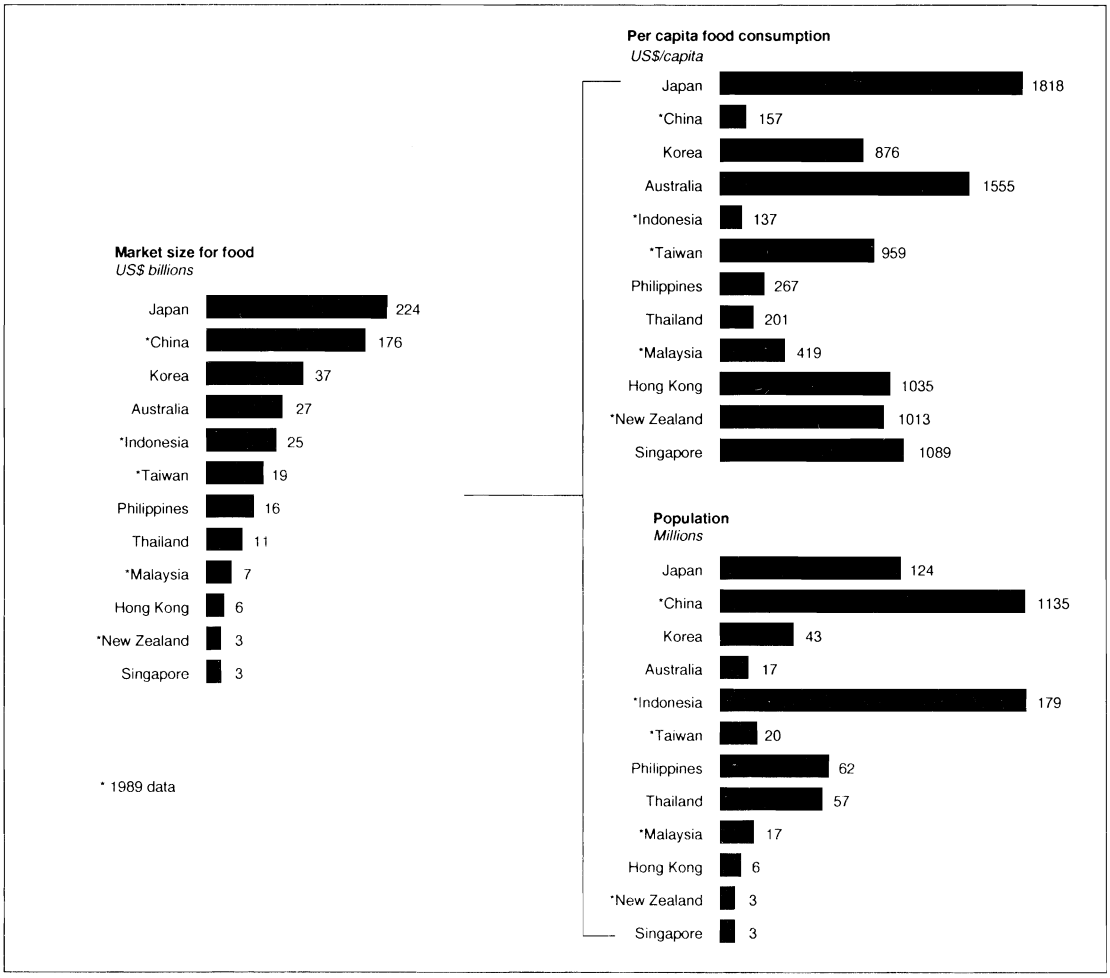

Figure 1. Food markets and consumption in Asia — 1988 data (White 1992)

could take many years and so the import trade would be opened up slowly, much as has happened in Japan.

The question of import duties would also need to be negotiated in South Korea and Taiwan as the duties on fresh fruit are in the range of 30–50% of the cost, insurance, and freight (CIF) value, and present a further impediment to increased trade.

Singapore

Singapore, with a population just over 3 million, is not a huge market, although with tourism and the ships chandling trade, it is larger than may first appear.

There are no restrictions on fruit imports into Singapore and so the full range of tropical fruit is available to the consumers.

Imports are around 100 000–120 000 t per annum, with bananas, pineapples and papayas from Malaysia representing more than 60% of all imported tropical fruit each year (Table 1).

Undoubtedly, the most sought after fruit in Singapore is the durian. When this is available the sales of all other fruit, including temperate fruit, decline. The volume of durian imports can vary greatly and reflects the effect of the season on the supply of the 'king of fruits'. Lychees similarly can be in undersupply in some seasons due to poor weather conditions causing reduced fruit set. Malaysia is the main supplier of durians, and Taiwan and Thailand are the main sources of lychees.

Thailand has targeted longans, lychees, and the durian as fruit with considerable export potential and the prices for these fruit in Singapore at times supports this decision. Certainly 'chicken tongue' varieties of lychees command a price premium as do some varieties of

Table 1. Imports of tropical fruit into Singapore

Fruit/major suppliers	1984		1991		1992	
	Quantity (t)	Value ($S'000)	Quantity (t)	Value ($S'000)	Quantity (t)	Value ($S'000)
Bananas (fresh or dried)						
Malaysia	25 559	5 016	44 225	13 309	33 587	11 001
Philippines	2 275	1 756	2 023	1 501	2 199	1 971
Total	27 971	6 868	46 270	14 810	35 854	13 273
Pineapples (fresh)						
Malaysia	13 350	2 004	15 062	2 402	14 898	2 475
Total	13 355	2 061	15 377	2 680	15 713	3 188
Avocados, mangoes, guavas, and mangosteens (fresh or dried)						
India	107	245	51	129	129	435
Malaysia	1 152	402	4 517	2 752	4 575	2 863
Philippines	1 354	4 876	858	2 918	780	2 848
Thailand	1 754	1 833	2 228	1 974	1 210	
Australia	74	394	543	2 279	894	3 290
Total	4 584	8 339	8 806	11 411	8 022	12 086
Durians (fresh)						
Malaysia	7 841	15 784	31 080	48 280	28 542	43 423
Thailand	2 245	2 322	2 944	2 734	320	588
Total	10 086	18 106	34 024	50 995	28 842	44 111
Longans (fresh)						
Malaysia	202	215	175	320	894	1 175
Thailand	3 704	10 895	1 784	3 982	3 313	8 120
Total	3 979	11 271	1 948	4 302	4 707	9 298
Lychees (fresh)						
China	99	732	47	643	92	936
Taiwan	453	1 653	378	754	1 039	1 205
Thailand	453	1 653	378	754	1 039	1 205
Total	18 030	13 926	2 285	5 841	1 478	3 237
Papayas (fresh)						
Malaysia	14 636	3 262	19 825	7 620	14 574	5 807
Total	14 643	3 324	19 825	7 620	14 574	5 807

Source: Singapore Bureau of Statistics.

durian. However, for other tropical fruit such as bananas, pineapples, papayas, guavas, mangosteens, and rambutans the wholesale prices in Singapore can be very modest.

Longan imports, chiefly from Thailand, often exceed 3000 t per annum. Another popular fruit is the mango which is sourced chiefly from Malaysia and Thailand. These two countries supply green/yellow-skinned varieties and local consumers are very knowledgeable about the differences between many of these varieties. The Alphonse types with attractive red blush are imported from India and Pakistan, and Australia supplies the most expensive Kensington variety during the period October to February.

The Carabao mango from the Philippines is a variety which is a little more expensive than, and appears to have lost market share to, the cheaper mangoes from Malaysia, and since the early 1980s, Thailand.

Hong Kong

There are no quarantine restrictions on the importation of tropical fruit into Hong Kong.

The fruit market in Hong Kong has been a strongly growing one for the past decade. The volumes imported are huge, as evidenced by the 120 000 t of oranges and 65 000 t of apples brought in every year.

Surprisingly, the total volume of all tropical fruit

imports is often less than that for Singapore and in 1991 reached 110 000 t overall. This may indicate that oranges, apples, and other temperate fruit are strong competitors for the consumers' dollars. Alternatively, it could also indicate that there are additional opportunities for well-presented, properly packaged tropical fruit in the Hong Kong market.

A comparison of the imports from 1983 and 1991 for six tropical fruit, indicates there has been strong growth in all of these except lychees, where supplies are finite and subject to seasonal fluctuations in the production areas of China and Taiwan (Table 2).

For popular fruit such as mangoes and pineapples, the Philippines is the main supplier and this situation is unlikely to change. But the market for both these fruit has virtually doubled over the past decade. Interestingly, Australia was the second largest supplier of mangoes in 1991 at 452 t. The main variety shipped

Table 2. Imports of tropical fruits into Hong Kong

Fruit/major suppliers	1983		1991	
	Quantity (t)	Value ($HK'000)	Quantity (t)	Value ($HK'000)
Bananas (fresh)				
Philippines	14 283	35 956	31 872	89 291
Thailand	4 199	7 425	3 858	25 462
China	3 478	5 474	5 490	12 600
Total	23 749	54 914	41 645	129 573
Pineapples (fresh)				
Taiwan	896	1 526	24	76
Philippines	348	988	4 408	13 816
China	23	35	549	1 294
Total	1 334	2 693	5 019	15 403
Mangoes (fresh)				
Taiwan	15	88	178	1 497
Philippines	6 564	33 047	12 983	76 402
Australia	6	414	452	8 697
Thailand	334	1 459		
Total	6 929	34 835	14 706	95 779
Avocados (fresh)				
Thailand	92	461	1 032	8 552
China	14	12	221	508
Malaysia			156	1 358
Australia	5	150	111	2 741
USA	118	1 973	75	2 322
Total	232	2 644	2 054	22 483
Lychees (fresh)				
Taiwan	1 455	6 259	5 210	27 185
Thailand	28	160	175	2 857
China	6 008	44 728	1 711	16 607
Total	7 490	51 148	7 102	46 769
Papayas (fresh)				
Taiwan	840	2 112		
Philippines	5	15	1 637	10 242
Thailand	2 361	8 688	308	1 777
China	291	568	417	732
Malaysia	192	940	10 391	82 423
Singapore			1 509	13 787
Total	3 712	12 504	1 276	109 201

Source: Hong Kong Bureau of Statistics.

from Australia has been Kensington, although a few Irwins, Keitt, and Tommy Atkins have also been exported to this market.

Bananas are largely supplied by the Philippines, with China and Thailand providing the remainder of the imports of almost 42 000 t in 1991.

The market for papaya has grown strongly since the early 1980s with Malaysia emerging as the dominant supplier.

Lychee imports stood at 7490 t in 1983, 7674 t in 1984, 8096 t in 1985 and 7102 t in 1991, the latest full year for available statistics. In 1986 imports exceeded 11 000 t. These figures tend to suggest that supply of lychees rather than the demand has been the major limitation to expanded imports.

Avocados, which are not a popular fruit, are now being imported in greater volumes but remain small at 2000 t per annum. Thailand has emerged as the main supplier.

In 1991, there were 24 230 t of other tropical fruit imported into Hong Kong, with 20 092 t coming from Thailand. There is no specific breakup of these figures as is available from Singapore Bureau of Statistics but durians and longans are expected to be the most important. This import trade has grown from 7631 t in 1984. In 1985, 12 531 t of other tropical fruit was imported into Hong Kong with 10 243 t derived from Thailand.

Taiwan

With a population of more than 20 million and rising per capita consumption in food, Taiwan is seen as a potential market for some tropical fruit in the future. In the past, Taiwan has been reasonably self sufficient in many fruits including tropicals. However, with limited opportunities for expansion of fruit growing areas, Taiwan will increasingly look to foreign suppliers to meet market demand. This is reflected in the increase in imports of fresh fruit of over 15% per annum in recent years.

In 1990, total fruit imports, volume 175 420 t, were valued at US$165 million. As can be seen from Figure 2, apple imports accounted for over 55% of total fruit imports.

The USA is the major supplier of fresh fruit to Taiwan, supplying 84% by volume of the total import market in 1990.

Over the period 1990–92 the only tropical fruit imported in any quantity into Taiwan has been the mangosteen. In 1990 imports were 964 t and by 1992 this has grown to 5656 t (Table 3).

For many other tropical fruit, Taiwan is a significant exporter to other parts of Asia. In 1990, Taiwan shipped 48 120 t of bananas to Japan and Korea, and 3742 t of pineapples, principally to Japan.

In the same year, exports of lychees reached 6190 t, with more than 1000 t being shipped to the following markets: Canada, Hong Kong, Japan, Philippines, and Singapore.

The main season for Taiwan lychees is May–July, for carambola November–February, for guava September – March, for mango May–July, and for papaya September –December.

While fresh fruit exports peaked in 1987 at 156 500 t, there has been a decline ever since due to competition from Ecuador and the Philippines in many of Taiwan's traditional export markets. By 1990 only 82 900 t of fruit were exported by the Taiwanese fruit industry.

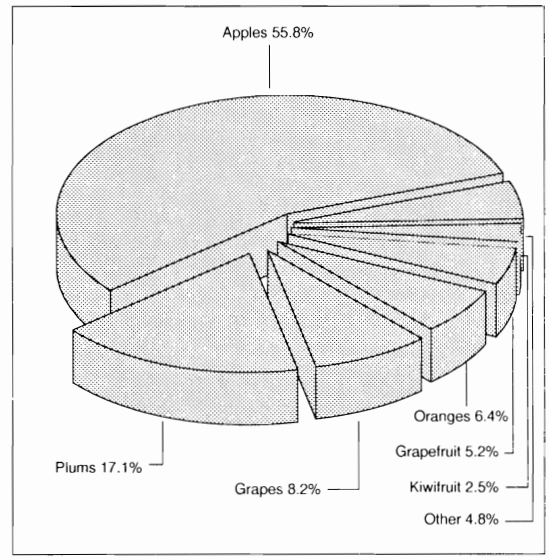

Fig. 2. Fruit imports into Taiwan in 1990

Japan

Imports of tropical fruit into Japan are still somewhat restricted given the concerns that the Japanese have about fruit fly.

Green bananas and pineapples are not regarded as hosts for fruit fly and so imports are substantial.

As the import figures illustrate in Table 4, over the past two years banana imports which used to exceed 900 000 t have now settled back to around 750 000–800 000 t per annum. The main suppliers are the Philippines and Ecuador, followed by Taiwan. Japanese importers are continually trying to develop additional South American suppliers such as Panama, Honduras, and Costa Rica.

Pineapple supplies come chiefly from Taiwan and the Philippines, although Taiwan may be replaced by supplies from Indo-China in the future. Total imports vary between 120 000–140 000 t per annum.

Table 3. Imports of tropical fruit into Taiwan

Fruit/major suppliers	1990		1991		1992	
	Quantity (t)	Value ($TW'000)	Quantity (t)	Value ($TW'000)	Quantity (t)	Value ($TW'000)
Mangosteens (fresh or dried)						
Indonesia	162	7 273	880.9	38 254	3 045.2	120 075
Malaysia	7	308	28.9	1 095	250.5	9 095
Thailand	780	34 187	506.2	19 119	2 282.7	87 535
Vietnam					45.0	1,377
Total	964	42 394	1 413.4	58 483	5 656.8	219 390

Source: Taiwan Bureau of Statistics

Imports of mangoes have grown slowly due to quarantine difficulties. In 1992 just over 8000 t were imported. The main suppliers are the Philippines and Mexico, but there were 10 countries shipping mangoes to Japan in 1992. In Australia, the Japanese market is viewed as a potentially good one for mangoes, hence research on vapour-heat treatment of the main variety Kensington Pride has received high priority.

Papaya imports likewise have been restricted because of the difficulty in developing a commercially acceptable disinfestation treatment. In most years Hawaii is the sole supplier, with imports around 5000 t per annum.

Avocado imports are even smaller than papaya at around 2500–3500 t per annum, but there is the perception that there is potentially a very good market in Japan for avocados, particularly if the fruit is properly promoted as cholesterol free. Imports are mainly from the USA and Mexico, and occasionally from New Zealand.

Some years ago the Japanese MAFF was embarrassed that they approved a treatment for the control of Fullers Rose Weevil in Florida grapefruit that proved to be commercially very risky. As a result, there were years when importers lost millions of dollars (U.S.) due to fruit injury problems and that has resulted in a very conservative approach being adopted by Japanese quarantine officials. This is quite correct for there is no point in approving a disinfestation treatment that is not commercially viable. Hence, in developing a disinfestation treatment for the Japanese market, data on the extent of fruit injury has to be included in any submission.

The potential for some of the other tropical fruits may be covered in a later conference paper. However, when Japanese importers come to Australia there is always quite genuine interest in fruit such as lychees, rambutans, and mangosteens.

South Korea

South Korea has a population of 44 million people with little or no ability to grow tropical fruit.

In 1990 a decision was made by the government to open up the domestic market to imported bananas. Prior to 1990, there were small quantities grown in plastic houses on the island of Cheju, and controlled imports from Taiwan.

In 1989 total banana imports were 21 169 t, but by 1991 the quantity of imports had grown dramatically to 314 748 t worth US$203 million (Table 5).

Similarly, in 1991 the domestic market was opened to pineapple imports for the first time. In 1991, some 3893 t were imported. However, in the first 7 months of 1992 imports were already 3261 t with the Philippines, Thailand, and Vietnam the main suppliers and for the full year imports were expected to exceed 6000 t.

Given that the government has now opened the market to banana and pineapple imports, it is hoped that other tropical fruit will be permitted entry in the near future, provided quarantine restrictions can be overcome.

In 1991, just under 1 t of mangoes were imported from the Philippines and 7.8 t of avocados. The USA and New Zealand, both regarded as free from fruit fly, were the countries supplying the avocados.

No other tropical fruit were imported into South Korea in 1991.

Strategies for Marketing Fresh Tropical Fruit in Asia

Exploit seasonal advantage

Each country needs to fully exploit their seasonal advantage in the production of tropical fruit.

To extend the season from any one location, storage and packaging techniques can be used. In recent years the development of laminated films which combine several characteristics such as moisture retention, partial permeability to gases, and the ability to absorb waste odours including the ripening gas ethylene, are close to commercial realisation.

Table 4. Imports of some tropical fruits into Japan

Fruit/major suppliers	1991		1992	
	Quantity (t)	Value (Yen'000)	Quantity (t)	Value (Yen'000)
Bananas (fresh)				
Taiwan	54 072	6 645 542	65 730	8 021 434
Philippines	586 853	44 466 049	546 860	46 173 563
Panama	18 205	805 510	2 194	213 521
Ecuador	135 016	10 045 130	152 163	11 892 068
Honduras	5 905	375 529	3 738	324 174
Costa Rica			5 692	597 739
Total	803 339	62 820 772	777 175	68 218 674
Pineapples (fresh)				
Taiwan	2 258	299 236	1 975	272 241
Philippines	135 414	6 824 164	125 391	6 923 836
Total	137 786	7 134 317	127 465	7 207 567
Avocados (fresh)				
USA	1 010	430 342	2 160	624 282
Mexico	1 645	444 931	1 398	356 422
Total	2 665	879 881	3 558	980 704
Mangoes (fresh)				
Thailand	20	9 070	18	11 671
Philippines	5 768	1 973 371	7 270	2 165 249
Mexico	1 036	548 278	734	397 292
Taiwan	46	4 162	14	7 789
Total	6 880	2 564 726	8 058	2 598 147
Papayas (fresh)				
Taiwan	2	1 034		
USA	5 268	2 639 088	5 182	2 359 948
Total	5 271	2 640 122	5 197	2 366 171

Source: Japan Bureau of Statistics

Table 5. Imports of some tropical fruits into South Korea

Fruit/major suppliers	1989		1990		1991	
	Quantity (t)	Value (US$'000)	Quantity (t)	Value (US$'000)	Quantity (t)	Value (US$'000)
Bananas (fresh & dried)						
Taiwan	20 126	14 823	14 830	11 846	15 538	13 253
Philippines	1 043	663	7 004	5 419	129 500	88 057
Ecuador					150 990	93 896
Vietnam					14 222	4 964
Total	21 169	15 487	21 834	17 266	314 748	203 512
Avocados (fresh)						
USA	18	81	10	80	5	25
N.Z.	1	4			3	15
Total	19	85	10	80	8	40
Pineapples (fresh)						
Indonesia					45	31
Philippines					3 585	2 085
Thailand					83	60
Taiwan					277	226
Total	0	0	0	0	3 893	3 126

Source: Republic of Korea Bureau of Statistics

Reduced use of chemicals

The worldwide concern by consumers about the chemicals used in food production systems can but increase in the future.

In orchards, the use of insecticides, fungicides, miticides, and herbicides will come under close scrutiny. Using integrated pest management techniques, producers will in the future be able to greatly reduce the amount of chemicals used in the field.

After harvest when the fruit is ripening, there has been great reliance placed on timely, effective, and often specific chemical control of postharvest rots. In some instances the efficacy of the chemical treatment can be improved by heat, for instance, as is used for mangoes.

In recent interesting work on pome fruit, researchers are finding that antagonistic yeasts can be used for the control of a number of postharvest rots. While the yeasts at this stage cannot completely replace the chemicals, they can allow the concentration used to be greatly reduced, particularly in the presence of inorganic additives.

The biological control of postharvest rots in tropical fruit will be an important area of research in the future.

Development of non–chemical disinfestation treatments

While this development has gone further with tropical fruit because of the demise of ethylene dibromide (EDB) than with temperate fruit where methyl bromide is still available for disinfestation, there is little doubt that all disinfestation treatments for the future will be non-chemical.

Although a number of countries in Asia accept irradiated food, including fruit, the reality is that even if the variety of a particular tropical fruit could withstand the treatment, the consumer acceptance of such a treatment is highly questionable. This situation is not likely to change in the short term.

Developing total quality management systems (TQM) for the industry

If consumption of tropical fruit in Asia is to continue to expand, there is a need to develop TQM systems that increase consumer confidence.

If fruit is harvested at the right stage of maturity, given the appropriate postharvest treatment, precooled as required before or after packing, and placed in properly constructed containers or cartons that will protect the fruit in the rigours of the marketing system in Asia, then there is every chance that the product will outturn more reliably.

This will involve assessing how the product is currently handled, possible improvements, and the problems. By developing a TQM system involving the growers, packing sheds, and the marketers, and educating them on what is specifically required for each fruit, the end result will be increased consumption in existing and new markets.

Getting greater value for the product

In the markets of Singapore, Hong Kong, Malaysia, and Thailand, there is a wide range of tropical fruit available to consumers. It is of variable quality in many cases. Tropical fruit produced locally or in the region often commands a relatively low price in comparison with imported temperate fruit.

There is no future in producing large quantities of variable quality low-value fruit. The challenge for the future is not only to increase the consumption of tropical fruit in Asia but also to increase the price so that producers can get a return on their investment and are prepared to make improvements.

With increasing disposable income, consumers in Asia will demand better quality and presentation. Retailers similarly will no longer tolerate the spotty, marked, mixed ripe local fruit but will demand that these fruit are of similar standard to imported produce from the USA, Chile, Australia, or Israel. The supermarkets will be the first retailers to demand this improvement in quality.

Throughout Asia there are major changes occurring in retailing. Although traditional wet markets continue to be the main outlet for fresh fruit, their proportion of the total retail trade is declining. For instance, in Hong Kong the two chains of Wellcome and Park-n-Shop have more than 350 outlets between them. In Indonesia, the Hero supermarket chain has 46 outlets and leads the other chains Gelael and Golden Truly.

In Taiwan in 1992 there were an estimated 185 supermarket outlets and the number was growing. The Hong Kong Wellcome group alone has opened more than 50 outlets over the past 4–5 years.

Greater use of branding and promotion

Asian consumers regularly purchase fruit and are aware of the health benefits of this product. However, these consumers are often conservative in their buying attitudes. For instance, lychees are available in summer not at Christmas time. Promotion will be needed to introduce new varieties and to encourage all year round consumption if supplies are available.

Branding is quite well developed in Asia and consumers react well to it. An example is the price differential achieved for different brands of oranges at any one time in Hong Kong. During June 1993, 17 brands of Californian Valencia oranges were on the market with the price

varying between $HK135 and $HK115 for the same size of fruit. This $HK20 variation per 20 kg carton is at the wholesale level. The variety of orange is the same, the count or size is the same as is the carton, but the brand or image is different.

The marketers of tropical fruit in Asia could well look at the success of the Californian citrus industry and learn from it. The strategies these growers, packers, and marketers have developed could be applied to the marketing of tropical fresh fruit out of Asia in the future.

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Trends and Changes in the European Market for Tropical Fruits and Their Impact on Technology Requirements

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Abstract

The European market for the major imported tropical fruits; pineapple, mango, avocado, and papaya has continued to expand. During the period 1987–1992 there was an 11% increase by volume of imports. The market share of minor tropical fruit has continued to grow but at a slower rate. Changes in market arrangements within the European Community market have enabled the strengthening of trans-European importer/distributors. This, combined with an increasing share being taken by multiple retailers for retail sales of tropical fruit, has influenced the marketing structure, placing new and more rigorous demands upon suppliers.

There exists within Europe a heightened awareness on the part of the consumer to issues of product quality and food safety, as well as to the environmental and social impacts associated with food production and marketing. These are addressed in the context of their impact on the organisation of fruit export industries, the application of technologies, and the need for investment in infrastructure.

The international fruit trade is now strongly market driven, demanding vertical integration and the delivery of produce within a framework of total quality assurance.

OVER recent years there has continued to be a steady growth in the import volume of mainstream and exotic tropical and subtropical fruit. This rate of growth is slower than that experienced in the early 1980s and may fall in 1993 as the economic recession spreads across Europe. Overall, the increase in imports of pineapple, avocado, mango and papaya by volume at 11% has not been matched by total value at 7% for the period 1987 to 1992. During this period, the longer term trend in prices has been downward, reflecting increasing competition between suppliers and the impact of economic slowdown on consumer demand. The fall in the value of the U.S. dollar between 1987 and 1992 has also contributed to the slower rates of growth in value when measured in European Currency Unit (ECU) terms. Table 1 provides the European import figures by volume and value for 1992 for selected tropical and subtropical fruits excluding bananas together with a summary of 1987 import data. Table 2 presents the export volumes to the European Community (E.C.) market by the major countries of supply in 1992.

Pineapple

Pineapple continues to play a dominant role in the E.C. tropical fruit market with a 15% growth in volumes imported between 1987 and 1992. France remains the largest importer and the principal supplier continues to be the Ivory Coast, which together with Costa Rica takes 74% of the total market share; other suppliers include Dominican Republic, Honduras, and Ghana. Some 61 000 t of imported pineapples were re-exported within the E.C. in 1992, the main trade flows being from the Benelux countries and Germany to other E.C. member states. The major suppliers offer fruit all year around and the industry is based on sea transport.

Avocado

E.C. imports of avocados fell by 13% between 1987 and 1992 as a result of heat and wind damage to the Israeli industry in 1988. France continues to be the major E.C. market importer, with the principal suppliers, Israel and South Africa, sharing 73% of the total E.C. market. In 1992 some 8500 t were re-exported from France, mostly to Germany, but also to the U.K. and The Netherlands. The calendar of supply, with Israel offering during October–May and South Africa March–December, enables these two sources to service demand throughout the year. Other suppliers include Mexico and Kenya.

Mango

Mango imports, although with overall smaller volumes of supply than pineapple and avocado, have shown

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Table 1. European imports (t) of some major tropical fruits in 1987 and 1992

Country	Pineapples	Avocados	Mangoes[a]	Papayas	Other[b]	Other[c]
Bel–Lux	51 712	1 137	1 513	392	468	486
Denmark	1 055	1 710	86	15	0	115
Germany	24 923	1 473	3 312	1 773	476	5 531
Greece	239	1 657	17	0	3	0
Spain	24 298	1 722	287	47	2	8
France	71 468	62 412	9 872	840	6 043	1 983
Ireland	311	0	1	2	0	0
Italy	31 271	267	550	270	167	31
Netherlands	9 492	5 145	12 932	2 332	1 316	3 615
Portugal	0	77	1 660	413	8	24
United Kingdom	13 879	12 250	12 221	1 818	1 517	2 820
Total 1992	228 648	87 850	42 451	7 902	10 000	14 613
Total 1987	199 213	101 211	24 796	4 198		
% change volume 1987–92	15	–13	71	88	d	d
Value 1000 ECU[e]						
1992	131 666	105 961	56 779	12 306	26 038	22 906
1987	128 987	111 137	39 041	6 996		
% change value 1987–92	2	5	45	76	d	d

Sources: EUROSTAT 1992. External trade, import statistics A 01-24; NIMEXE 1987. Analytical tables of foreign trade.
[a] Includes guava and mangosteens
[b] Fresh tamarinds, cashew-apples, lychees, jackfruit, sapodillo plums
[c] Passionfruit, persimmons, other stone fruits, other berries excluding E.C. imports from temperate countries
[d] Changes in classification prevent a direct comparison with earlier years
[e] Exchange rates: 1987, 1 ECU = US$1.15; 1992, 1 ECU = US$1.29.

significant growth in both volume and value. The major market for mango continues to be the U.K. (29% of the E.C. total), followed by France (22%). The Netherlands imports over 30% of all mangoes in the E.C., but then re-exports these to other member states; consumption in the Netherlands therefore accounts for only 15% of the E.C. total. The main suppliers in 1992 were Brazil, USA, Venezuela, Mexico, and Israel. The relatively short season of supply from all sources means that no single country dominates the supply base and fruit are sourced from over 25 different countries.

Papaya

Whilst significant growth has been seen in the import volumes for papaya over the past 5 years, this has been from a small base and the total volume remains relatively low at 7902 t in 1992. Brazil and Costa Rica dominate the supply base, both having the capacity to produce fruit all year around.

Minor exotics

A wide range of minor tropical fruits are imported into the E.C. from sources throughout the world. Larger volume items include lychee, passionfruit, persimmon, and carambola, but the list extends to include guava, cape gooseberry, breadfruit, mangosteen, rambutan, kumquat, and cherimoya. The classification of records on imported volumes and value of these lines has changed over the past 5 years within the E.C., preventing direct comparisons of 1992 figures with earlier years. However, as with major tropical fruit imported into the E.C., the minor exotics have also seen a relative reduction in the rate of growth in the market in recent years.

General

The concentration of market share held by a relatively small number of suppliers is worthy of attention, as are the shifts in sources of supply over time. Taking mango as an example, and taking account of the increase in volumes marketed, over the period 1987 to 1992 the top five exporters maintained approximately a 50% share. Brazil, Venezuela, and Mexico remained in the top five throughout the period, whereas Mali and Burkina Faso fell to become minor suppliers. Puerto Rico (USA) and Israel, however, rose from insignificant levels to being suppliers within the top five. An analysis of these changes may be illuminating and might expect to be related to the level of the technological base and the application of such technology within aggressive

Table 2 Major exporting countries to the European Community in 1992 by volume (t)

Pineapples		Avocados		Mangoes[a]		Papayas		Other[b]		Other[c]	
Ivory Coast	132 062	Israel	37 445	Brazil	7 635	Brazil	3 960	Madagascar	5 578	Israel	2 885
Costa Rica	38 271	South Africa	26 640	USA	5 190	Costa Rica	1 726	South Africa	3 916	Malaysia	2 400
Dom Republic	28 891	Mexico	10 423	Venezuela	3 208	Jamaica	936	Thailand	298	Iran	1 932
Honduras	13 920	Kenya	6 614	Mexico	3 086	Malaysia	253	Mauritius	58	Thailand	1 112
Ghana	7 126	Brazil	742	Israel	2 507	Ivory Coast	208	Israel	53	Colombia	1 115
Others	8 378	Other	5 986	Others	20 825	Others	819	Others	97	Others	5 169
Total	22 8648	Total	87 850	Total	42 451	Total	7 902	Total	10 000	Total	14 613

Source: EUROSTAT 1992. External trade, import statistics A 01–24.

[a] Includes guava and mangosteens.
[b] Fresh tamarinds, cashew-apples, lychees, jackfruit, sapodillo plums.
[c] Passionfruit, persimmons, other stone fruits, other berries excluding E.C. imports from temperate countries.

marketing systems. West Africa is unlikely to have held such a technological capacity, in contrast to its competitors in Puerto Rico and Israel. Despite the efforts therefore of the early/mid 1980s, West Africa has been unable to maintain its competitive advantage and thus market share.

E.C. tariff arrangements

Fresh tropical fruit entering the E.C. are subject to one of three possible tariff arrangements depending on the country of origin. The three broad tariff groupings are: the E.C. Common External Tariff (CET); African, Caribbean, and Pacific (ACP) preferential terms; and the Generalised System of Preferences (GSP) for developing countries outside the ACP group. There are, however, a number of exceptions whereby specific country tariff arrangements are in place.

The E.C. CET is levied upon tropical fruit imports from outside the E.C., excluding the ACP countries and developing countries which fall under the GSP. The tariff rates applicable vary by tropical fruit and, for some commodities — avocados, for example — the time of year. Tropical fruit from ACP countries enter the E.C. market duty-free, while developing countries not signatory to the Lomé convention receive preferential treatment under the GSP scheme. Israel is the major beneficiary of individual country preferential tariff arrangements. Table 3 presents, for a selection of tropical fruits, the rates of duty applicable under the E.C. CET, ACP, GSP, and for Israel.

Table 3. EC, CET, ACP and the GSP rates of duty on selected tropical fruits (% ad valorem)

Fruits	CET	ACP	GSP	Israel
Pineapple	9	0	9	9
Avocados				
1 Dec–31 May	4	0	3.5	0
1 June–30 Nov	8	0	6	0
Mango	4	0	4	0
Papaya	2	0	0	2

Source: HM Customs and Excise Tariff 1991.

The ratification of the current Uruguay Trade talks would have significant repercussions on the current tariff regimes. Large reductions in the E.C. CET are projected for tropical fruits. These would be in the order of 50% and may even entail the complete removal of duty. In such a situation, the GSP would also have to be amended. In recognition of this, a major review of the GSP scheme is due once the outcome of the current GATT round is known. The ACP countries will be subject to increased competition and, in cases of the complete abolition of duty, will have no element of protection. Tropical fruits which are grown in member E.C. countries, e.g. avocados in Spain, will continue to be afforded an element of protection. Tariff reductions are therefore likely to be more modest, perhaps in the order of 20%.

Distribution Structure

The completion of the European internal market in January 1993 has seen an increase in the establishment of trans-European import/distribution companies. The majority of major national import companies have now formed either marketing and distribution arrangements with sister companies in each E.C. member state and/or take-overs have taken place.

This reflects the growing interest on the part of the major import companies in Europe to have the capacity to market and distribute throughout Europe, increasing not only market share but also the capacity to move in and out of specific markets depending on the prevailing supply and demand situation.

The role of small individual country-orientated importer/ distributors is likely to diminish over time with the exception of specialist importers supplying ethnic minority groups unique to, or focused within, particular geographic regions of the E.C.

The multiple retailers have taken an increasing share of the retail distribution of fresh fruit across Europe. This is seen particularly in the U.K. where their share has risen from 22% in 1976, 43% in 1987, to 53% in 1991. The larger U.K.-based multiples have major expansion plans including expansion into other E.C. member countries. Such expansion means an increase in shelf space for produce with the potential for an increase in volumes handled.

At the same time, however, there is an upsurge in discount multiple-retail stores and with this, the possibility that produce will become caught in the aggressive downward pressure on prices established in order to attract overall retail multiple market share. The direction in which multiple retailing moves will influence the consumer purchasing pattern as well as the future role and structure of the traditional wholesale market and independent retailer.

Suppliers to multiples are increasingly required to offer 12-month delivery of each product line, at a consistent and pre-specified quality and within a stable or pre-determined price structure.

Legislation

The European Community has been formulating legislation to ensure that each member countries' regulations relating to the fruit trade operate in harmony. Any national initiative that distorts trade and competition or has a protectionist character is seen to be incompatible

with the Treaty of Rome. The main issues which concern trade in fresh produce are as follows.

Quality control

The recent directives centre upon the methods to be adopted in order to police and monitor quality standards of produce moving into the E.C. and between member states (Anon. 1992a). Some 40 fresh horticultural commodities are covered by current E.C. legislation relating to quality. The crops included are primarily those within the E.C. Most tropical fruit imported into the E.C. is not covered by quality standards, although a range of proposed and guideline standards for quality are available through the UN/ECE (1991). Under the Joint FAO/WHO Food Standards Programme, the Codex Alimentarius Commission has a schedule of activity to define guideline standards for carambola, lychee, mango, papaya, pineapple and prickly pear by 1993; avocado and bananas by 1995 and oranges, persian limes, pummelo and mangosteen by 1997. The report of the fourth session of the Codex Committee on tropical fresh fruit (FAO/WHO 1993) outlines the present status of these proposals.

Food safety

U.K. national legislation relating to Food Safety and Consumer Protection incorporated in the Food Safety Act of 1990 (Anon. 1990) is likely to contribute to the structure of future E.C. legislation. A draft directive aims to harmonise food hygiene standards across the E.C. and supports the principle of 'mutual recognition of safety standards by raising confidence in the existing standards of hygiene and food safety at all stages of the production and marketing chain in each E.C. member state'. Distributors of fresh produce in the U.K. are placed under legal obligation to take all reasonable precautions and exercise all due diligence to assure a number of critical quality and safety characteristics of fresh produce.

Food Hygiene Regulations in the U.K. (Anon. 1991) have specified that foodstuffs, including in the context of fruit and vegetables, pre-prepared and semi-prepared products, must be stored below 5°C.

Pesticide residues

There are two broad lines of approach being adopted in the E.C. related to pesticide controls, one concerned with liability and legal obligation and the other with specifications for maximum residue levels (MRLs). In the U.K. the *Food and Environmental Protection Act* (Anon. 1985) provides that it is a defence for a person charged for an infringement of the pesticide residue legislation to prove to the courts that 'all reasonable precautions and all due diligence were exercised in order to avoid liability of an offence'. The subsequent *Pesticide (Maximum Residue levels in Food) Regulations* (Anon. 1988) make it an offence to leave or cause to be left on produce residue levels exceeding the MRLs. This placed responsibilities with the producer. Subsequent legislation in the U.K. and proposed E.C. regulations and directives will allow criminal liability to lie at any point along the production, marketing, and distribution chain.

These 1985 and 1988 *Acts* in U.K. have therefore had a significant impact on the structure and relationships within the chain; including those buyers procuring produce from outside the E.C.

The 1988 *Act* was the driving force behind the development of a 'Code of Practice for Pesticide Control for Produce Marketing Organisations' (Anon. 1992b). This code of practice has been adopted by the majority of players in the horticultural crop industry within the U.K. and now influences sourcing worldwide.

Progress on harmonisation of permitted MRLs has been slow. Over 50 substances for use on products of plant origin should fall under harmonised E.C. legislation by the end of 1993 (Anon. 1992c).

Phytosanitary Regime

The phytosanitary regime has been harmonised and a revised directive came into force in June 1993 (Anon 1992d,e). Phytosanitary certificates for products originating in the E.C. have been abolished for products transported between member states. Entry of some products into certain member states, e.g. some citrus into Greece, Italy, and Corsica, is prohibited. All other fresh fruits will, in principle, be allowed to enter the E.C. if they meet the specific demands of the E.C. Phytosanitary Services in advance. A list of temperate fruits requiring phytosanitary certification has been drawn up. To date, those crops which require phytosanitary certification include citrus, *Annona* sp., persimmon, mango, and passionfruit; the requirements for other tropical fruit remain under discussion.

Food Additives

Harmonisation on food additives remains under discussion with proposals pending. The current proposal (Anon 1992f) may permit beeswax (E901), carnauba wax (E903), candelilla wax (E902), and oxidised polyethylene wax (E914) postharvest treatment of some fruits; this proposed legislation remains under discussion. Exporters should examine legislation before applying inks and adhesive labels directly to fruit.

Packaging

Several European countries, led by Germany, have introduced regulations or codes of practice intended to provide environmental benefits by limiting the disposal of waste packaging. Re-use, recycling and minimisation of packaging are the routes adopted. In some instances, such as for sales (retail) packaging in France and Germany (Boyle 1992), packages need to be registered and fees paid to disposal organisations. An E.C. directive, which should supersede national legislation, is still under discussion; the current draft (Anon 1992g) states that 10 years after the directive comes into force a minimum of 90% of all packages should be recyclable and/or reusable. There is currently a strong trend away from packages constructed from composite materials, or incorporating additives which limit recycling capability, e.g. waxes or polyethylene coatings. Increased interest is also being shown in reusable plastic transport containers.

Others

Other issues relating to labelling, including information on pre- and postharvest treatments, metrication, transport, and environmental issues — notably long-term use of chlorofluorocarbons (CFCs), are also areas of concern under the E.C. program of harmonisation.

Consumer Trends

The consumer requires a 12-month availability of the full range of products; seasonal supply of products plays a greatly diminished role as a feature of the market and importers/retailers strive to service this all-year-round demand.

The past 10 years have seen a number of changes in the food industry with increased demand for semiprepared foods, often adding-value to the product along the market chain, together with an increased demand for fast foods, nouvelle cuisine, and easy-to-prepare/easy-to-eat products. The last is, for example, reflected in the increasing demand for easy-peel citrus as opposed to the traditionally marketed navel or valencia oranges.

The consumer with increasing knowledge and awareness requires choice and diversity: 10 years ago apples may have been marketed as green or red; today, named varieties are presented at the retail level offering choice in terms of flavour, texture, and colour.

Reinforcing the effects of legislation, the consumer is demanding a high standard of presentation of quality at the retail level including product uniformity, freshness and ready-to-eat. There is increasing awareness and concern over the use of pre-and particularly postharvest pesticides. While codes of practice, 'due diligence', and conformity to MRLs go some way towards meeting consumer pressure, in the long term it must be expected that the number of registered pesticides, as well as the acceptable levels of MRLs will be pushed down further.

The market for organic produce continues to remain static and has not fulfilled the expectations of the mid-1980s.

Increasing competition and downward pressure on prices mean that political, social and, possibly, wider environmental issues are in practice of less relevance than at any time in the last 15 years.

Impact on Systems and Technologies

The dynamic state of the structure of the E.C. import/distribution trade, the changing and harmonising legislation within the E.C., and the increasing awareness and demands of the consumer make the E.C. market increasingly challenging for the exporter. As supplying countries become more aggressive in what is a strongly market-driven industry, so new suppliers must ensure that strategies developed to penetrate the market are robust, and reflect a flexible and strong technological base. Gone are the days when a few consignments could be placed on any of the major wholesale markets of Europe in the hope that an easy return would be achieved.

Table 4 highlights some of the systems and technologies that need to be considered in reflecting the market trends within the E.C.

Codes of Practice for Product Management

The demands of the consumer, backed increasingly by legislation, in particular issues of food safety and 'due diligence', mean that the industry must now focus on full commercial integration, addressing all aspects of the industry from production planning to retail delivery. Such integration not only allows the opportunity to address quality-related issues but provides the means of reducing costs through the entire chain and, where appropriate, adding value at source through for example semiprocessing, prepackaging, and prepricing.

To achieve such objectives, a code of practice agreed by all parties needs to be established. This should also define the method of operation and program of action.

There are several components that need to be addressed in developing such a code of practice including the following major features.

Company organisation

- Policy statement
- Management structure
- Staff responsibilities
- Company information sheet

Table 4. Impact of market trend on horticultural crop production and marketing systems and technology

Market trend	System/technology
Market centralisation	• Rationalise export industry to service client • Develop longer term strategy • Deliver to limited access points in Europe • Consider regional supply strategy
Changing market	• Integrate production/marketing • Market intelligence • Increase flexibility in the supply base
All year supply	• Technologies to spread season of production – protected cropping – genetic screening – flower initiation – agro-ecological spread
Downward pressure on price	• Optimise on sea transportation – Controlled atmosphere/ modified atmosphere – improved reefer container – postharvest management • Increase productivity – genetic screening – agronomic research – production management
Quality assurance	• Integrated temperature management • Integrated product management including manipulation of fruit ripening • Define product specification/ establish quality assurance procedures
Packaging	• Develop reusable/recyclable packaging • Meet E.C. specification of size/palletisation
Reduce pesticide residues	• Genetic manipulation • Pesticide application technology • Integrated pest management • Codes of practice on usage • Non-chemical postharvest treatments
Due diligence/food safety	• Establish integrated quality assurance procedures

Procurement and control of raw materials
- Conditions of supply
- Raw material inspection and control

Process control and the management of quality during production
- Packhouse
- Equipment and packhouse hygiene
- Personnel: hygiene and resource requirements
- Process control

System in support of 'due diligence'
- Audit of system
- Pesticide residue analysis
- Control of harvesting and field-packing operations
- Temperature checking
- Maintenance of records
- Standardisation of analytical equipment

Within this framework, decisions can be taken on the level and type of investment in human and physical resources, as well as the extent of, and need for, technological interventions.

An environment whereby the supplier, importer, and distributor are committed into the longer term and can strategically plan their operations, has the potential to enable new technologies to be tested and applied.

Conclusion

In a market environment in which the pace of expansion for tropical fruits has declined from the rapid growth in terms of both volume and returns seen in the early 1980s and with changing market structures, legislation, and consumer attitude, importers/distributors are looking more critically at their production supply base.

Exporting countries need to assess their comparative advantage, ensure a robust and flexible technological base, and establish operational procedures and practices that ensure economic and financial viability. All players in the production, marketing, and distribution chain need to work together to make the most of what is an increasingly competitive and challenging market.

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Postharvest Handling of Avocado, Mango, and Lychee for Export from South Africa

D.L. Milne*

Abstract

A brief description is given of production areas, cultivars, and total exports of avocado, mango, and lychee from South Africa. Packhouse and transport procedures are outlined, including sea shipment and its evaluation.

A review is given of current postharvest research on mango destined for sea export, including fruit-maturity studies, postharvest disease control, and storage temperatures.

Avocado fruit physiology is discussed in relation to current postharvest research on cold injury, disease control, and recommended temperature regimes. Brief reference is also made to the 'ready-to-eat' concept and avocado processing.

Current postharvest lychee research is discussed, including SO_2 treatment, low pH treatments, and sodium metabisulfite dips.

THE South African subtropical fruit industries have their own specific logistical problems. Firstly, the major production areas are in the northern and eastern Transvaal, some 1700 km from the nearest suitable export harbour. This harbour, Cape Town, is in turn some 10 000 km from the European ports to which we export.

Volumes of subtropical produce do not currently justify the use of 'Reefer' vessels with refrigerated holds, so we are dependent on the use of refrigerated container vessels, which depart from Cape Town every 9 days, and take 14 days to travel to Europe. Fruit must therefore be held in Cape Town in a special refrigerated container-store, awaiting the departure of each vessel. When fruit reaches the distributors in Europe it is therefore 23–26 days old.

Avocado

The cultivar spread in South Africa differs from that of other major exporters such as California and Israel. Fuerté still constitutes approximately 60% of our exports, with Hass following at 25–30%. Other cultivars include Edranol, Pinkerton, and Ryan. Exports have risen from 2 million 4-kg cartons in 1982 to between 7 and 8 million over the past 4 years. Predictions are that the latter figure could double within the next 5 years.

The main avocado export markets are France, the United Kingdom, Switzerland, Germany, and Scandinavia, and our fruit reaches these markets from March until September. Fruit size differs significantly according to cultivar, as shown in Figures 1 and 2.

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The effect of orchard practices and conditions on fruit quality

Cultivar

South African experience shows that the Fuerté is the cultivar which is most vulnerable to cold injury and resultant internal physiological disorders (Rowell and DuRand 1982; Van Lelyveld and Swarts 1978). The key problems which occur are as follows.

Early cold damage. This is expressed as relatively large, black and clearly defined, slightly sunken areas on the skin of the fruit (Swarts 1979a).

Late cold damage. Expressed as a faint, overall sooty blackening or bronzing of the skin of the fruit.

Pulp spot. The occurrence of gradually darkening grey spots in the flesh of the fruit on cutting open (Swarts 1979c). The disorder varies from season to season (Swarts 1985b).

Grey pulp. A light but uninterrupted greying of the mesocarp, especially at the distal end of the fruit. It is generally associated with ageing of the fruit.

Rootstocks

Köhne et al. (1992) have shown that clonal rootstocks have an impact on postharvest physiological disorders in Fuerté, with G6 performing better than Duke 7 (Fig. 3). It has also been shown that the quality of Fuerté fruit on

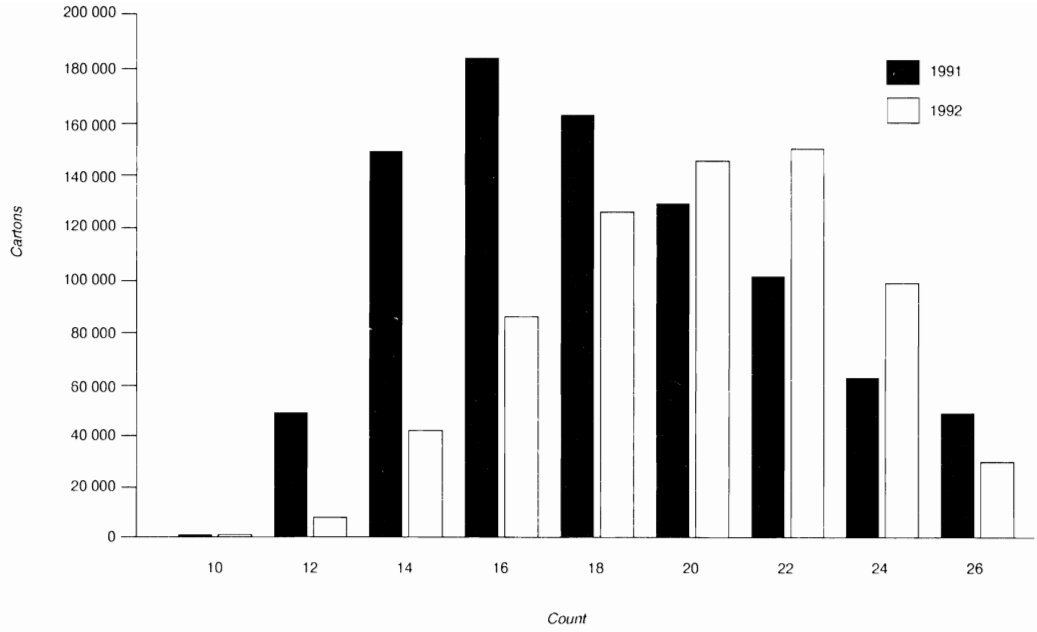

Figure 1. Count distribution of South African Hass avocados in 1991 and 1992

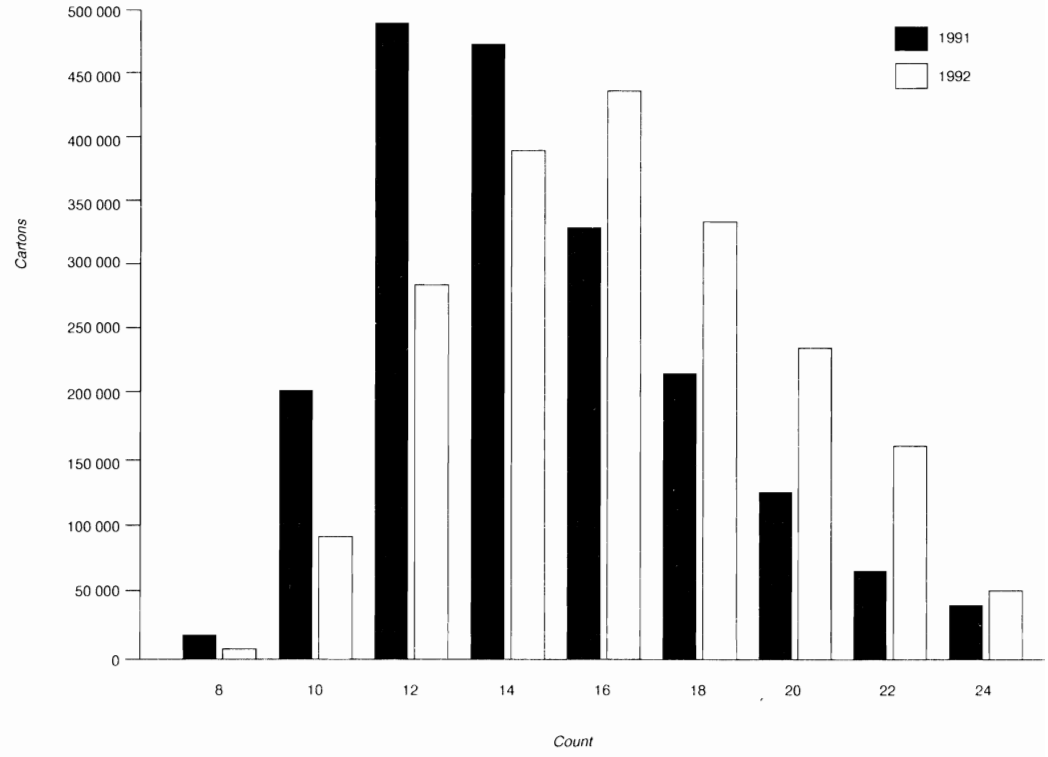

Figure 2. Count distribution of South African greenskin avocados in 1991 and 1992

seedling rootstocks varies significantly (Fig. 4) (Köhne et al. 1992).

Rootstocks also affect Hass fruit quality (Table 1) as shown by Köhne et al. (1992).

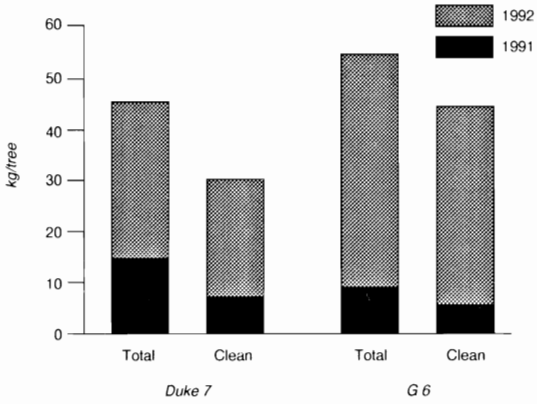

Figure 3. Effect of clonal rootstocks on Fuerté avocado fruit quality and yields in 1991 and 1992 (Köhne et al. 1992)

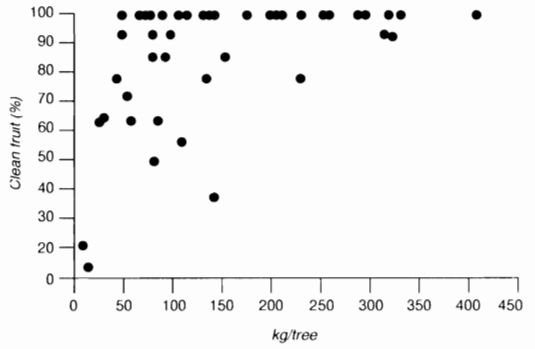

Fig. 4. Variation in Fuerté fruit quality between individual trees on seedling rootstocks (Köhne et al. 1992)

Table 1. Yield and quality of Hass avocados as affected by rootstock. The two rootstocks with the lowest yield, namely Barr Duke and D9, also had the poorest internal quality. Thomas compared favourably with the commercial standard, namely Duke 7 (Köhne et al. 1992).

Rootstock	Yield (kg/100 trees)	Percent fruit internally clean
Thomas	92.68	96.2
Duke 7	62.05	100.0
G755	12.05	100.0
D9	7.37	64.3
Barr Duke	3.13	70.0

Tree vigour

Witney et al. (1986) have shown that vegetatively vigorous trees tend to produce fruit with a lower Ca-content and consequently poorer storage ability. These observations were confirmed by Vorster et al. (1989). In trees with a high fruit:leaf ratio, it can be expected that the incidence of sunburn will also increase significantly (Bezuidenhout and Vorster 1991).

Wolstenholme and Whiley (1990) have made some helpful proposals on how tree vigour can be manipulated to the benefit of the grower.

Smith and Köhne (1992) have shown that heavy bearing Fuerté trees can yield fruit with better export quality, than low yielding trees. (Table 2).

Table 2. Quality of fruit from 'A' trees (consistently heavy bearing) and 'E' trees (consistently very low bearing) over two picking rounds (April and May 1991) (Smith and Köhne 1992). Values give the percentage of fruit free of the disorder listed

	Picking round 1		Picking round 2	
	'A' tree	'E' tree	'A' tree	'E' tree
External				
Cold damage	95.1a*	86.4b	93.4a	82.1b
Internal				
Pulp spot	94.2a	96.2a	93.6a	94.5a
Vascular discoloration	94.2a	92.3a	80.5a	67.1b
Grey pulp	99.2a	98.5a	96.6a	82.9b
Total	82.2a	69.2b	67.3a	42.5b

* Mean separation in rows per round by Duncan's multiple range test at the 5% level.

Calcium

Since the work of Tingwa and Young (1974), a great deal has been published on the role of calcium in relation to cold-induced physiological disorders of avocados (Witney et al. 1986; Vorster and Bezuidenhout 1988; Vorster et al. 1989; Bower 1988). Cultural practices should therefore be aimed at minimising spring flush and supplementing soil Ca levels (Fig. 5).

Seasonal effects and picking rounds

The effect of season on fruit quality was reviewed by Eksteen and Bester (1987). Any conditions promoting poor fruit-set but vigorous vegetative growth, are inclined to lead to poor storage quality of fruits. In 1982 nearly half the South African Fuerté crop had to be exported by air due to severe pulp-spot incidence. Early

and late picking also has a significant effect on Fuerté fruit quality (Smith and Köhne 1992 (Fig. 6); Bower 1988; Cutting and Bower 1987; Vorster et al. 1989).

Irrigation

Bower (1988) has shown that water stress during the first 3–4 months after fruit set affects the activity of abscisic acid (ABA) and of the browning enzyme, polyphenol oxidase and consequently adversely affects fruit quality during storage (Bower and Cutting 1987).

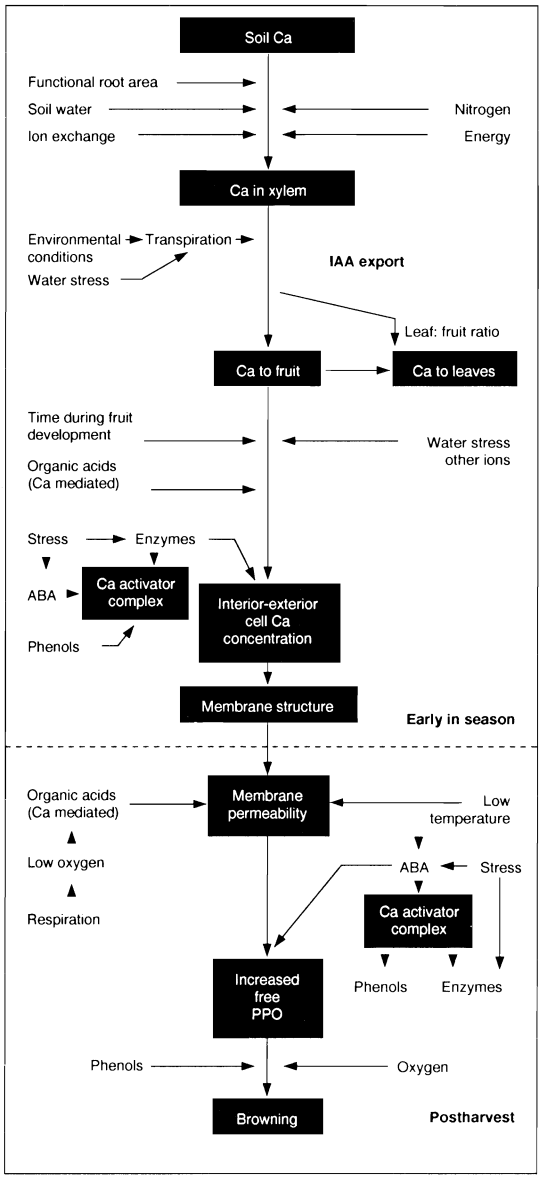

Figure 5. Schematic representation of possible interactions between calcium and other plant and environmental factors in the determination of avocado fruit quality (after Bower 1988)

Abscisic acid, phenolics, and polyphenol oxidase (PPO)

The Natal University group has been investigating the interactions of abscisic acid (ABA) and PPO for the past 5–6 years. Their research has shown that ABA infusion into the fruit also raises PPO levels, causes a decline in phenolic substrate levels, and increases pericarp browning. They link stress-induced, increased ABA levels to pericarp browning during the ripening process (Bower et al. 1986; Hofman and Husband 1987; Cutting and Bower 1987; Cutting et al. 1989, 1990.)

The effect of increasing fruit maturity on fruit base mineral composition, phenolic content and the resultant influence on postharvest fruit quality and ripening physiology of Fuerté avocado, was investigated by Cutting et al. (1992). Late harvested fruit with increasing maturity had reduced calcium and magnesium concentrations. A reduction in ripening time was associated with a decrease in fruit calcium concentration. Total fruit phenolics increased with increasing fruit maturity, and this was associated with an increase in the incidence of the cold storage-induced mesocarp discoloration. However cold storage was found to have no effect on total fruit phenolic concentrations.

Fertiliser applications

The interactions of potash (K), calcium (Ca), and magnesium (Mg) with physiological disorders of avocado fruit are complex. Koen et al. (1989) found that

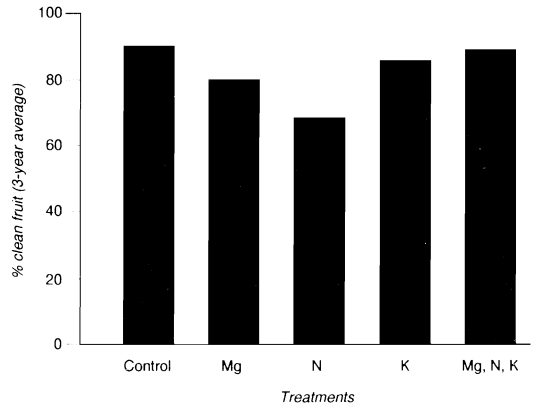

Figure 6. Effect of fertiliser applications on the quality of early picked Fuerté fruit during the period 1990–92 (Kremer-Köhne et al. 1992a)

high K/Ca and K/Mg ratios tend to make the fruit more susceptible to grey pulp. This related to high soil and leaf potash (K) values. Grey pulp incidence was reduced when the Ca + Mg/K ratio in the soil and leaves was high. High soil Ca and Mg levels and a high Ca + Mg/K ratio were also found to be correlated with an increase in vascular browning (Koen et al. 1989, 1990).

In a three-year study carried out on Westfalia Estate, Fuerté avocado trees received soil applications of K_2SO_4, $MgSO_4$, and LAN during the period September–February. After subjecting fruit to simulated sea export, i e. four weeks of storage at 5.5°C, fruits were examined for internal physiological disorders (pulp spot, grey pulp, and vascular browning). The three-year mean yield from heavily N-fertilised trees tended to be lower than that of the other treatments. However, in this study, none of the treatments increased the percentage of fruit free of physiological disorders over the three-year period, when compared with the untreated control (Fig. 6). N applications alone considerably increased the percentage of fruit with physiological disorders. However, when N was applied in combination with K and Mg, the percentage of fruit free of physiological disorders did not differ from the untreated control (Kremer-Köhne et al. 1992a).

Two orchards of Fuerté at Westfalia Estate were found to differ significantly regarding the susceptibility of the fruit to pulp spot (Bezuidenhout and Vorster 1991). In the orchard with low pulp-spot incidence, the levels of Ca, Zn, and Mn in the leaves were found to be higher by 27–45% than in the orchard with high pulp-spot incidence.

Orchard temperatures

Swarts (1982) demonstrated that there was a strong correlation between number of hours in which orchard temperatures dropped below 17°C for two days prior to packing, and the susceptibility of fruit to cold injury.

In a commercial study carried out in the Tzaneen area of the Northern Transvaal, Smith and Lunt (1984) confirmed that as night temperatures fell below 17°C prior to picking, and as the oil content of the fruit increased, the fruit became less susceptible to cold injury. Swarts (1982) was the first person to propose adjusting storage temperatures downwards as the season progressed.

Fruit maturity (oil/water content)

Avocados of all cultivars for export (except Hass and Ryan) must contain not more than 80% moisture. It is recommended however, that the cultivars Hass and Ryan are not exported unless the moisture content is less than 77%, as experience has shown that at above 77% moisture, ripening can be uneven and shrivelling may occur. Due to persistent problems with exported Edranol (shrivelling and grey pulp especially), a maximum moisture content of 74% is recommended (Van den Dool and Wolstenholme 1983).

For plantings in the cooler, more southerly area of inland Natal, research has indicated that the following moisture percentages should be adhered to, to ensure proper ripening of fruit destined for export:

Fuerté – 75% moisture
Edranol – 72% moisture
Hass and Ryan – 70% moisture.

Growth regulators

Research carried out by Kremer-Köhne et al. (1992b) showed that a dosage of 12.5 mL paclobutrazol (CPPU) per tree, applied by ULV applicator gave a significant Fuerté yield increase over a two-year period. In a trial in which CPPU was applied to Hass trees over a two-year period, CPPU gave a good response in quantity of exportable fruit in the first year only (Köhne et al. 1992b) (Fig. 7).

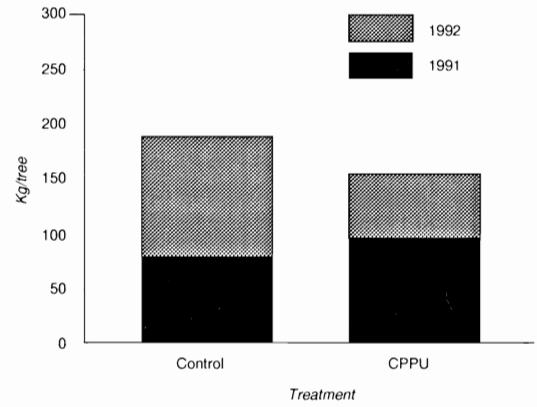

Figure 7. Yield of export size Hass fruit (kg/tree) as influenced by CPPU treatment in 1991 and 1992 (Köhne et al. 1992b)

Postharvest factors

Temperature

Some of the pioneers of research on the effects of low temperatures on storage of avocados were Kosiyachinda and Young (1976), Swarts (1978, 1979a,b,c, 1980, 1982) and Wang (1982).

The rate of development of external cold injury of Fuerté avocados at various low temperatures was clearly demonstrated by Swarts (1980) (Fig. 8).

The relationship between ethylene production, the climacteric, and ripening of Hass avocados at various temperatures, was demonstrated by Eaks (1983).

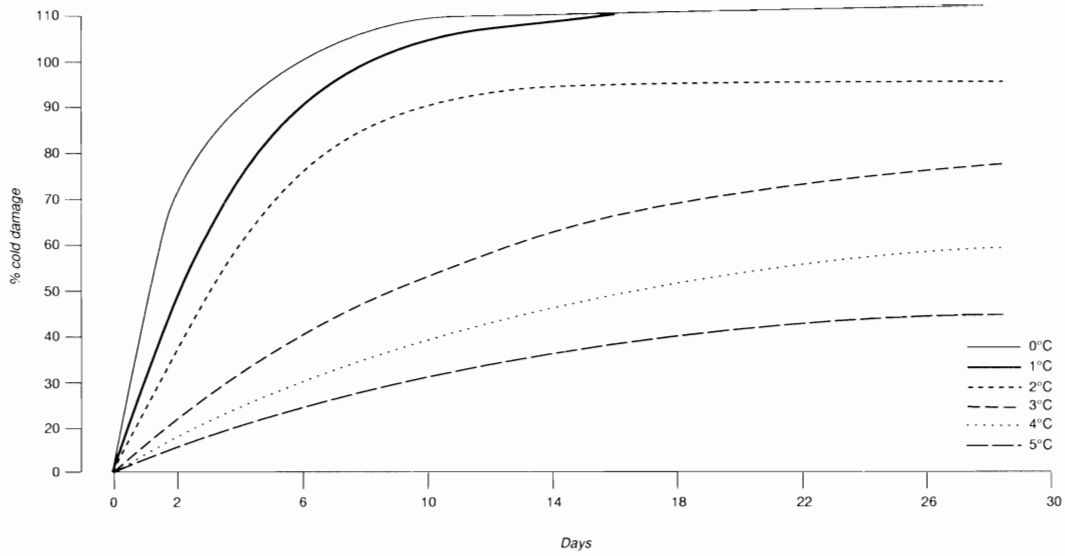

Figure 8. The incidence of cold damage in Fuerté avocados stored for various periods and at various low temperatures (after Swarts 1980)

In 1981–82 the South African Avocado Growers' Association placed a technical officer in Paris to evaluate the arrival and consequent ripening of fruit. This led to analysis of large quantities of data and the drawing of conclusions regarding the main causes of postharvest problems (Bezuidenhout and Kuschke 1982, 1983).

It has been agreed for many years that prompt removal of orchard heat is important for the retention of fruit quality. However Slabbert and Toerien (1984) showed that forced cooling using extraction fans, could increase external cold injury to Fuerté fruit early in the season. However, speed of cooling did not influence the occurrence of pulp spot or grey pulp.

Bezuidenhout (1983) drew up a climacteric model for Fuerté fruit and was able to establish that excessive cold prior to the climacteric is favourable for pulp spot to develop. Once the climacteric has passed, temperatures can be lowered. He also found that large Fuerté fruits are more susceptible to physiological disorders than small fruits. Pulp-spot susceptibility drops later in the season, whereas grey pulp increases steadily, especially if high temperatures occur in the post-climacteric phase (Bezuidenhout 1983).

Following on this research, Toerien (1986) demonstrated in a trial that 3.5°C in the preclimacteric phase caused increased cold injury to Fuerté avocados when compared with 5.5°C. He therefore proposed a model for cooling which would adjust temperatures downwards in transit.

Vorster et al. (1987) followed up with trials in which the schedules proposed by Toerien (1986) were evaluated on various cultivars. Early season Fuerté fruit were found to be very sensitive to external cold injury, and the use of 7.5°C as storage temperature for the first week, followed by 5.5°C for two weeks and 3.5°C for one week, was found to reduce the incidence of early cold injury during the first half of the season, when compared with the standard of 5.5°C for four weeks.

The step-down temperature also resulted in a significant reduction in pulp-spot symptoms. These authors proposed a step-down temperature program, not only for the storage period, but also for the season (Vorster et al. 1987, Eksteen and Bester 1987).

By 1990 a more sophisticated schedule of shipping temperatures, based on the oil content of fruit had been developed (Vorster et al. 1990) (Table 3)

Time

It can be expected that the export of tropical and subtropical fruits under refrigeration will not be straightforward. What is also clear is that one of the most important factors determining fruit quality is the total time × temperature combination.

Vorster et al. (1988a) have shown that dramatic increases in external cold injury in Fuerté occur if the time of storage is extended from 21 to 28 days. Similarly grey pulp increases in both Pinkerton and Hass as the storage period is extended.

Bower (1988) also found increases in total postharvest disorders from 14% after 21 days to 30% after 30 days and to 58% after 44 days.

'Brown cold damage' is a disorder that is very seldom present when the container arrives in Europe. It usually

Table 3. Recommended air delivery temperatures (°C) for the export of Fuerté avocados (Vorster et al. 1990)

Fruit moisture (%)	Coldroom and packhouse	Cold truck	Holding store	Vessel (2 weeks)
78.5	7.5	7.5	7.5	7.5 (last week 5.5)
77.5–78.5	7.5	7.5	7.5	7.5 (last week 5.5)
76.5–77.5	7.0	7.0	7.0	6.0 (last week 5.5)
75.5–76.5	6.5	6.5	6.5	6.0 (last week 5.5)
74.5–75.5	6.5	6.5	6.5	5.5 for entire trip
73.5–74.5	6.0	6.0	6.0	5.5 for entire trip
72.5–73.5	6.0	6.0	6.0	5.5 for entire trip
71.5–72.5	5.5	5.5	5.5	5.5 for entire trip
69.5–71.5	5.5	5.5	5.5	5.5 (last week 4.5)
67.5	5.5	5.5	5.5	5.5 (last week 3.5)

develops only after the fruit is placed at ambient temperature. It is characterised by lesions or marks that are brown to dark brown in colour (as opposed to black) and which have relatively clearly defined edges and which are very slightly sunken. Initial symptoms are faint and then darken with time. The affected area can be anywhere on the fruit surface and usually only a few fruits in a carton are affected.

'Brown cold damage' definitely appears to be correlated with age of fruit (after picking) and this, coupled with low temperature storage for long periods, appears to aggravate the problem. For example, fruit placed at ambient temperature on arrival in Europe (22 days) showed no symptoms. However, after a further 10 days of cold storage, the symptoms clearly developed after 2 days at ambient temperature. Once again, this malady appears to be time × temperature related. Desiccation may, however, also play a role.

After problems were experienced with fruit arriving soft in Europe, a detailed analysis of seasonal data was made by Bezuidenhout (1992). He showed that a deviation in holding temperature 1°C higher than recommended for a 22-day transit time, increased the softness of fruit from a firmometer reading of 25 to 35 (Table 4). Furthermore, a similar increase (1°C) over a total transit period of 28 days, caused an increase in softness from 32 to 46 on the firmometer (Table 4). It is therefore clear that a total management strategy in which time and temperature are both controlled, is necessary if a good outturn of fruit quality is to be achieved.

For this reason, a date-coding system was introduced for all avocado exports and a prohibition was placed on the export of fruit harvested more than 12 days before the time of departure from Cape Town.

Ventilation

Early research by Boelema (1987) showed that a significant improvement in cooling could be obtained if an interlocking and well-ventilated carton was used in place of the 'telescopic' carton previously used.

Investigations by Haas and Felsenstein (1985) on the cooling rate of avocados packed in cartons in a wind-tunnel indicated that there is no significant gain in increasing, beyond a certain value, the free-flow area (total area of openings as a percentage of carton area) perpendicular to the direction of openings of air flow. Cooling rate seldom improves above 9% free-flow area. The cartons which are being used in South Africa have a free flow area of 8.5% in the direction of vertical air flow (refrigerated truck and container), which is close to the ideal percentage. In the direction of horizontal airflow, this percentage is more than 11.4% (Vorster et al. 1990).

For all pallets to receive the same amount of cold air, a controlled airflow pattern in the coldroom is necessary. Temperature recordings of fruit in the coldroom of a commercial packhouse were found to show big differences in cooling rates, depending on the position of the pallet in the coldroom. In an uncontrolled configuration, fruit were found to be at a pulp temperature of higher than 9°C after cooling for 24 hours at 6.5°C. However, in the same uncontrolled configuration, there were also fruits which had already cooled below 9°C after only 3 hours. It is therefore recommended that a controlled airflow pattern be effected in the packhouse cold store (Vorster et al. 1990).

Table 4. The influence of fruit age and temperature deviations on fruit firmness at outturn overseas

Fruit age (days)	Temperature deviation	Firmometer reading
22	Nil	25
22	1°C	35
28	Nil	32
28	1°C	46

Moisture loss

It is well known that moisture loss can increase the symptoms of cold injury in fruits (Couey 1982).

Water loss is certainly one of the most important factors leading to overseas fruit deterioration. Increased moisture loss resulting in stress during storage, not only enhances polyphenol oxidase (PPO) activity and visual symptoms of physiological disorders, but also increases the prevalence of pathological disorders (Bower and Cutting 1987). The relative humidity in the storage atmosphere therefore plays a vital role. Cutting et al. (1992) have shown that more mature fruit are less subject to moisture loss than relatively immature fruit.

A basic rule in heat dynamics is that the greater the temperature gradient (T) and the less the volume of air in the system, the higher the moisture loss will be from the fruit. By decreasing the volume of air (i.e. by using a cooling system with a bigger capacity) and restricting T, moisture loss can be limited. The design of the cooling system in a packhouse therefore plays a major role in preventing water loss from fruit and in final fruit quality (Vorster et al. 1990).

Modified and controlled atmosphere

Using 10% CO_2 and various O_2 concentrations, Truter and Eksteen (1982) showed that a mixture of 10% CO_2 and 2% O_2 extended the shelf life of Fuerté, Edranol, and Hass avocados while reducing grey pulp and virtually eliminating pulp spot. However, an increase in anthracnose was observed.

This work was followed up by Truter and Eksteen (1987) who found that a 25% $C0_2$ shock treatment applied one day after harvest also gave very good results in reducing physiological disorders, without the concomittant increase in anthracnose. These results were confirmed by Bower et al. (1989). They state that although controlled atmosphere (10% $C0_2$, 2% 0_2)is superior to other forms of storage, the economic and logistical realities must also be taken into account. CA costs per kg, from Cape Town to Europe are currently more than double the costs using conventional containers. This cost increase must therefore be compared with the potential price advantage of landing good quality fruit in Europe. Currently, this is not regarded as economically viable.

Faubion et al. (1992) indicated that Hass avocados could be stored successfully for up to 60 days, using a CA of 2% 0_2 and 5% $C0_2$. Similar results have been obtained with Hass avocados in Australia (McLauchlan et al. 1992; Jordan and Barker 1992).

Natural resistance

Prusky et al. (1991a) have described how avocado fruit are free of anthracnose caused by *Colletotrichum gloeosporioides* at harvest and yet develop decay lesions during ripening. The resistance of the unripe fruit was found to be due to two antifungal compounds in the peel of the fruit. The levels of these compounds were found to drop during the ripening process and the authors therefore proposed various ways of manipulating this natural resistance. By using anti-oxidants Prusky (1988) achieved delayed development of anthracnose and stem-end rot. Similarly, Prusky et al. (1991b) were able to increase natural resistance using CO_2 shock treatments.

Korsten et al. (1991a) have carried out extensive research on the suppression of postharvest diseases, using naturally occurring orchard antagonists. *Bacillus subtilis* applied in commercial Tag wax or in a water dip, was found to significantly reduce anthracnose, *Dothiorella/Colletotrichum* fruit-rot-complex, and stem-end rots in packhouse trials. *Pseudocercospora purpurea*, the cause of 'black-spot', is controlled in South Africa by the application of 2–3 copper sprays during the rainy season.

Marketing aspects

The South African Avocado Growers' Association (SAAGA) is a voluntary organisation with approximately 600 members, representing at least 90% of the total production.

The total crop in 1992 was 9.2 million 4 kg cartons, of which 7 million were exported. The crop is exported by ten or more major exporters who either grow the fruit themselves or export on behalf of groups of growers or cooperatives.

The attitude of French importers towards supermarkets is generally antagonistic. This appears to be because supermarket chains are putting more and more pressure on importers by forcing a discount on avocado prices, by spreading their purchases of avocados over several importers, and by enforcing a delayed payment system which puts heavy financial strain on the importer.

The hypermarket and supermarket share of the fruit and vegetable retail market has increased by an average of 2% per annum for the last 5 years (as opposed to a decline in consumer support for greengrocers, street markets, etc.). Although this trend might not necessarily continue, a 50% plus share of the fruit and vegetable retail market enjoyed by the supermarkets, is to be taken seriously.

In the U.K. situation, prepackers work closely and to a high set of standards with supermarkets. Pre-ripened fruit of guaranteed quality is supplied to them as set out in a written set of standards. This is done with much success despite an economic climate which is far more recessionary than in France.

Quality of export fruit is controlled in South Africa by

inspectors located at packhouses and at the ports of export. They are appointed by the Perishable Products Export Control Board (PPECB).

All local market and export cartons are levied by SAAGA and the funds generated are used to finance field officers, an overseas evaluator, research, and local promotions.

Research funds are administered by a research committee which allocates funds for State, university, and private research projects. These projects are reported on at an annual research symposium and the data published in the SAAGA Yearbooks.

The PPECB is responsible for monitoring temperature control on export vessels and provides the industry with feedback on each vessel as well as an annual report. Similarly, the overseas evaluator assesses the fruit on arrival of each vessel, giving immediate feedback on quality aspects. As date- and grower-codes are present on each carton, problem consignments can easily be identified and followed up. An annual report is also produced by the overseas evaluator.

In addition, a weekly newsletter is faxed or posted to all growers and exporters, giving details of volumes to be shipped, volumes in transit, and feedback from overseas markets.

There is also an Exporters' Committee which can be called together to take marketing decisions on volumes, counts, grading standards, etc., during the course of the season.

As regards promotions, there is a Local Market Promotions Committee of SAAGA responsible for all generic promotions, advertising, etc. Major importers in overseas countries currently undertake their own promotions. However, SAAGA is currently supplying technical data to those organisations interested in promoting the 'ready-to-eat' concept. This is regarded as a concept with the strongest pull for increased sales.

Processing of 'factory grade' fruit is currently carried out on a steadily increasing scale, producing either avocado oil for cosmetics, etc. (5000 t) or frozen pulp (Guacamole) (100 t).

Mango

Mango marketing in South Africa differs from most subtropicals in that it is still dominated by local consumption. In addition, on the local markets, fresh fruit sales account for only 14 000 tonnes whereas processing consumes 25 000 tonnes, of which 19 000 tonnes is used in the manufacture of 'Achar', a type of chutney (Table 5).

Exports have increased fairly rapidly however, from 190 000 cartons (4 kg) in 1984/85, to 1.1 million cartons in the past two seasons.

The Achar market is predominated by fibrous cultivars such as Peach, Sabre, Long Green, and Sugar. However, export cultivars are all fibreless and include Tommy Atkins, Kent, Keitt, Sensation, Zill, Irwin, Haden, and Heidi. Numerous other cultivars are also under test, especially with regard to their suitability for export.

The logistics for export are virtually identical to those described for avocados. However, Germany and the U.K. are major markets, followed by France and Switzerland.

Fruit maturity

As exports have been undertaken only relatively recently, research into fruit maturity was started in South Africa only in the late 70s and 80s. Van Lelyveld and Smith (1979) attempted to correlate fruit flesh colour with picking maturity. In general they found that fruits were sufficiently mature for export when half of the flesh had coloured yellow. However, cultivars differed, with Sensation fruit being ready for harvest at 10% yellow, whereas Keitt could hang beyond the 50% yellow state before harvesting.

Van Lelyveld and Smith (1979) also followed on the work of Harkness and Cobin (1951) in testing flotation (i.e. specific gravity) of fruit to assess maturity. They found that, with Sensation mangoes the fruit were mature enough to export 18 days after the period when at least 15% of the sample had the same specific gravity as water.

Bezuidenhout (1988) tested factors such as total soluble solids (TSS), internal and external colour, firmness, and shoulder development for determining picking maturity. With Zill and Irwin a good correlation was found between shoulder development (a non-destructive factor) and internal colour of the fruit. However he pointed out that climate, irrigation, and fertilisation could influence both factors. In the case of Sensation he found a close correlation between TSS and internal colour.

This research was followed up by Oosthuyse (1991a) who criticised the internal flesh colour index as being (a) destructive, (b) not correlating with time taken for fruit to ripen, (c) subjective in nature, and (d) variable between cultivars. Using a penetrometer with a 6-mm plunger, he evaluated pulp-penetration pressure of the fruit flesh (after cutting away the peel and 23 mm of

Table 5. Marketing of South African mangoes (t), 1987–92

Year	Processing		Fresh		Total
	Achar	Juice	Local	Export	
87–88	10 000	1300	11 000	1500	23 800
88–89	12 000	1500	12 500	2400	28 400
89–90	12 000	3000	14 500	3000	32 500
90–91	16 000	4000	144 000	2700	37 100
91–92	19 000	6000	14 000	4400	43 400

pulp). He found that in Kent mangoes, pulp-penetration pressure, although also destructive, correlated well with internal colouring and also with the period required for the fruit to reach the eat-ripe stage. Furthermore, he recommended penetration pressure as being a more objective measurement than pulp colour.

Wara-Aswapati et al. (1992) also made successful use of the specific gravity method and the measurement of TSS. However, they expressed the view that these methods of determining fruit maturity were time-consuming and rather impractical.

Lizada (1991) gave a very useful review of mango fruit physiology and factors evaluated for determining fruit maturity. However, it was also clear from her review that no single factor could be used for evaluating the maturity of all cultivars.

As cultivars differ significantly, there is still much research required in this field.

Storage temperatures

Before 1990, small quantities of mangoes were shipped by sea from South Africa at a temperature of 11°C. However, Oosthuyse (1990) commenced a series of trials in which various cultivars were subjected to simulated sea shipment (four weeks) at various combinations of temperatures varying from 6 to 10°C. His research included step-down temperatures as these had already been successfully used for our avocados. Two weeks at 8°C followed by two weeks at 6°C was found to be suitable for Irwin and Kent, whereas Zill responded best to a longer period at 6°C. Tommy Atkins and Sensation were found to be the least temperature-sensitive cultivars whereas Keitt was relatively succeptible to cold injury. Oosthuyse concluded that the processes leading to fruit coloration and fruit softening, operate independently. He also noted that chilling injury appeared to increase the susceptibility of the fruit to soft-brown rot.

Studies by Eksteen (1991) in the same year, showed that commercial sea-export consignments were not being cooled effectively due to inadequate ventilation in the pallet stacks, and probably also due to inadequate precooling prior to shipment. Both these problems have been addressed by the mango industry.

In 1991 Oosthuyse (1991b) tested the feasibility of allowing fruit to ripen partially after picking, before being cold-stored. The pre-ripening of picked fruit at 20°C was found to lead to a reduction in cold-related skin disorders and an improvement in skin colour but also to a severe increase in disease incidence. At that time he therefore recommended direct packing after their arrival overseas.

Working with Kensington mangoes, Chaplin et al. (1991) found that when fruit was stored at 1 or 5°C, chilling injury increased with time. These injury symptoms increased even further when the fruit was transferred to 30°C for ripening. Storage at 15°C led to full softening and ripening within 3 weeks. They found that in Kensington mangoes, lowering of storage temperature suppressed flesh colour in the ripened fruit but had little effect on skin colour.

Research by McLauchlan and Barker (1992) showed that with Kensington mangoes seasonal differences may have a profound effect on the response of the fruit to various storage temperatures.

Oosthuyse (1992), in a study aimed at evaluating a number of cold-storage temperature regimes for Kent and Irwin, found that the incidence of decay directly after four weeks of cold-storage, was positively related to the degree to which ripening had taken place during cold-storage (expressed as reduction in pulp penetration pressure) (Fig. 9).

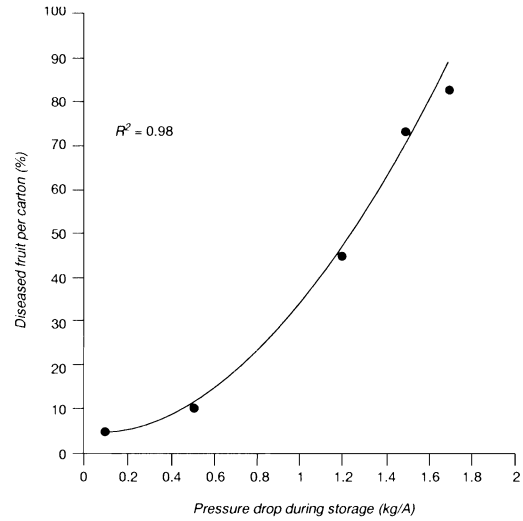

Figure 9. Pressure drop (i.e. increased softening of Irwin mangoes during storage in relation to disease incidence after storage (Oosthuyse 1992)

Naturally occurring anti-fungal compounds, identified as 5-substituted resorcinols, have been identified in the skin of mango (Cojocaru et al. 1986). Only after harvest did the concentration of these compounds decrease, this reduction coinciding with the appearance of decay. Moreover, ethylene treatment, which is known to hasten ripening, also hastened the reduction in concentration of these compounds and the appearance of decay, whereas storage under sub-atmospheric conditions, which were effective in delaying ripening, also delayed the appearance of decay (Droby et al 1986). In view of these findings, a plausible explanation for the differences in percentage decay directly after cold-storage might be offered by equating the extent of ripening during cold-storage with the extent of decline in anti-fungal substances in the skin.

It was recently reported by Prusky et al. (1993) that exposure of mango fruit to high concentrations of CO_2 for 24 hours soon after harvest dramatically enhanced skin concentrations of anti-fungal compounds, and consequently delayed the onset of decay development. Preliminary results obtained in South Africa indicate anthracnose suppression through the use of CO_2 shock treatments, but no beneficial effect on soft brown rot.

Oosthuyse (1992) finally recommends the harvesting of decay-sensitive cultivars at a more advanced stage of maturity (2–3 weeks later than at present), but then holding the fruit at 8°C to prevent further ripening during the storage period. For Sensation, however, which is very resistant to decay, he suggests that storage temperatures of 11–13°C may be feasible.

Physiological disorders

This is too large a topic to deal with in any great detail. However, under South African conditions Tommy Atkins has been found to show many physiological disorders in fruit at the time of picking. These include papery cavity, split-pip, 'varkhart', browning at the stem-end, and jelly-seed. After extended cold-storage this cultivar may also show non-pathological browning around the pip.

Sensation shows a fair amount of jelly-seed at picking but is also susceptible to internal browning if stored at low temperatures (6°C).

Heidi, a South African selection, appears to be very sensitive to cold injury, and temperatures above 11°C may be required for successful export.

Keitt is already susceptible to spongy-tissue at picking and shows severe lenticel damage if exposed to low temperatures for long periods. It is nonetheless regarded as a good export cultivar.

Lizada (oral presentation 1992, IV International Mango Symposium) reported that spongy tissue does not occur in Carabao mango in the Philippines at picking time. Modified atmosphere storage was found to increase the problem, particularly at low O_2 levels. Lizada suggested that the build-up of acetaldehyde might lead to tissue breakdown. This was confirmed by O'Hare and Prasad (1992) who found that Kensington mangoes stored under 10% CO_2 showed reduced chilling injury but internal build-up of acetaldehyde and ethanol.

Waxes

Although basically only cosmetic in nature, waxes are normally applied in the packhouse. However polyethylene-based waxes may be withdrawn in future in the United Kingdom. The alternative wax recommended is shellac wax. Recent research by J. Lonsdale (pers. comm.) has, however, shown that shellac wax causes a severe retardation of skin colouration. These results were similar to those obtained by Du Toit Pelser (1988) when using 'Semperfresh'.

Diseases

It was Lonsdale et al. (1991b) who first reported in South Africa that *Hendersonia creberrima*, the causal organisms of soft brown rot, had been reclassified by Sutton and Dyko (1989) as *Nattrassia mangiferae*. According to Sutton (quoted in Lonsdale and Kotzé 1993), it is possible that *Dothiorella dominicana* may in fact represent an immature stage of *Nattrassia mangiferae*. It is possible therefore that *Nattrassia mangiferae*, *Hendersonia creberrima* and *Dothiorella dominicana* all represent the same fungus. This is also discussed in the recent review by Johnson and Coates (1993).

At harvest, a group of several endophytic fungi may be present in the stem-end tissue of mangoes. Preharvest or postharvest factors could influence which pathogen gains the advantage and invades the fruit to cause stem-end rot (Johnson et al. 1992; Johnson and Coates 1993). Peterson et al. (1991) detected *Lasiodiplodia theobromae* from a greater proportion of the stem-end rot lesions on fruit held at 25°C than at 13°C and in mixed inoculation studies on detached mango fruit, Johnson et al. (1993) confirmed that storage at 30°C favoured the success of *Lasiodiplodia theobromae* over *D. dominicana* as the cause of stem-end rot, while the reverse occurred at 25°C and lower. This may explain the apparent difference in the main cause of stem-end rot in tropical versus subtropical growing areas.

Johnson et al. (1991, 1993) reported that stem-end rot in Kensington Pride fruit is caused by *Dothiorella dominicana*, and species of *Phomopsis*, *Pestalotiopsis*, *Botryosphaeria*, *Botryodiplodia*, and *Colletotrichum*. Johnson et al. (1992) were the first to report the endophytic nature of these infections.

In Thailand, Sangchote et al. (1992) recorded *Dothiorella dominicana*, *Lasiodiplodia theobromae*, *Colletotrichum gloeosporioides*, *Phomopsis mangiferae* and *Fusarium* and *Pestalotiopsis* species infecting the peduncle of the fruit prior to harvest. The cultivar Kaew was found to be the most resistant to stem-end rot.

Disease control

During the 1990 mango season, benomyl, the only postharvest fungicide registered on mangoes in South Africa, was withdrawn for use. Lonsdale et al. (1991a) and Lonsdale (1992a) therefore conducted a series of trials with hot water dips and various chemicals. A hot water dip (55°C/2 min) plus Prochloraz (40.5–81 g a.i./100 L) effectively controlled anthracnose and soft brown rot without being phytotoxic. Five-minute hot water dips at 55°C plus prochloraz or 5 minute hot water

dips at 55°C followed by ambient temperature (± 25°C) dips in prochloraz were found to be phytotoxic, particularly at the higher doses, causing a burn on the skin surface.

Hot water (52°C/5 min.) followed by an ambient temperature spray of chloramizol sulfate (100 g a.i./100 L) effectively inhibited the development of soft brown rot under mild soft brown rot disease pressure. However, under high disease pressure, such as found in Kent mangoes, chloramizol sulfate was found to be ineffective. An ambient temperature dip in guazatine(100g a.i./100 L) for 40 seconds preceded by a hot water dip (52°C / 5 min.) was also found to control soft brown rot effectively in mildly infected Keitt fruit.

Lonsdale (1992b) also found that pre-bloom (winter) sprays of copper oxychloride were beneficial in reducing anthracnose and soft brown rot. Additional copper sprays were beneficial for anthracnose suppression but not for the control of soft brown rot.

Ionising radiation has been explored as a postharvest treatment on mangoes for more than 20 years in South Africa, commencing with the work by Brodrick et al. (1972). The most recent work is that of Lonsdale et al. (1991b) and Lonsdale (1992a), who found that a dosage of 0.75 kgy in combination with hot water treatments, gave effective control of both anthracnose and soft brown rot, but could cause lenticel damage on Kent and Sensation fruit.

A submission has been made to the French authorities for approval of this treatment for commercial consignments, but no response has been forthcoming to date.

Biological control of postharvest diseases of mango has received considerable attention in South Africa (Korsten et al. 1991b 1992) and two *Bacillus* species occurring naturally in mango orchards have shown promise as antagonists for the suppression of both anthracnose and soft brown rot. Biological control of anthracnose has also been reported by Koomen et al. (1990).

Overseas evaluation

The mango industry, as is the case with avocados, places a technical officer overseas during the export season. His evaluations are of great value as they can identify causes for deviations in disease incidence. These deviations may be due to the grower's management, to packhouse management, to climatic variations between production areas, or to shipping temperatures and general handling. It was interesting to observe that cold injury to fruit can be experienced when pallets are held at ambient temperatures in France, which may drop as low as 2°C during our export season.

Lychee (Litchi)

Lychee production areas in South Africa are virtually identical to those of avocados. Current plantings are dominated by the cultivar HLH Mauritius (= Tai So) which constitutes 75% of the production, and McLean's Red, a Madras-type.

In the 1991–92 season two million 2kg cartons were exported to Europe (mainly France and U.K.). However, exports dropped to 1.5 million cartons during the 1992–93 season due to drought conditions in the production areas.

Our export season extends from mid-November to mid-February. During this period Madagascar also exports an equivalent volume of fruit to France.

During the next five years, South African exports are expected to more than double, and could quadruple by the year 2000 due to extensive new plantings (Milne 1992) (Fig. 10).

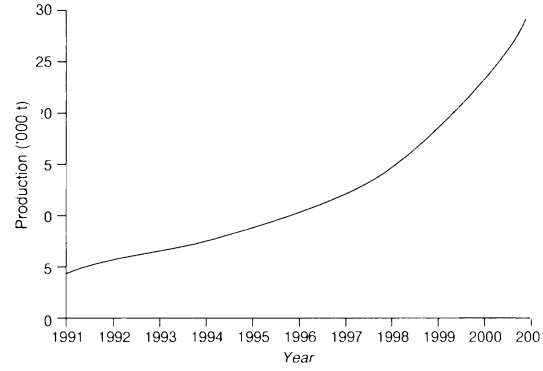

Figure 10. Projection of total yields of lychees in South Africa over the next 10 years

Most fruit (± 70%) is exported by sea at 1°– 2°C, the total storage time being 23–26 days. In Thailand, storage temperatures of 5°C have been used successfully for 3–4 weeks (Wara-Aswapati et al. 1992).

Diseases in South Africa

Roth (1963), Lonsdale (1988), and Botha et al. (1988) have described numerous disease organisms including bacteria, fungi, and yeasts occurring on stored lychee fruit in South Africa. Symptoms of some of the more common diseases are illustrated by Lonsdale and Kremer-Köhne (1991).

Postharvest treatments

Sulfuring of lychees in South Africa was developed over a number of years but was only technically reported

in 1985 by Swarts (1985a). The process has a fungicidal effect but also ensures fixing of the red colouring of the skin and prevents skin brittleness during storage.

Towards the end of 1989 the French importing authorities announced a reduction in the tolerance levels of SO_2 in imported lychees. The acceptable level was reduced from 20 ppm to 10 ppm in lychee pulp (aril). At that time Kremer-Köhne (1993) showed that some South African commercial samples, especially of Madras fruit (McLean's Red) were exceeding the required norms. This problem was rapidly addressed by the industry.

Duvenhage (1993) explored the use of sodium metabisulfite dips as an alternative to SO_2 fumigation of fruit. Sodium metabisulfite was found to give satisfactory control of skin browning and, in combination with a dilute HCl dip, gave a superior skin-colour and taste, when compared with the standard SO_2 treatment.

Ahrens and Milne (1993) and Oosthuizen (1993a,b) also obtained good results using low HCl concentrations, following standard SO_2 treatment. This research followed on the results first obtained by Underhill (1989), Zauberman et al. (1991) and Bagshaw et al. (1991). Underhill et al. (1992) also found that low pH dips did not significantly reduce the eating quality of the fruit.

In Thailand, Sittigul et al. (1992) showed that browning of the lychee pericarp was less likely to occur if fruit were harvested when fully mature (91–100% of peel red). Similarly in South Africa, Milne and Ahrens (1993) found that fumigation of immature green fruit with SO_2, resulted in very unsightly green fruit arriving on export markets.

Underhill (1990) found that lychee fruit could lose a relatively large amount of moisture before showing symptoms of browning. Fruit stored at 24°C for six hours lost 7% of the skin weight, and this increased to 40% after four hours. It was only after 64 hours, when 60% of skin moisture had been lost, that skin-browning occurred.

In 1993 Lonsdale carried out a series of postharvest trials aimed at avoiding the use of SO_2. These included use of 'Vitafilm' wrappings, 'Freshpack' gas mixtures (CO_2 in N_2), vacuum packaging, and radiation (Lonsdale 1993).

Preliminary results suggest that fruit packed in 'Vitafilm' and then irradiated at 0.75 kgy or 1.5 kgy, are more susceptible to decay development after storage than are untreated fruit, the response being dose-related. It seems likely that the radiation process damages the skin of the lychees, making it more susceptible to penetration and colonisation by microorganisms. Fruit first dipped in hot water prior to being wrapped in Vitafilm and then irradiated, did not react in this manner, probably because the hot-water treatment eradicated the surface microbes on the lychee skin (Lonsdale 1993). It should be mentioned that in these trials, disease incidence was generally very low, due to the prevailing drought conditions.

In Mauritius fruit, browning was controlled for 28 days at 1°C when 20% Freshpak was used. Similar results were obtained with vacuum packaging and Vitafilm packaging. However, with the exception of the Vitafilm-packed fruit, fruit exposed to normal atmospheric conditions after the full cold-storage period, turned brown within 30 minutes of exposure. Lonsdale (1993) concludes that, as expected, the near anaerobic conditions of the gas packaging treatments resulted in the damage of cells in the lychee skin and the release of polyphenol oxidase and peroxidase enzymes, which reacted with the anthocyanin pigment and oxygen once fruit was exposed to normal atmospheric conditions, thereby inducing browning.

Biological control of postharvest diseases through the use of naturally occurring antagonists has been explored by Korsten et al. (1993). *Bacillus stearotermophilus* and two other *Bacillus* species occurring naturally on the lychee leaf phylloplane proved as effective as benomyl hot-water dip treatments.

Conclusions

A number of challenges confront South Africa with regard to marketing in the future.

Avocados

Export markets are becoming more sophisticated with regard to size and cultivar required. The industry will have to adjust its export strategy accordingly. An example is the fact that the U.K. currently consumes 77% of the count 10 (366–450 g) greenskins, whereas Scandinavia has a market (albeit limited) for count 22 (171–190 g) to count 24 (156–170 g). Supermarkets often request two differing counts, e.g. 12 (306–365 g) and 18 (211–235 g) throughout the season.

The ready-to-eat concept for avocado sales is a development of major importance which is already effectively exploited in California. Processing into pulp also presents great opportunities for the industry.

Mangoes

The mango is one of the most versatile fruits from a marketing point of view. Nearly 60 per cent of the crop is currently processed and exports have trebled in the last three years. The greatest challenge for export is undoubtedly the mastery of fruit maturity and consequent cold-storage schedules.

However the mango is also susceptible to a multitude of pests and diseases. Effective integrated control programs will have to be developed if economic exports are to be maintained.

Lychees

Nearly all current research on lychees is aimed at extending the notoriously short season and also at finding a replacement for treatments such as sulfur dioxide. Once these problems have been overcome, it is envisaged that the lychee export market will grow significantly.

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The Market for Tropical Fruits in Japan

H. Kitagawa*

Abstract

Japan imported 771 175 t of bananas, 127 466 t of pineapples, 8059 t of mangoes, 5197 t of papayas, 3559 t of avocados, 2027 t of coconuts, 885 t of lychees in 1992, and 98 t of durian, 28 t of cherimoya, 18 t of cactus fruit, 16 t of passionfruit, and 1.5 t of pitaya in 1991.

Japanese like delicious and exotic fruits very much and buy them at a very high price. They distinguish fruit from other foods. To Japanese, eating fruit is a special luxury similar to the use of alcoholic drinks. Japan currently produces some 5 500 000 t of fruit and imports 1 500 000 t each year, but there is still a large demand for tropical fruits, if they are of high quality.

The biggest problem in importing tropical fruits is plant quarantine. This paper discusses the market for tropical fruit in Japan and some problems in importing and marketing.

FRESH tropical fruits imported by Japan are listed in Table 1. The biggest volume is that of banana, 771 175 t in 1992. The exporting countries or areas are Philippines (70%), Ecuador (20%), Taiwan (8%), Panama, Costa Rica, Honduras, and Malaysia. Banana import peaked in 1972 when 1 062 884 t were brought into the country, fell to a low of 575 895 t in 1983, since when the volume has slightly increased.

The second highest volume import is pineapple. In 1992, 127 466 t of pineapple were imported from Philippines (98%), Taiwan (1%), Thailand, and USA (Hawaii).

The volumes of other imported tropical fruits are not large. This is due to plant quarantine regulations and demand factors which will be discussed later.

Mango ranks third with 8059 t imported from Philippines (90%), Mexico (9%), Thailand, Taiwan, and Fiji. Mangoes from Mexico, so-called apple mangoes command a high retail price: 1000–2000 Yen (US$9–18) per fruit depending on the size. Thailand started exporting mangoes, variety Nang Klarngwun, in 1986, but the volume was unexpectedly small. This was found mainly to be due to anthracnose and stem-end rot which infect young fruit on the tree and develop during transportation and after arrival in Japan. To control these diseases bagging of fruit on the tree, which is commonly practiced in Japan (Kitagawa et al. 1992), was recommended. In addition to Nang Klarngwun, importation of Nam Dorkmai, Pimsen Dang, and Rad varieties was permitted in January 1993. However, if these diseases are not controlled the volume will not be increased.

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Papaya occupies the fourth position in imports, with a volume of 5197 t in 1992. Most comes from Hawaii with small amounts from Fiji, Mexico, and the Cook Islands. If imports of papaya from Southeast Asian countries are permitted, the volume will greatly increase.

The fifth fruit is avocado. Some 3559 t were imported in 1992 from USA (California) 61% and Mexico 39%. Avocado is becoming familiar to Japanese consumers so imports will increase.

The sixth is coconut of which 2027 t were imported in 1992 from the Philippines 90%, Thailand 9%, Malaysia, Costa Rica, Indonesia, Sri Lanka, and Palau. Many Japanese feel nostalgic for coconut because of the famous song by Thoson Shimazaki about coconut drifting ashore. There is no quarantine restriction to importing coconut, so the volume can be easily increased if demand increases.

The seventh fruit is lychee, with a volume of 885 t in 1992. Because of plant quarantine problems, only Taiwan is exporting lychee to Japan, and the volume changes each year depending on production in Taiwan. Many Japanese are not familiar with lychee and demand will greatly increase with its promotion.

Only very small volumes of other tropical fruits are imported as shown in Table 1. This is due to plant quarantine regulations and supply limitations. Among these fruits, durian from Southeast Asia is not subject to quarantine regulation but imports were only 98 t in 1991. Japanese consumers are not yet familiar with durian. Some of the tropical fruits are imported only out of curiosity but there will be a large demand for fruits such as cherimoya, mangosteen, and rambutan.

Table 1. Fresh fruits imported into Japan

Fruit	Volume (t)			Exporting country or area and % of total in 1992, 1991 or 1990
	1990	1991	1992	
Banana	757 520	803 340	771 175	(Phil. 70, Ecuador 20, Taiwan 8, Panama, Costa Rica, Honduras, Malaysia)
Grapefruit	156 655	260 784	244 578	(USA 97, Israel 2, S. Africa 1)
Orange	145 188	82 017	171 700	(USA 97, Austral. 2, S. Africa 1)
Pineapple	128 249	137 786	127 466	(Phil. 98, Taiwan 1, Thai., USA)
Lemon & lime	103 884	89 079	93 416	(USA 98, Mexico 1, S. Africa, N.Z., Austral.)
Kiwifruit	58 880	42 651	52 265	(N.Z. 93, Chile 4, USA 3)
Melon (watermelon incl.)	16 771	21 359	20 695	(USA 73, Mexico 23, N.Z. 4, Iran, Austral.)
Grape	12 040	7 568	7 732	(Chile 52, USA 39, Taiwan 8, N.Z., Thai., China)
Cherry	6 858	5 814	12 617	(USA 99, N.Z. 1)
Mango	5 510	6 885	8 059	(Phil. 90, Mexico 9, Thai., Taiwan, Fiji)
Papaya	5 367	5 271	5 197	(Hawaii ca 100, Fin, Mexico, Cook I.)
Coconut	4 523	1 724	2 027	(Phil. 90, Thai., 9, Malaysia, Costa Rica, Indonesia, Sri Lanka, Palau)
Strawberry	3 244	3 639	3 416	(USA 97, N.Z. 2, Taiwan, S. Korea, China)
Avocado	2 163	2 665	3 559	(USA 61, Mexico 39)
Lychee	1 209	1 257	885	(Taiwan 100)
Pomegranate	549	565	–	(USA 100)
Persimmon	237	246	–	(N.Z. 100, S. Korea)
Pomelo	121	134	–	(USA 100)
Durian	88	98	–	(Thai. 99, Singapore, Phil.)
Raspberry	26	34	–	(USA 87, N.Z. 13)
Cherimoya	71	28	–	(USA 89, Mexico 6, N.Z. 5)
Pepino	11	13	–	(N.Z. 100)
Passionfruit	14	1.6	–	(N.Z. 77, USA 17, Mexico 6)
Cactus fruit	7	18	–	(Vietnam 68, Mexico 32, USA)
Tamarillo	6	5	–	(N.Z. 100)
Feijoa	7	6	–	(N.Z. 69, USA 29, Mexico 2)
Nectarine	7	0	–	(N.Z. 100)
Pitaya	0.8	1.5	–	(Vietnam 78, USA 11, Mexico 11)
Maracuja	1	0	–	(Mexico 100)
Sapodilla	0.3	0	–	(Mexico 100)
Total	1 409 431	1 473 381	1 553 839	

Source: Statistics of imported fruit and vegetables. Japan Fresh Produce Import Faciliation (NISSEIKYO), Tokyo.
Note: – = not available

Plant Quarantine

Japan does not harbour fruit fly or codling moth. Susceptible fruits grown in areas infested with designated pests such as Mediterranean fruit fly, Oriental fruit fly (mango fly), melon fly, Queensland fruit fly, and codling moth cannot be shipped to Japan. However, when the Japanese plant quarantine authorities certify that a fruit shipment will not, because of strict adherence to regulation including proper disinfestation treatment prior to shipping, be a danger in spreading these insects in Japan, a special permit will be given. The countries and areas, fruits, and disinfestation method which have special permits are shown in Table 2.

In addition, if the Japanese government thinks that there is a risk from other pests which may not be listed in the present quarantine regulations, such as the Mexican fruit fly, it may consult with the exporting country regarding treatments needed. For example, mangoes from Mexico are subjected to hot water treatment (46.1°C for 90 min.)

Ethylene dibromide (EDB) fumigation was long used to disinfest these fruits, but after this material was found to be carcinogenic the Japanese Government banned its use on all fruits from December 1987. Cold treatment and vapour heat treatment were developed as substitutes and many fruits are being treated as in Table 2.

Vapour heat treatment sometimes causes physiological disorders. For example, internal breakdown was at first very serious in mangoes from the Philippines I

helped the research of the Postharvest Horticulture Training and Research Center, University of the Philippines on the consumer side (Esquerra et al. 1990), and now it is not a commercial problem.

Ionising radiation is another potential method of disinfestation. Some Japanese consumers, however, are very apprehensive of irradiation and it is likely that irradiated fruit will not be acceptable to them even if the treatment is permitted by the authorities.

In summary, research on plant quarantine and disinfestation methods that might be granted Japanese Government approval is urgently needed to expand trade in tropical fruits.

Processed Fruits

One means of avoiding the plant quarantine problem is to import or export processed fruits. Canned pineapples are the major processed tropical fruit imported in to Japan, amounting to 60 937 t in 1992. Exporting countries were Thailand 50%, Malaysia 20%, Philippines 17%, Indonesia and various other countries. Importation of canned pineapple became free in 1991. There are about 200 000 t of canned pineapple produced in Japan, mostly in Okinawa, but the volume is decreasing. The total demand for canned pineapple is not expanding, but imports will increase as domestic production decreases.

As well as canned pineapple, 12 676 t of canned mixed fruits were imported in 1992. Some tropical fruits are among these.

Freezing is another method to process tropical fruits. In 1991, 3125 t of frozen pineapple were imported, from Thailand 91%, USA 8%, Vietnam and China. Recently frozen mangosteen, durian, and other tropical fruits have become more common in retail stores or restaurants, but the import statistics are not available. The biggest problem with frozen fruit is that it does not taste the same as fresh fruit. Research will be needed to achieve a better quality product.

Some dried tropical fruits are also imported. Though the statistics are not available, the volumes involved are thought to be small.

Transportation

There are three ways to transport commercial fruit to Japan: chartered boats, container boats, and by air. The lowest-cost transport is chartered boats. Most bananas

Table 2. Fruits given special entry permits by the Japanese Government

Country or area	Fruit (cultivar)	Designated pests	Disinfestation method
Australia	Orange	Md, Qu	CT (1.0°C, 16 days)
	Lemon	Md, Qu	CT (1.0°C, 14 days)
Canada	Cherry	Cd	MB
Chile	Grape	Md	CT (0°C, 12 days)
China	Melon (Hamigua)	Ml	(Pests controlled area)
Uighur		–	
Israel	Orange	Md	CT (0.5°C,14 days)
	Grapefruit	Md	CT (0.5°C, 13 days)
	Sweety	Md	CT (1.5°C, 16 days)
New Zealand	Cherry	Cd	MB
	Nectarine	Cd	MB
	Apple	Cd	MB + CT (0.5°C, 25 days)
Philippines	Mango (Carabao)	Or,Me	VHT (46.0°C, 10 min)
Spain	Lemon	Md	CT (2.0°C, 16 days)
S.Africa & Swaziland	Orange, lemon & grapefruit	Md	CT (– 0.6°C, 12 days)
Taiwan	Orange	Or	CT (1.0°C, 14 days)
	Mango (Irwin, Haden)	Or, Ml	VHT (46.5°C, 30 min)
	Lychee	Or	VHT (46.2°C, 20 min) + CT (2.0°C, 42h)
Thailand	Mango	Or, Me	
	(Nang Klarngwun)		VHT (46.5°C, 10 min)
	(Nam Dorkmai, Pimsen Dang, Rad)		VHT (47.0°C, 20 min)
USA	Nectarine, Walnut	Cd	MB
Hawaii	Papaya (Solo)	Md,Or,Me	VHT (47.2°C)
Washington	Cherry	Cd	MB
Oregon	Cherry	Cd	MB
California	Cherry	Cd	MB

Notes: Cd, codling moth; Md, Mediterranean fruit fly; Me, melon fly; Or, oriental fruit fly; Qu, Queensland fruit fly; CT, cold treatment; VHT, vapour heat treatment; MB, methyl bromide fumigation.

and pineapples imported are carried by chartered boats. Three or four chartered boats of 3000–4000 t ply between Davao, Philippines and Japan every week carrying banana, pineapple and coconut. These fruits can be sold at very low prices in Japan.

Chartered boats, however, need to carry large volumes, so many fruits are transported by container ships. Container ships have the advantage of carrying as little as needed and at a reasonably low cost. Also, their temperature regulation is quite strict.

Container ships, however, are not available from every city or area. For example, there is no container line from Hawaii to Japan. All papaya from Hawaii imported into Japan, more than 5000 t a year, are therefore carried by air. Of course, air transportation has the advantage of speed. Clearly, it is necessary to consider the transportation method when planning to export fruit to Japan.

Fruit for Japanese

The quality of drinking water in Japan is excellent. So there was no need for people to eat fruit as a source of water. Also as vegetables are readily available all year round, vitamin C deficiency has never been a problem in Japan. Thus Japanese people have not considered fruit as very important to health.

For centuries the most important fruit was dried persimmon. As there was no sugar production, it was the sweetest food. This led, in my opinion, to Japanese considering fruit as a table luxury rather than a food (Kitagawa 1991a).

After the Meiji Restoration in 1868, the government introduced apple, cherry and other fruits and encouraged the farmer to produce for the market. Farmers started to grow fruit intensively because they could sell it at a very high price if they delivered a high quality. When Muscat or Alexandria grapes or muskmelons were introduced, farmers started to grow them in glasshouses as the English nobles did at their castles, employing the court gardeners. At present, many fruits are being cultivated in plastic houses or under plastic roofs. Some houses are heated to produce early fruit.

In the early years of the 20th century, fruit were purchased only by a few wealthy people and generally considered, much like flowers, as ornaments or gifts. As this custom still exists, you will see various kinds of fruit in gift baskets and beautifully decorated boxes being sent to respected persons, friends, or sick people. For this purpose, fruit should be excellent in external appearance and this is why size, colour, and overall fruit quality are so important for the fruit trade in Japan.

In more recent years, however, fruits have become primarily consumed as food. Current fruit consumption, however, is 63 kg/person/year (total domestic production + imports minus exports including fresh and processed per population) which is not large when compared with other countries. Japanese make a distinction between eating fruit and other foods. To them eating fruit is a pleasure or luxury similar to taking alcoholic drinks. It is quite common for a family to share a single apple as dessert. So, an apple should be large, have a good appearance and be of good eating quality.

One of the characteristic features of fruit marketing in Japan is the presence of quality fruit stores which sell only fruit. In the first class shopping area of a large city there are stores in which fruits are sold on a large scale at very high prices. In this type of store, it is not uncommon to pay for a single apple or grapefruit 500–1000 Yen (US$4–9) and 10 000 Yen (US$90) for a musk-melon.

Fruit of high quality commands an extremely high price when sold in quality fruit stores; however, the price for fruits of slightly lower grade is far lower. In Japan the difference in price between high quality and lower quality fruit is much larger than in other countries. Also, rare and exotic fruits are sold at a very high price. However, if a fruit loses rarity and becomes more common the price goes down and sometimes even consumption decreases.

At the present time there are two types of tropical fruits in Japan: those imported in large volumes and sold at a very low price, and those imported in small volumes and sold at a very high price. Banana and pineapple are the former. They are the cheapest fruits in Japan and the quality fruit store does not handle them except for special cultivars. On the other hand, Mexican mango, cherimoya, durian, and many other tropical fruits are in the latter category. They are imported in small volumes and sold at very high prices at quality fruit stores. Small quantities of mangosteen (651 kg) imported from Colombia in 1989 sold at more than 1000 Yen (US$9) per piece at quality fruit stores.

In summary, Japan produces some 5 500 500 t of fruits and imports 1 500 000 t of fresh fruits a year. There is a big demand for tropical fruits if they are of high quality (Kitagawa et al. 1990; Kitagawa 1991b)

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Diagnosing the Causes of Outturn Problems in Imported Tropical Fruits

Anna Snowdon*

Abstract

Deterioration in tropical fruit consignments may take the form of physical, physiological or pathological damage. Importers need to know whether the causes of damage can be traced to pre-shipment factors (such as latent infection) or to carriage conditions (such as improper temperature control which may cause chilling injury). Prompt examination of damaged cargo is essential. In addition to accurate diagnosis of the nature of deterioration, it is important to observe patterns of damage; losses are frequently due to a combination of adverse factors, and may thus be the responsibility of different parties. The exporter is responsible for presenting cargo 'in good order and condition' to the carrier. He should also supply carriage instructions appropriate to the commodity; these need to be accurate, succinct and unambiguous. Under the Hague Rules, a ship owner is required to exercise due diligence but is excused liability for damage arising from 'inherent vice' of the goods. It is the duty of the importer to mitigate his losses and, depending on the case, it may fall to the cargo underwriter or the carrier's Protection and Indemnity Club to bear the loss. A proper understanding of cargo deterioration can lead to reduction of losses in the future.

THERE is an increasing international trade in tropical fruits; the five most important (banana, pineapple, mango, avocado, and papaya) are finding new markets, while diverse minor tropical fruits are becoming more widely known and appreciated in temperate countries (Proctor and Cropley, these proceedings). Storage potential of tropical produce is limited by a general susceptibility to chilling injury (Watada 1982); at the requisite moderate storage temperatures (5–15°C, according to commodity) postharvest life tends to be measured in weeks, or even days, compared with the months of storage possible for the main temperate commodities (such as apples or grapes stored at temperatures close to 0°C) (Hardenburg et al. 1986). Markets may be at the other side of the world, with strict quarantine regulations necessitating insect disinfestation procedures which may further curtail storage life. If to these difficulties is added the great diversity of requirements for different tropical fruits, the inexperience of some exporters who attempt trial shipments, and the deficiencies of certain carriers, it is perhaps not surprising that some consignments arrive in poor condition. Deterioration results in loss of money and loss of confidence, and often there is a dispute over liability (Snowdon 1979). Clearly, it is important to determine the causes of deterioration, firstly as a means of resolving cargo claims, and secondly so as to be able to avoid similar losses in the future (Amezquita and la Gra 1979; Harvey 1978; Snowdon 1988).

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Methods

Cargo surveys are carried out in response to a request from one of the parties involved, namely the importer, the exporter, the cargo underwriter, and the carrier (e.g. ship owner or charterer) or his insurer. Whenever possible, the cargo is examined while still in the ship's hold. As soon as the hatch is opened, the temperature of the produce is taken by means of an electronic spear thermometer. Throughout discharge, observations are made on the condition and temperature of cargo in different locations in the hold. Note is taken of the design of the chamber, the position of air vents and thermometers, the power of the fan system, and the way in which the goods have been stowed. Photographs, both general and close-up, form an important part of the survey record. Details are taken of the program of loading in the country of origin, the atmospheric temperature recorded by the ship's officers during loading, and the progress of the voyage, including any delays, detours, or adverse weather en route. Enquiries are made as to whether or not the Master received specific carriage advice from the exporter. For a reefer (refrigerated) cargo additional details are recorded: the method of refrigeration, the rate of fresh air exchange, the fre-

quency of defrosting, and the time taken to cool the cargo to the requested carriage temperature. The ship's refrigeration log shows air delivery, air return, and hatch temperatures recorded every four hours, and sometimes also relative humidity and carbon dioxide concentration. During examination of produce carried by refrigerated container, it is necessary to note the position and readings of any portable temperature recorder which may have been placed inside at the time of 'stuffing' (filling) the container; some exporters use these as an independent check.

Further observations on the cargo may be carried out on the quayside, in the dock shed, and in the laboratory. A similar procedure is used for cargoes carried by road, rail, or air.

The first stage in diagnosis is to determine the nature of the deterioration. There may be *physical damage* in the form of cuts, bruises, or insect burrowings (Drake 1983; Kader 1992). There may be adverse *physiological changes* such as watersoaking of the flesh or a failure to ripen, or even simple senescence (Kader 1985; Knee et al. 1985). There may be *pathological decay* incited by microorganisms which can be isolated and identified (Grogan 1981; Persley 1993; Ploetz et al. 1993; Rossman et al. 1987; Sutton 1985), and finally there may be *chemical injury* manifest as bleaching, pitting, or visible residue.

Once the nature of the deterioration has been determined (or at least postulated), it becomes feasible to investigate the contributory causes and to find out when they became operative. For imported produce the broad commercial question is: can the deterioration be ascribed to adverse pre-shipment factors, adverse carriage conditions, or a combination of both?

Pre-shipment Factors

All aspects of pre-shipment history are relevant and may require investigation. Some information can often be obtained from the importer, who is usually in close communication with his shipper (exporter). Alternatively, a visit can be made to the producer country in order to observe current practices at first hand.

The *weather* during the growing season has an important bearing not only on crop development but also on the incidence and severity of diseases (Moline 1984; Johnson and Coates 1993). These are also much influenced by *crop husbandry* (Hofman and Smith, these proceedings; Palti 1981). The care and attention (or lack of it) given to *harvesting and grading* is later manifest in the quality and condition of the fruit (Kader 1992). *Postharvest treatments* may include application of heat or cold, and chemicals such as fungicides and antioxidants (Eckert and Ogawa 1985; Shewfelt 1986; Eckert 1990; Paull 1990; Barkai-Golan and Phillips 1991; Prusky and Gat 1992). Choice of *packaging* determines how well the produce will be protected en route (Peleg 1985; Wills et al. 1989). Some types of tropical fruit benefit from *precooling* before shipment, and the efficiency with which this is done may be crucial to quality maintenance (Lipton 1978; Wade 1984; Worthington-Smith 1985).

Carriage factors

The method of *stowage* determines how well air can circulate through the cargo, and must be related to the intrinsic *design and function* of the vessel's equipment (Hales 1973; Scrine 1981; Thomas et al. 1983; Alders 1987). Similar principles apply when the cargo is carried by road, rail, or air (Gac 1974; Harvey 1981; Ryall and Pentzer 1982; Isenberg 1984; Anon. 1985; Nicholas 1985; Ashby et al. 1987). *Carriage instructions* need to be accurate, succinct, and unambiguous; in practice, however, they are often misleading or non-existent. Finally, if there is a delay, the *length of journey* may become relevant, particularly for tropical fruits, most of which have a characteristically short postharvest life (McGlasson et al. 1979).

In diagnosing the causes of deterioration, it is important to look for *patterns* of damage on several levels (Snowdon 1990). For example, in fruit consignments carried by ship, there might be patterns discernible as follows:

- in or on the individual fruit
- within the package
- within the hold
- within the vessel
- over the season
- over the years (usually related to weather).

Three case studies illustrate some of the principles outlined above.

Case Study No. 1
Panamanian Bananas to Antwerp

The refrigerated vessel had five holds, each divided into four decks. The vessel first loaded Californian and Arizona citrus (minneola tangelos and lemons) in Brownsville, Texas, and these were stowed in Nos 3 and 4 Lower Holds, viz. Decks 3C, 3D, 4C, 4D (Fig. 1). The vessel subsequently suffered a main engine breakdown which necessitated the ordering, air-freighting, and installation of spare parts, resulting in a 9-day delay before the vessel could leave Brownsville. (During this period the refrigeration continued to operate normally and the citrus was maintained at the requested temperature of 5°C.) The vessel then proceeded to Armuelles, Panama, and loaded bananas in all the remaining chambers, including Decks 3A, 3B, 4A, 4B (Fig. 1). The carriage temperature of 13°C was achieved within the normal time and, after a 10-day voyage, the vessel arrived in Antwerp.

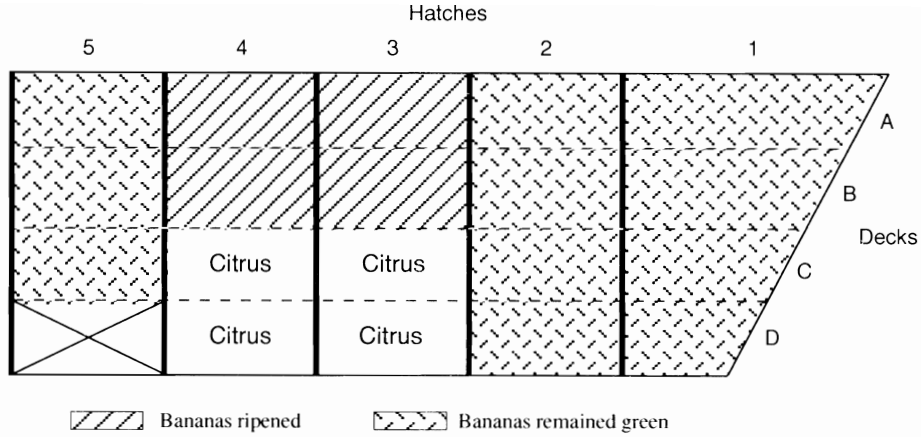

Figure 1. Stowage plan and pattern of damage in refrigerated vessel from Case Study 1

On discharge of the cargo, it was found that the citrus was seriously decayed by *Penicillium digitatum* and *Penicillium italicum*, and that a substantial quantity of bananas had undergone premature ripening. The pattern of damage was as follows: the bananas stowed in Hatches 1, 2, and 5 (all decks) were in perfect condition, being hard green, while the bananas stowed in Hatches 3 and 4 Tween Decks were in various stages of ripeness. The evidence was that there was no pre-shipment difference between the different lots of bananas; all were from the same origin and had been cut and packed during the same period. The difference in outturn condition appeared to be a function of location in the vessel, in that those bananas stowed above the citrus (and only those bananas) had ripened prematurely.

Bananas ripen in response to ethylene, whether it be endogenous or from an external source (Liu 1976; Marriott 1980; Blanpied 1985; Knee et al. 1985). During shipment, a policy of constant fresh air exchange serves to purge the hold atmosphere of the small quantities of ethylene produced by green bananas (Stover and Simmonds 1987). In the present case, however, there must have been substantial quantities, such that ripening was 'triggered' despite normal air refreshment. The explanation is that prodigious amounts of ethylene are produced by mouldy citrus, partly by the fruit itself in response to stress, but mostly by the mould *Penicillium digitatum* (Waks et al. 1985).

The pattern of damage within the vessel thus indicated that the bananas had ripened in response to ethylene from mouldy citrus stowed in proximity. The question then became: by what route had the hold atmospheres intermingled? There were three possibilities. First, some ships are badly designed, in that the fresh air intake vents of one chamber are located too close to the exhaust vents of another chamber, with obvious consequences. Second, if a ship is not well-maintained, the hatch seal between decks may be imperfect. Third, the design of many ships allows access to the battery space on each deck, via vertical trunking which, when in use, temporarily interconnects all the decks of a particular hold. In the present case it was established that the fresh air vents were not at fault, that there was a substantial gap in the hatch seal between 3B and 3C (but not between 4B and 4C), and that daily access to the battery spaces would have permitted substantial mingling of atmospheres within the decks of individual holds.

During protracted litigation, lawyers for owners of the banana cargo suggested that the problem could have been avoided if all the citrus had been confined to one hold (four decks). However the two commodities were loaded at different ports, the citrus first, and besides the increased loading time which would result from the use of only one hatch, it would not be good stowage policy to sail from the first port with one hold filled and the others empty, because of possible instability problems.

Lawyers for owners of the citrus cargo argued that stowage in two hatches was justified, but that there should have been airtight separation between the various decks, so as to preclude the possibility of interaction between incompatible commodities.

Lawyers for the ship owner argued that since the leaky hatch seal in Hold 3 could not account for the ripening in Hold 4, then lack of maintenance was not causative; the predominant route for the intermingling of atmospheres must have been via the access trunking, a normal design feature of refrigerated vessels. They also pointed out that had the citrus been healthy it would not have produced ethylene, and so the problem would

not have arisen. Opposing lawyers countered with the accusation that had there not been a delay owing to main engine failure, the citrus would have still been in a healthy state as loaded. The evidence was, however, that the citrus was 'end-of-season' and, according to the ship's chief officer, was showing signs of blue/green mould even at the time of loading.

The case was complicated by the fact that the vessel was on charter, and so there was further dispute about liability between ship owners and charterers. The eventual outcome was two separate settlements without recourse to a trial.

Case Study No. 2
Pakistani Mangoes to Dubai

There is an established trade between Pakistan and the Arabian Gulf, the voyage time being little more than 3 days. Mangoes are highly prized, both by the Arab population and by migrant workers, many of whom are from the Indian sub-continent; the market is especially strong at the time of the Muslim festival signifying the end of Ramadan. It was in view of this that the exporter decided to despatch an entire shipload, rather than (as is more usual for mangoes) a containerload.

The vessel was refrigerated, and the requested carriage temperature was 12°C. On arrival in Dubai, however, the cargo was said to be hot, and the fruit was manifestly unacceptable, being discoloured and apparently rotten.

Lawyers for the cargo owner alleged that carriers had failed, either through a refrigeration breakdown or incompetence of ship's personnel, to cool the fruit as requested, and that it had deteriorated in consequence.

Lawyers for the ship owner pleaded that large quantities of mangoes had already been assembled at the loadport (Karachi) at the time of the ship's arrival, and that some of the fruit was already ripening or ripe when received on board.

The evidence was that the mango-growing areas were at a great distance from Karachi, and that harvesting, packing and transport of such a large quantity (435 t) had taken several days. So great had been the pressure to despatch the cargo on time that only a small proportion of it was properly packed in shallow, well-ventilated cartons; instead, most of the fruit was in large plywood cases lined with newspaper and possessing no means of ventilation.

Mangoes are climacteric fruits, characterised by a sudden rise in respiration rate (and hence heat production) at the onset of ripening (Krishnamurthy and Subramanyam 1973; Lakshminarayana 1973; Caygill et al. 1976; Hubbert et al. 1987). In the present case, it was concluded that ripening was well underway before loading, that packaging was inappropriate, and that even an efficiently-run refrigerated vessel could not be expected to dissipate the heat produced by such a cargo. At the same time it had to be acknowledged that the vessel was in fact not operating efficiently, owing to poor maintenance and inexperienced personnel.

The case against the vessel was defended in a local court in Dubai, which found that despite the inherent defects in the cargo, ship owners were partly responsible for the loss.

Case Study No. 3
Greek Oranges to Novorossiysk

This example concerns oranges which, though not usually classified as 'tropical fruit', may be of considerable importance in some tropical countries, such as Brazil, Mexico, India and Pakistan. The case is included because it illustrates some of the pitfalls which may be encountered when new markets are sought. There had been a traditional trade between Greece and the former Soviet Union, in which citrus was shipped into the Ukrainian port of Odessa and subsequently despatched overland to various destinations including parts of Russia. Following the dissolution of the Soviet Union into separate republics, it was decided to ship directly to the Russian Black Sea port of Novorossiysk.

The voyage, from the Greek port of Nafplion via the Bosphorus, takes only three days and so it is appropriate to ship citrus in ventilated space at ambient temperature rather than to pay a higher freight rate for refrigerated space. During the winter months, however, cold, wet, or windy weather may preclude the possibility of continuous full ventilation.

The port of Novorossiysk is engaged primarily in exporting cement and importing grain; there are also specialised berths for timber and fish, but apparently no tradition of dealing with perishable horticultural produce. At the time of arrival of the orange shipments there was serious congestion, following closure of the port for several days as a result of stormy weather. Many vessels were forced to wait at anchor 'in the roads', and for various unexplained reasons some of the ships carrying oranges spent several weeks waiting for a berth. Even after a berth was secured, there was sometimes a shortage of dock labour to unload the cargo. From a series of shipments during December and January, two will be considered, both of which had been subjected to a delay of approximately four weeks.

The first vessel had small holds with shallow decks, in which the cartons had been well-stowed, six tiers high, and with air channels both fore-and-aft and athwartships. There were written carriage instructions but with no mention of the required ventilation policy. The Master knew from experience, however, that it was probably wise to continue ventilation (albeit at a reduced rate) even when outside conditions were unfavourable; it is better to risk cold injury to a small proportion of the

cargo (close to the air intake vents) than to risk suffocation of the whole. Thus, despite atmospheric temperatures well below 0°C, the fans had been operated almost continuously, but at half speed. The cargo on discharge was found to have pulp temperatures in the region of 5°C; there was no sign of chilling injury or freezing injury, but a proportion of the fruit had been rotted by *Alternaria citri*, *Penicillium digitatum*, and *Penicillium italicum* (Ceponis et al. 1986; Whiteside et al. 1988). The cargo was nevertheless deemed commercially acceptable.

The second vessel had comparatively large deep holds. The cartons had been stowed twelve tiers high and without air channels. There were no carriage instructions. The fans had been operated sporadically because of the cold and because of a fear that they might break down if operated continuously. One of the weather deck hatch covers lacked a rubber seal, thus allowing rain water to penetrate and drip on to the surface of the stow. The fruit in all holds had self-heated owing to poor ventilation; even when air was being introduced into the holds, it was unable to penetrate the solid stow. Respiratory heat and moisture had built up and, in the leaking hatch, the stow had undergone total collapse. Pulp temperatures were between 20 and 50°C, and the predominant causes of decay were *Aspergillus niger*, *Aspergillus terreus*, and *Trichoderma viride*, all of which have optimal growth temperatures in the region of 30°C (Holliday 1980). Much of the cargo had to be dumped, and the ship was arrested by way of security.

The condition of any cargo on outturn is the resultant of its pre-shipment condition coupled with the environment to which it is subjected while on board ship. In the first shipment the disadvantage of delay had been partially offset by the optimisation of shipboard environment (through good stowage and judicious ventilation); deterioration was significant but limited, because the temperature had been maintained low enough to slow down fungal growth but not so low as to cause chilling or freezing injury to the fruit. Despite the inadequate carriage instructions the cargo had been well cared for.

In the second shipment the critical factor was the poor stowage, which probably rendered the ventilation policy irrelevant. Arguably a solid stow would have been adequate for the prospective voyage of three days, but it became disastrous as the delay lengthened. In one of the tween deck spaces the deterioration was compounded by the additional adverse factor of water ingress. Liability has not yet been determined, but it is likely that, under the terms of the contract, ship owners would be responsible for the leaking hatch cover and charterers for the stowage. Whether blame for the delay can be attributed to the importer's representative or to the harbour authorities remains to be seen.

Legal Aspects of Cargo Claims

There are two main types of contract under which goods are carried by sea, viz. Charters and Bills of Lading. Charters can be divided into three main categories: Bare Boat Charters, Time Charters, and Voyage Charters. When a vessel is on bare boat charter (or demise charter, as it is sometimes known) the owners effectively hand over the running of the vessel to the charterers who operate her as if they owned her, subject only to their paying hire to the owners; charterers are responsible for cargo claims. When there is a time charter the owners allow the use of the vessel for a specified time in return for payment; they retain control of the vessel and provide a crew although they are obliged to operate her in accordance with charterers' instructions. In a voyage charter, where a vessel is chartered for a single voyage, owners retain complete control of the vessel and they receive freight. In both time and voyage charters, owners are usually liable for cargo claims, although they are excused liability for those arising as a result of unseaworthiness, provided that they have exercised personal due diligence in this regard. There are printed forms of charter in common use, but these are often supplemented by additional clauses. In the majority of cases the rights of the cargo claimants depend on the terms of the Bills of Lading under which the cargo is carried.

Bills of Lading are perhaps the most important documents in international trade. They are negotiable documents and represent the goods. Generally, whoever holds the Bills of Lading owns the goods, save where they are held by banks by way of security. A Bill of Lading has been described as 'a receipt for goods shipped on board a vessel, signed by the person who contracts to carry them, or his agent, and stating the terms on which the goods were delivered to and received by the ship. It is not the contract, for that was made before the Bill of Lading was signed and delivered, but it is excellent evidence of the terms of the contract'. The Bill of Lading will usually state that the goods were 'shipped in apparent good order and condition' and, if this is unqualified, ship owners are estopped (a legal term meaning 'prevented') from alleging that the goods were visibly in poor condition on shipment. The Bill of Lading can, however, be endorsed if the goods were in damaged condition on shipment.

After shippers (exporters) have effected shipment, they are entitled to receive a Bill of Lading from the ship, and traditionally three originals are prepared. The shippers have probably sold the goods to receivers (importers) who, under the terms of their contract, are obliged to pay cash against documents or by means of a letter of credit. In the former case, shippers will probably hand the shipping documents to their bank who may be providing finance, and the bank passes them to a corresponding bank in the country of destination. The bank

will release the shipping documents (i.e. the invoice, Bills of Lading, and insurance policy) to the receivers against payment. If payment is to be by means of an irrevocable letter of credit, the shippers receive payment on surrendering to the bank the documents required by the letter of credit. Letters of credit can be complicated, and their requirements must be met precisely.

Before a meeting of the International Law Association in the Hague in 1921, and the Diplomatic Conference on Maritime Law in Brussels in 1922, ship owners could in general insert such terms as they wished in their Bills of Lading. The purpose of the above meetings was to devise a code imposing minimum obligations on owners, and this code is generally known as the Hague Rules. In England, the *Carriage of Goods by Sea Act* of 1924 gave statutory effect to the Hague Rules. The English Act provides that all Bills of Lading issued in this country are to incorporate the Act. The legislation in different countries varies and in some, for example the United States, the local law provides that the Hague Rules are to apply both to Bills of Lading issued in the United States and to those which require delivery of the goods there. Ship owners can always accept more responsibilities than the minimum required by the Hague Rules, but they cannot lessen their liabilities other than is specifically permitted.

Basically the Hague Rules require ship owners to exercise due diligence with regard to the seaworthiness of the carrying vessel. From the lawyer's point of view, a vessel can be technically unseaworthy if she has minor defects, for example a leaking hatch cover. If the defect could have been ascertained in the absence of negligence, then the exercise of due diligence could not be established. There is a large volume of case law which assists practitioners when advising whether or not due diligence could be established.

The Rules also require that ship owners 'properly and carefully load, handle, stow, carry, keep, care for and discharge the goods'. However, provided that ship owners can satisfy the requirements regarding the vessel's seaworthiness and the exercise of due diligence, they can rely on various exceptions from liability, including liability for loss and damage resulting from 'wastage in bulk or weight or any other loss or damage arising from inherent defect, quality or vice of the goods'. A cargo with inherent vice has been defined as 'any cargo which by reason of its own inherent qualities is lost without any negligence by anyone', and as possessing 'an inability to travel safely under ordinary commercial conditions'. The exception does not apply to the extent that the damage has been aggravated by the owners' breach of contract, e.g. his failure to care properly for the cargo. If, therefore, deterioration is due partly to inherent vice and partly to improper stowage, then ship owners are liable for the extra damage resulting from improper stowage.

In brief, it is the responsibility of the exporter to present cargo 'in good order and condition' and to supply appropriate carriage instructions. It is the responsibility of the carrier and/or charterer to care for the cargo in transit. In case of deterioration, it is the responsibility of the importer to mitigate the loss and to submit a prompt and well-substantiated claim. The cargo may have been insured by a cargo underwriter, and the vessel is probably entered in a P & I (Protection & Indemnity) Club which provides cover against losses and claims of various kinds.

The claimant or plaintiff must prove that the damage occurred during the period the cargo was in the custody of the carrier. He meets his initial burden of proof by producing clean Bills of Lading (stating that the cargo was shipped in apparent good order and condition) along with evidence of damaged condition on outturn. This is the claimant's prima facie case. When the goods are in packages, or when the cause of damage is not apparent, then he cannot rely on Bills alone but must adduce evidence that the goods were in fact in good condition on shipment. The burden then shifts to the defendant (the carrier) to establish a legal excuse from liability, and the most common is a plea of 'inherent vice'.

Similar principles apply to goods carried by other means. Air cargo is covered by the Warsaw Convention which, however, applies only to international carriage. Goods are shipped under an Air Waybill (AWB) or Air Consignment Note which is deemed to be the contract of carriage. The carrier is liable for loss or damage, including damage occasioned by delay, unless he can prove that all necessary steps to avoid loss were taken, that there was contributory negligence by the consignor, or that there was contributory negligence by the air crew.

Clearly, in all cases of loss through deterioration, it is essential for each party to arrange for immediate and accurate assessment of the quantum, nature, and causes of loss. In the short term this will assist in the prompt settlement of claims; furthermore, a proper understanding of cargo deterioration can lead to reduction of losses in the future.

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Marketing of Tropical Fruit — Session Summary

Chairman: Dr Ma. Concepcion C. Lizada, Post-Harvest Training and Research Centre, Philippines
Rapporteur: Mr Colin Bunt, Piccone Horticultural Consultancy, Australia

THIS was a very interesting session, exploring diverse aspects of what became a more general theme of the conference: international trade in tropical fruit and impediments to it.

In the first paper presented, Mr David Minnis from Australia gave a broad overview of the potential of tropical fruit markets in Asia, focusing mainly on the established markets in Singapore, Hong Kong, Taiwan, Japan, and South Korea, but noting the potentially lucrative markets in North Asia. An indication of the future potential of Asian markets is perhaps provided by Korea, which has opened up to fruit imports in only recent years. Banana imports, for example, rose more than fourteenfold between 1990 and 1991, from 21 000 to 315 000 t.

Mr Minnis outlined various strategies he saw as essential to the successful marketing of fresh tropical fruits in Asia, including exploitation of seasonal advantage, reduced use of chemicals, development of non-chemical disinfestation treatments, and introduction of total quality management (TQM) systems that increase consumer confidence in fresh fruit.

Ms Felicity Proctor from the U.K. presented a paper co-authored with Mr J.P. Cropley, on trends and changes in the European market for tropical fruits. It was clear from her presentation that, as in Asia, the European fruit trade is strongly market driven, with the major focus on consistent delivery of products of acceptable quality. The main tropical fruits imported into Europe are pineapple, mango, avocado, and papaya, and the market for these has increased steadily. Markets for minor exotic fruits such as lychee, carambola, mangosteen, and rambutan have, however, declined in relative terms in recent years. Ms Proctor's presentation covered the distribution structure in Europe, legislation impacting on the fruit trade, and trends in consumption, and stressed the need for codes of practice for product management.

Dr Lindsay Milne provided participants with an exhaustive account of postharvest handling practices for South African avocadoes, mangoes, and lychees destined for European markets. Research in South Africa on postharvest handling of lychees, including SO_2 and low pH treatments, and sodium metabisulfite dips, was of particular interest to Southeast Asian participants.

Professor H. Kitagawa gave an interesting account of the market for tropical fruits in Japan, which is strongly influenced by the Japanese conception of exotic fruit as something very special. Conference participants were intrigued by this and the remarkably high prices that Japanese consumers are prepared to pay for what they see as desirable pieces of fruit. On the other side of the coin, Japan's plant quarantine regulations remain a significant hurdle to expansion of trade in tropical fruits.

Finally in this session, Dr Anna Snowdon from the U.K. provided some fascinating insights into what can, and does, go wrong during shipment of tropical fruits to distant markets, and the financial and legal ramifications. Three case studies lent added weight and interest to her presentation. They covered disasters involving shipment of bananas from Panama to Antwerp, of mangoes from Pakistan to Dubai, and of citrus from Greece to Russia.

Harvesting, Processing, and Transportation

When to Harvest — Maturity Standards versus Harvesting Indices

Amos Blumenfeld*

Abstract

Harvesting in the optimal stage of fruit development has a pronounced effect on income. Harvesting too early results in incomplete use of the yield potential of an orchard, and in fruits which are not at their peak quality. Delaying harvest results in losses due to fruit abscission and softening, leading to shortened shelf life, reduced storage, and increased internal disorders. Considerations of harvesting criteria will be discussed in general, with examples of several fruits.

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Fruit Packing House Operations to Improve Returns

Clive Murray* and Cameron George†

Abstract

Packing houses are commonplace on larger orchards in Australia. With shortages of unskilled labour, increasing labour costs, and a requirement to improve quality, Thai primary producers, packers, and exporters are investing in packing shed machinery to improve returns. Examples from existing packing sheds in Thailand and Australia in comparison with traditional methods of handling fruit in Thailand, justify investment in equipment in both the mango and citrus industries in Thailand based on minimal throughputs. Benefits are shown to be savings in labour and reduction of postharvest losses. This is in addition to the other benefits that include easier supervision and higher possible throughputs.

At an FAO regional expert consultation on handling, processing, storage, and transport of horticultural produce held in Bangkok in 1990, postharvest loss figures for fruit in Southeast Asia were reported to range from 0–100% for banana, 15–30% for citrus, 20–33% for mango, and 40–100% for papaya.

The highly perishable nature of fresh horticultural produce means that the problems and solutions can be very complicated. Many of the problems relate to partial or total quality loss during the marketing chain. While the solutions may be known, they are not always applied. This may be the result of lack of knowledge by the specific operator, poor management/supervision, and/or economic factors.

The packing shed is the focal point for application of postharvest treatments and quality standards. The entire process, specific to the product being handled, correctly applied and supervised, is essential to deliver a consistently high quality product as demanded by the overseas or local market.

Any investment in a packing shed needs to be justified through:

- increased returns by generating a higher selling price;
- increased returns by decreasing production /packing costs;
- increased demand for the product; or
- decreasing postharvest losses of product caused by incorrect or inadequate postharvest treatments.

In this paper we attempt to show why and how packing sheds improve returns to growers.

Background

By way of example we will concentrate on mango production, but with sorties into other industries.

There are three reasons why mangoes deteriorate after harvest:

- physical deterioration;
- postharvest diseases; and
- physical injury.

Physical deterioration

Examples of physical deterioration include: excessive ripeness; chilling injury; weight loss; and green-skinned ripe fruit caused by incorrect ripening temperatures

Excessive ripeness. Overripe fruit is more susceptible to physical injury and breakdown. To some extent, development of ripening can be slowed with correct temperature management.

Chilling injury. Most tropical fruit are sensitive to temperatures below 10°C. Mango, cv Kensington, will suffer from chilling injury at temperatures below 13°C, although the development of chilling injury is time/temperature dependent.

Weight loss. Weight loss is not a serious problem in mangoes unless extended periods are required between

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harvest and the consumer market, i.e. greater than 7 days. Other tropical fruits, lychee and rambutan for example, are extremely sensitive to weight loss.

In some parts of the USA, mango waxes are being used to improve the storage life of the fruit. However, storage at the correct temperature at humidities above 90% is recommended in Australia if extended holding periods are required.

Incorrect ripening temperatures. Mangoes will not skin colour correctly if they are ripened at too high a temperature, although flesh colour is not significantly affected.

For cv. Kensington, best flavour development is when fruit are ripened at 27°C, while best external skin colour is best at 16°C a compromise of 20–21°C is normally used.

Disease development

The two major postharvest diseases of mango are anthracnose and stem-end rot. Both infect the fruit on the tree, but do not generally develop until the fruit ripens. Regular field sprays are necessary to reduce the level of infection. Also, it is now standard practice in Australia to apply a postharvest dip of hot Benlate, either in the packing line or as a stand-alone operation to control both diseases. The treatment should be applied within 24 hours of harvest.

Other diseases such as 'transit rot' can be partly controlled through good sanitation and by ensuring that the packing area is clean and free of decomposing material. *Aspergillus* commonly gains entry as a result of poor conditions.

Physical injury

Physical injuries include: sapburn; hot water injury; lenticel spotting; abrasion injury; impact injury; and pressure bruising.

Sap burn. Sap burn can be controlled either chemically or physically. A 1% solution of hydrated lime, citric acid, or sodium bicarbonate added to the wash water may help. Detergent washes are also used to reduce injury caused by sap burn. An alternative is to harvest the fruit with the stem attached and then desap on a commercial desapper or meshed rack.

Hot water scald. This can be caused if either the temperature or dip time is exceeded. Variety's vary in their temperature tolerance, with Nang Klarng Wan being able to tolerate 55°C and Nam Dok Mai 50–52°C. In commercial dip tanks, both temperature and dip time can be controlled.

Lenticel spotting. This can result if the fruit are held for extended periods in the wash water.

Abrasion injury. Abrasion injury may be caused by: fruit being brushed on dirty equipment; too much brushing; and/or vibration of mangoes during transport. To avoid scuffing of the fruit, the packing shed equipment should be cleaned regularly with sanitisers.

Excessive brushing for polishing will show as grey brown areas on the cheeks of the fruit. Brushing should not be longer than 30 seconds on soft brushes. Vibration damage during transport results when the fruit are packed too loosely. Packs should be tight and slightly overpacked at the packing shed.

Impact damage. A drop height of more than 300 mm will cause damage to unripe and sprung fruit. Ripe fruit are much more sensitive. Means of minimising impact damage include manual handling, palletising, and proper carton design.

Pressure damage. Pressure damage can result if, for example, cartons collapse or are overpacked. Unripe fruit can be handled in bulk bins, but sprung and ripe fruit will be damaged if packed more than two fruit high.

Cost Benefits of Mechanisation in Packing Shed Operations

General

Typical packing shed operations usually include some or all of the following:

- Receival, checking, and unloading
- Packaging, including washing, waxing, treatment with fungicide, grading, sizing, packing
- Despatch, checking, loading
- Storage, fumigation, ripening, curling, degreening, cooling, etc.

Labour savings

Desapping. In Thailand, mangoes for export are traditionally channelled through middlemen who buy from a number of growers. In these cases, fruit are normally delivered already desapped, this operation being done on-farm by the growers. Desapping in the packing shed is not always required.

The exception to this will be the larger, more professional growers/companies who are able to export direct. These operators will have their own desapping procedures.

Traditional methods of desapping require about 6–7 persons to handle 600 kg of fruit per hour. A mechanical desapper can handle the same work with 3 people.

The financial savings here may not be significant at present. However, it is possible that within a few years labour rates in Thailand could rise to Baht200/day (US$8) or more.

Of greater current importance is the unavailability of unskilled farm labour in Thailand. The investment in industry in Thailand has absorbed much of the labour.

Farm owners are now faced with serious labour shortages for both pre- and postharvest operations. This has resulted in losses as the grower has been unable to manually handle the harvest.

New farms are now being designed with mechanisation in mind whereas in the past, farm layouts were designed to allow maximum numbers of trees per unit area.

Sorting/packing. Traditional methods of sorting the fruit are completely manual and are both slow and labour-intensive.

A lack of uniform fruit size affects both speed of packing and final presentation of the packed cartons.

With packers packing uniform fruit sizes to standard counts per carton, they need to concentrate only on fruit quality.

The estimates in Table 1 indicate labour savings from mechanical packing of almost Baht1000/day.

Table 1. Sorting and packing cost estimates[a]

Packhouse operation	No. of labourers required	
	Mechanised system	Manual system
Unloading	2	2
Desapping	2	5.6
Repacking	0	1
Singulation	1	0
Sizing	0	5.5
Packing	3	4.3
Cartons	1	2
Loading	2	3
Total	11 × 80	23.4 × 80

[a] Assume labour costs of Baht 80.00/day

Quality savings

Apart from the reduction in labour inputs, there are the additional benefits of quality improvement. This leads to increased returns and an improvement in growers' profits.

Postharvest losses can adversely affect the percentage of marketable fruit. This is controllable with application of correct postharvest procedures. The benefits of postharvest treatment of mangoes have been well documented.

Because of the way in which fruit are purchased in Thailand — through some middleman sourcing from a number of growers — the application of some form of postharvest treatment is essential. The exporter under these circumstances has no control over the preharvest program. It is possible that under such buying conditions and without postharvest protection, losses could reach 50%.

Such potential losses are difficult to quantify, but assuming only a 20% loss because of postharvest diseases, the potential losses on say, the Hong Kong market, could be as given in Table 2. A 20% loss here would represent Baht 83 610.00. This is in addition to the loss in reputation and possible future orders. We believe that sea freight of Thai mangoes has not developed as it should have because of previous experiences with such losses.

Table 2. Estimates of postharvest handling costs (Baht/kg)

	No treatment	Treatment
Fruit	15.00	15.00
Treatment	0.00	0.20
Labour	0.40	0.18
Carton (Baht18.00/12 kg)	1.50	1.50
Transport (local)	0.20	0.20
Sea freight (US$4000/15 t)	6.80	6.80
Documentation	0.33	0.33
Sub-total	24.23	24.01
Total plus margin	27.87	27.61
Total value/container (Baht)	418 050.00	414 150.00

Estimates of the cost benefits of mechanised packing shed operations are given in Table 3. Note that these assume that refrigeration and packing costs are equal and that this example covers the sale of mangoes from the packer to the wholesaler. The example indicates that, for 10 000 trays of mangoes, the difference in returns could be as high as $AUS39 120.00. This could be achieved by the installation of a treatment and grading system costing approximately $AUS50 000.00.

Table 3. The cost–benefit of mechanising average-size (10 000 trays) mango packing houses in Australia.

	Treated	Untreated
Trays dispatched	10 000.00	10 000.00
Wastage en route	2% = 200.00	10% = 1000.00
Trays saleable	9800.00	9000.00
Wastage during sale period	5% = 490.00	20% = 1800.00
Total trays sold	9310.00	7200.00
Average price per tray	$AUS12.00	$AUS8.00
Total value	111 720.00	57 600.00
Average cost of treatment/tray = $1.50	15 000.00	0.00
Nett value	96 720.00	57 600.00

Source: George and Courtier Pty Ltd, unpublished data.

The treatment is so dramatic in effect that, whereas only 25% of the untreated line may be saleable 10 days after picking, at least 85% of the treated fruit will still be saleable. It is only in recent years that the growers in Australia have realised the benefits of correct posthar-

vest treatment, either through their own facilities or those of others.

Other Advantages

There are other advantages of mechanical handling systems on which accurate costs cannot be easily calculated. These are listed in Table 4.

Table 4. Miscellaneous advantages of mechanical fruit handling systems

Operation	Mechanised system	Manual system
Handling	Manually handled twice, desapping and packing.	Manually handled at least 5 times.
Treatment	Desapped without contacting the floor. Water sprays remove dirt, dust, leaves etc. Hot water treatment possible in line.	Desapping done at ground level, encouraging disease Normally no hot water treatment carried out.
Cooling/ brushing	Fruit are brushed for improved presentation.	Fruit skin is not cleaned.
Sizing	Accurate over the whole day's production.	Variable between worker and time of day.
Packing	Faster, more uniform pack. Machine sets the pace.	Packing slow and regulated by the worker or supervisor.
Space	Requires less space.	
Supervision	Supervision of staff easier as there are fewer of them.	
Labour availability	Fewer staff required.	
Quality	Postharvest treatment ensures less post-harvest disease.	No control over disease development.

Another Example

Pomelo

A leading pomelo exporter annually exports about 500 000 pieces of fruit per year. Traditionally these were waxed by hand, requiring a workforce of about 70. With a mechanised wash/wax/dry system designed for pomelo, his staff requirements were reduced to about 25 workers.

Also, hand waxing had caused problems with anaerobic respiration leading to bitter off-flavour development. With a mechanical system, wax application is accurately controlled, preventing such problems. Wax consumption is also reduced by up to 50%.

In addition, the fruit are washed to remove dust and chemical residues, further improving the appearance of the commodity after it has been waxed.

Conclusion

It is relevant to note that the local market is now demanding that citrus, including lower grade fruit from northern Thailand, be waxed. As the middle class in Bangkok demands fruit that looks better and lasts longer, pressure will be put on growers and packers to invest in equipment that delivers the required product. As noted this is already beginning to happen with citrus.

Thai packers and exporters are turning more to post-harvest systems to:

- reduce labour in the packing shed;
- improve quality for both local and export markets;
- increase volume of exports; and
- increase demand of their product.

Fruit Handling Systems in Developing Countries

Ma. Concepcion C. Lizada*

Abstract

Most developing countries are in the tropics where fruit handling systems require measures to ameliorate or eliminate the adverse effects of high temperatures and relative humidities. In most cases, appropriate systems have been developed for export fruits, rather than fruit intended for domestic consumption. Environmental factors and the lack of appropriate support systems make the local marketing of fruit in developing countries a high-risk enterprise. The fruit handling systems and marketing arrangements in developing countries have evolved in a manner that takes these factors into consideration.

Experience in research and development work on fruit handling systems in the Philippines has clearly underlined the role that simple technological innovations, such as those designed for heat dissipation, reduction of physical injury, or disease control, can play in reducing risks. This paper illustrates this observation by describing work on the handling systems for mangoes, bananas, and papaya in the Philippines.

THE development of appropriate handling systems for fruit, or any produce for that matter, requires familiarity with the nature of the product and its interaction with the postharvest environment. This is illustrated by the triangle of postharvest interactions (Fig. 1), which determines the technical feasibility of a postharvest technology or a handling system. The commodity, whose postharvest behaviour and quality are determined by its genetic characteristics and physiological status, constitutes the base of this interaction. Inherent quality at harvest is defined by preharvest factors. These include environmental factors such as temperature, relative humidity, water potential, and light, as well as cultural and pest management practices. However, the ultimate quality is the end-result of the interactions of the commodity with the postharvest environment. Handling systems might have a direct effect on the fruit. These might be satisfactory, but might also favour the proliferation or survival of postharvest pests and pathogens. Conversely, a treatment that might guarantee fruit disinfestation may also render the fruit unmarketable.

Many developing countries are in tropical regions, where the product might be exposed to elevated temperatures, which accelerate fruit deterioration through the enhancement of normal physiological processes such as respiration and ethylene production and action. Moreover, relatively high temperatures in the field during fruit development or in the handling route can render the tropical fruit more susceptible to chilling injury and other disorders. The combination of high temperature and relative humidity favours the growth of postharvest pathogens and, therefore, the development of rots during handling. The tropical environment is also favourable to the survival of insect pests, some of which are of quarantine significance and may infest the fruit in the field or after harvest. These factors have to be given due consideration in developing fruit handling systems in tropical countries.

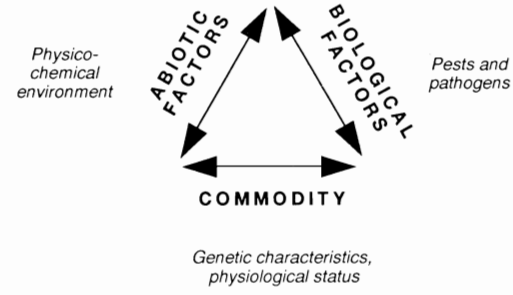

Figure 1. The triangle of postharvest interactions (modified after Nelson, University of California at Davis, unpublished data

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Superimposed upon the requirement of technical feasibility are those related to economic viability and acceptability, given the existing situation in the handling route. Thus, in the development of appropriate systems the following questions have to be considered: (a) Does the handling system work, i.e. does it meet the objective of extending shelf life, reducing disease, or effectively disinfesting the fruit without adversely affecting quality? (b) Does it pay, i.e. is the added cost of a treatment offset by the benefits gained? and (c) Is it acceptable? Such considerations necessitate an integrated view of handling requirements, which constitute only part of the production-marketing continuum (Fig. 2), whether in a developed or developing country situation. Very frequently in developing countries, however, the support systems needed, e.g. farm-to-market roads, facilities for the maintenance of the cool chain and communications, extension services, credit, and appropriate policies are inadequate or might not even be in place. Moreover, the nature and scale of production and trading in developing countries render horticultural marketing a risky enterprise.

The variety of handling systems for horticultural produce and other perishables that have evolved in developing countries highlight the market-defined nature of their development. In the Philippines, for example, both the production and handling systems for major horticultural fruits vary, depending on the target market, which might be categorised into export, local higher class, and traditional domestic markets (Table 1). Typically, the handling systems for export fruits are well developed and organised relative to those for fruits intended for local markets. Preharvest care and the whole range of postharvest operations needed to meet the quality requirements of the importing country all entail added costs, which are, however, offset by the income derived from export fruits.

Table 1. Types of markets for some major tropical fruits in the Philippines.

Fruit	Markets
Banana	Export markets (Japan, Hong Kong, the Middle East, New Zealand, Singapore, Korea) Higher class markets, e.g. supermarkets and markets catering primarily to tourists Typical wet markets
Mango	Export markets (Japan, Hong Kong, Singapore, Australia, E.C.) Local markets
Papaya	Export market (Hong Kong) Local markets

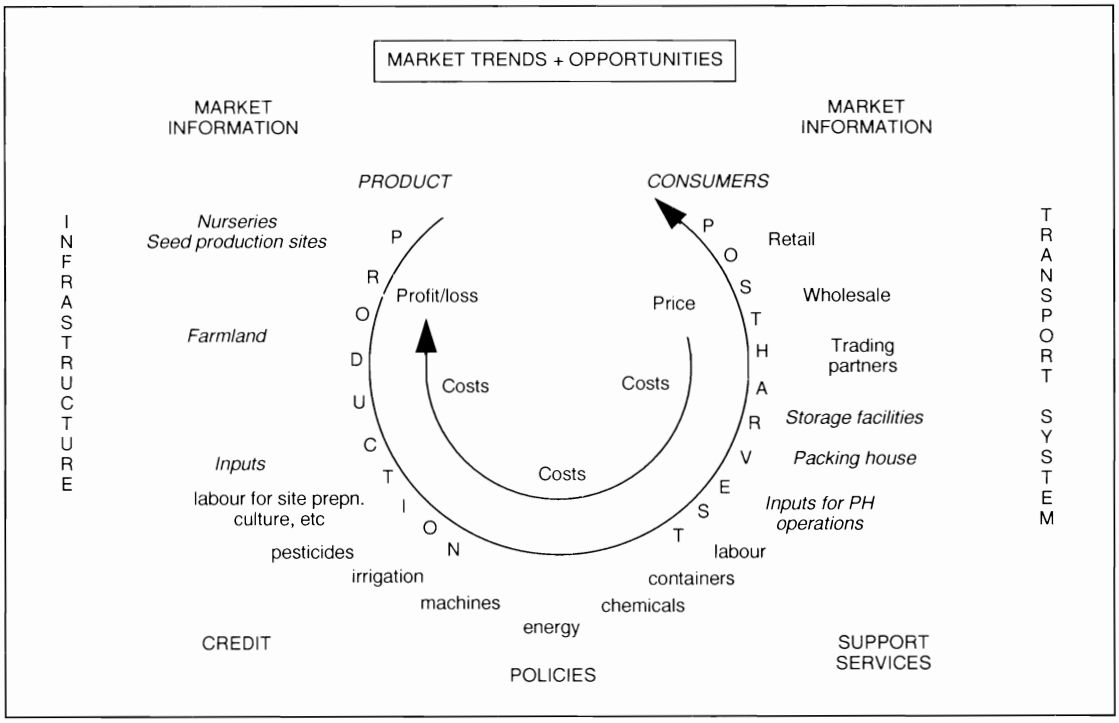

Figure 2. The production–marketing chain (FAO 1989)

The domestic marketing of tropical fruits in developing countries is more problematic. The inherent perishability of the product, and technical and extra-technical inefficiencies in the handling route, on the one hand, and the relatively low capacity of most domestic consumers to pay as well as the highly elastic demand for these fruits, on the other, render the domestic marketing of tropical fruits in developing countries a high-risk enterprise. For example, many fruit growers and traders in the Philippines dread the summer months, when a wide variety of fruits is available in the local market and losses attributed to high temperature increase.

The seemingly manipulative practices of traders frequently serve as a hedge against the risks involved in marketing these commodities. Quality is usually sacrificed in the traders' deliberate attempt to cut costs. This is exemplified by the traders' practice of requiring the overpacking of fruits in crates or bamboo baskets, while paying only for the volume corresponding to the normal capacity of the container. Not only is this practice intended to reduce packaging costs, it is perceived as a means to compensate for losses which can neither be completely avoided, nor compensated for by raising consumer prices. The trader usually makes up for such losses by directly or indirectly depressing farmgate prices, with the producer getting less for his product. This, in turn, depresses any incentive for the farmer to improve production practices to enhance the inherent quality of his fruits.

Banana Handling Systems in the Philippines — a Typical Example

The postharvest handling systems for banana in the Philippines typify the above situation. Export bananas consist mainly of Cavendish types, which constitute about 98% of the bananas exported to Japan. The other markets include Hong Kong, Singapore, and the Middle East. Some of the rejects from export are shipped to Manila, although the principle cultivars sold in local markets consist of 'Baba', 'Lakatan', and 'Latundan'. The combined volume of the cultivars intended for domestic consumption constitutes approximately 79% of the total production (Valmayor et al. 1990).

Systems for bananas intended for export or sale in higher class markets

The production and marketing system for Cavendish bananas for export is an integrated and well-coordinated system. Bananas are grown in large plantations where standard practices starting from land preparation to pest and cultural management are observed. Both field sanitation and aerial spraying are employed to control pests and diseases. The plants are propped with bamboo and recommended fertilisation rates are followed. Developing bunches are protected by bagging and tagged to facilitate identification of fruit scheduled for harvesting.

Harvesting usually involves two workers, with one severing the bunch and the other supporting it. In most plantations the bunches are conveyed from the field to the packinghouse by a system of cableways designed to avoid damage during hauling. Through all the packinghouse operations, care is taken to protect the fruit from injury which might result in blemished fruit. Standard procedures for determining calibration size and visual quality are followed before deblossoming, dehanding, and washing. Defective, under- and over-sized hands are culled and the acceptable fruit weighed, subjected to fungicide treatment, labelled and packed in 12.5-, 13- or 18-kg capacity fibreboard cartons lined with perforated polyethylene film to avoid 'box burns'. These cartons are of sufficient mechanical strength to withstand subsequent handling, stacking, and wetting during ripening. The cartons are loaded into ships and transported at the recommended temperature of 12.5°C. The outcome is high quality fruit which meets the standard requirements of consumers in the export market.

Some of the reject Cavendish bananas are sea-shipped over a period of 3–4 days from Davao to Manila. These are bulk-loaded in non-refrigerated but ventilated five- or ten-footer vans. The fruit might also be packed in wooden crates or even fibreboard cartons.

'Lakatan' grown in the Davao area goes through a similar handling route; however, the operations for ripening in Manila differ. Although one trader ripens 'Lakatan' with ethylene at controlled temperature, most fruit of this cultivar is allowed to ripen with or without carbide at non-refrigerated temperatures, as full coloration is achieved even at ambient temperatures. Most 'Lakatan' bananas are retailed in traditional outlets, with a smaller proportion going to supermarkets and higher class fruit stalls. In contrast, most reject Cavendish bananas are retailed in higher class markets, which require that the fruits be ripened at controlled temperatures with the use of ethylene gas. A small proportion is allowed to ripen at ambient temperatures and is sold mainly in traditional wet markets. A small volume of 'Latundan' bananas is produced in Davao, employing cultural management techniques approximately those for Cavendish. This cultivar, which is more perishable, is airflown to Manila and sold in higher class outlets.

Systems for bananas intended for traditional wet markets

In contrast to fruits grown for export or for higher class markets in Manila, bananas intended for most wet markets are principally produced in backyard farms or obtained from perimeter plantings scattered over wide areas. Little care is provided other than the removal of dry leaves. No effort is exerted to ensure that the fruits

harvested are of sufficient maturity, with most producers relying simply on finger size. Harvesting is usually a one-man operation, frequently resulting in some damage to the bunch. De-handing is sometimes done in the field, with both the bunch and the hands often coming into contact with the soil. The scale of production necessitates the consolidation of fruit from different farms, collected over a period of 1–2 days. Fruits are hauled from the field to the collection area on horseback, carabao-drawn carts, or even tricycles.

Although bananas can be grown almost anywhere in the Philippines, the Manila market depends on the island of Mindanao for a consistent supply of the fruit, as this island is outside the typhoon belt. Most bananas come from scattered farms in the Davao and Agusan provinces.

Fruits assembled from small farms in Agusan are transported in ten-wheeler trucks, jeepneys or trailers to the port, where they are bulk-loaded into ten-footer conventional (non-ventilated) container vans, following a pattern of loading which approximates a tight pack and is believed to minimise vibration in transit. Transport time is 3 days. Consignees in Manila take over the shipment upon arrival. Stripping is usually done soon after arrival, with several wholesalers buying the volume they require from the same load. The wholesalers also haul the fruits from the van to waiting jeepneys and transport them to wholesalers or retail markets.

Problems encountered

Various problems arise from technical and extra-technical inefficiencies in the handling route for bananas intended for the local market. Due to the nature and scale of production of these fruits, the inherent quality is usually inferior. As most farmers are hardly in a position to undertake the marketing of their fruits and have to rely on traders, they are usually not aware that lack of pre-harvest care and appropriate cultural management result in losses as the fruit goes through the handling route. This lack of awareness compounds the effect of low farmgate prices on the farmer's willingness to provide pre-harvest care to the developing fruit.

Fruits in a single shipment are invariably of mixed maturities and a wide range of expected green life. It is not surprising, therefore, that some fruits ripen prematurely in transit.

Careless handling throughout the marketing route reflects the lack of awareness of the need to protect fruits against injury. During a forum, members of the Confederation of Shipowners and Operators (CISO) insisted that bulk-loading of bananas cannot inflict damage even to the bottom fruits as these are hard and resistant to injury. Although ship operators and traders are conscious of the effects of injury on visual quality, they do not associate the reduction of green life of a whole load with injury and are unaware of the nature of stress ethylene production. Handlers at the port usually stand, sit, or even walk on the fruits during loading.

Traders and ship operators are only too aware of the consequent reduction in shelf life with high temperatures. However, loading areas in the ports have no provisions for shading the fruits to be loaded or the filled container vans, which are left out in the sun while awaiting loading into the ship's hold.

Injury, high temperatures, over-mature or ripening fruits, and the type of container van used have led to losses arising from the 'green-soft' disorder. When this disorder occurs, a large proportion of fruits in a van becomes fermented and, in many instances, is rendered unfit for human consumption. This condition is referred to by traders as *laga* (literally translated as 'boiled'). A portion of the shipment might ripen normally, but has to be disposed of immediately. Many wholesalers and retailers simply refuse to buy from such loads, unless bananas are in short supply.

Besides the physical problems existing in this handling system, shippers have to contend with such risks as being 'shut-out', i.e. their loaded container van not provided space on the ship's hold, or arrival delayed due to unforeseen breakdown of the vessel.

Innovations to alleviate the problems

Through the years, banana traders and shippers have introduced innovations designed to cushion the effects of a system fraught with inefficiencies and barely fit for handling most perishable crops. For example, a pattern for piling fruits up in the van has been developed to minimise movement (Fig. 3). This is reminiscent of the system employed in wholesale markets in Thailand, where bananas are ripened in piles with carbide.

Having to use the container van type currently available in Nasipit or Cagayan de Oro, shippers have resorted to opening the doors during transit to help dissipate heat and provide some ventilation. To discourage pilferage the open end of the load is covered with bamboo slats. More recently, large bamboo crates (Fig. 4), which have the same capacity as ten-foot containers, have been allowed by some shipping lines. As many of these crates could not withstand the rigours of handling during the return trip to Mindanao, one shipping line constructed steel banana crates patterned largely after the bamboo crates (Fig. 5). Both the bamboo and steel crates are lined with banana stalks to cushion to minimise abrasion.

Despite all these innovations, losses of about 30% are not unusual. Occasionally, entire shipments are lost.

Potential for postharvest interventions

Considering the scale of operations of banana trading, the conditions that fruits are subjected to, and the risks

Figure 3. Pattern of stacking bananas bulk-loaded in container vans, side view (left) and top view (right). The right-hand photograph was taken during emptying of the van in Manila: the stacking pattern is most clearly seen in the left-most stack of fruit.

Figure 4. Bamboo crates used for shipment of bananas

Figure 5. Steel crates used for shipment of bananas

encountered in the present handling system, shippers and traders are understandably reluctant to adopt new technologies that add to marketing costs. Our experience at the Postharvest Horticulture Training and Research Centre (PHTRC) at the University of the Philippines at Los Baños, in implementing the project 'Postharvest Technology for Bananas' sponsored by the International Development Research Centre (IDRC) of Canada, pointed to several possibilities for intervention.

The first consisted in addressing, through seminars and discussion, the lack of awareness of the requirements for handling perishable crops. After we had emphasised the need for ventilation and presented the design of a ventilated van to the representatives of CISO present at a forum, one shipping line had a number of ventilated vans built. More of such vans have since been constructed and demand for them is high among the banana shippers of Davao.

The potential for introducing technological innovations exists, as long as the requirements for appropriate technologies are met. In the IDRC project, we attempted to apply the modified atmosphere (MA) technology which is known to effectively delay ripening in bananas in cartons or crates. This consists of enclosing the fruits in a plastic bag such that there is limited exchange of air, leading to a reduction in oxygen levels. Our initial attempts involved closing the doors of the vans during shipment and providing sachets of adsorbents to lower the ethylene levels in the load. This treatment led to a high incidence of the 'green-soft' disorder, although one wholesaler had the impression that the incidence was low relative to their usual experience with closed vans. This highlighted the difficulty of utilising the usual MA system, since some fruits in the load had actually begun to ripen and produce ethylene. Ethylene in combination with low oxygen is known to induce the 'green-soft' disorder. This led us to evaluate the effect of ethylene adsorbents in vans shipped with the doors open. A series of trials demonstrated a significant reduction in ripe fruits upon arrival in Manila. Shippers have expressed interest in using the adsorbents.

The participation of shippers and traders in our trials proved invaluable. These practitioners provided us with insights gathered over years in the business. Moreover, they themselves were able to innovate by simply watching us set up the trials, then modifying some of the ideas we shared with them. This is illustrated by our attempt to reduce compression damage by providing a horizontal rack. In a number of trials we provided a horizontal rack running the entire length of the van, but covering only half its width (Fig. 6). This was done so that the unracked portion could serve as the control. This set-up also required a vertical divider. A spinoff from these trials was unexpected. Although the horizontal racks reduced compression damage, the shippers thought they were too expensive to construct. However, they picked up the idea of providing vertical dividers (Fig. 7), which were cheaper to construct and actually reduced the proportion of ripe fruits. The vertical dividers reduced the bulk and allowed for the dissipation of heat. Most banana shippers now use these vertical dividers.

Conclusion

Although numerous problems are encountered in the marketing of horticultural perishables in developing countries, there are opportunities for interventions which reduce losses and can enhance the income derived from horticultural enterprises. While well-managed systems exist, these are geared primarily for export, and might not be appropriate for the domestic market.

Research and development efforts aimed at improving domestic marketing systems for horticultural produce in developing countries require an approach that allows participation by the potential users of the technology. In turn, this requires an approach where the postharvest specialist is both a researcher and an extension agent. Alternatively, the extension worker might be involved from conceptualisation, through implementation, and in information dissemination and technology transfer. In contrast to the usually linear flow of information or interaction among the researcher, extension worker, and target clientele, such an approach requires an interaction among these players from conceptualisation to technology transfer (Fig. 8).

Figure 6. Setting up a trial to evaluate the use of horizontal racks. A horizontal rack running the length of the right-hand half of the van was used.

Figure 7. Typical vertical divider now routinely used in bulk shipments of bananas

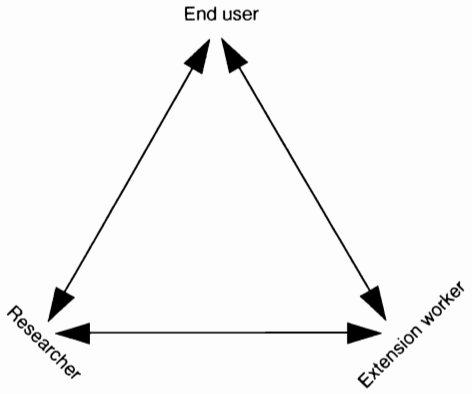

Figure 8. Scheme for participatory R&D in postharvest horticulture

Acknowledgments

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Impact and Vibration Damage to Fruit during Handling and Transportation

D.J. Hilton*

Abstract

Export markets and, to a lesser extent, home markets are increasingly demanding fruit of consistent high quality. To achieve the required standards, quality management at all stages of production and distribution is becoming very important. Mechanical damage, which can occur during harvesting, packinghouse operations, handling, and transport, represents a serious hazard to quality and has the potential to reduce significantly the value of the product. It is therefore important to be aware of the mechanical impact and vibration environment to which fruit is exposed at every stage. It is also necessary to determine quantitatively the damage susceptibility of fruit at various stages of ripeness, and under the time/temperature regimes encountered between harvest and when the fruit appears on the retail counter. Designing a total quality management (TQM) system for optimum results requires knowledge of all these factors, while implementation ideally requires an integrated approach involving all parties in the production–distribution chain. The paper reviews research relating to impact and vibration damage, and outlines how this knowledge can assist with optimum design and selection of packaging, stacking patterns, handling procedures, etc. and make other contributions to a TQM system. Suggestions are made regarding priority areas for future study and research.

As growers, distributors, and exporters of tropical fruit seek to expand their activities, they encounter markets which increasingly demand quality and consistency. While it is fairly common to find markets over-supplied with low quality fruit, it is the fruit of consistent, high quality which will tend to be sought and which frequently (though not always) attracts the price premium. Achieving high quality on a consistent basis is therefore an important goal. To do this, it is necessary, as far as possible, to maintain control of all processes involved in production, handling, and distribution. Total quality management (TQM), a concept well-recognised in engineering production, is now fast becoming the catch-phrase in horticultural production, as a means of guaranteeing the required quality and product consistency. It involves monitoring and product sampling at all stages of production, harvest and postharvest operations, handling, and transport.

Poor handling, inadequate packaging, bad stacking, poor road surfaces, and bad driving practice on the part of truck and forklift operators are responsible for most of the mechanical damage which we see in fruit at the market. Handling damage can occur during the following stages.

1. Picking
2. Placing into collection bags, baskets, boxes, or bins
3. Transport to the packinghouse
4. Unloading at the packinghouse
5. Cleaning, grading, sorting, ripening, and packing
6. Movement into coldstore
7. Loading onto transport
8. Transport to wholesale market or port
9. Off-loading
10. Handling at wholesale market or port
11. Loading onto secondary transport
12. Secondary transport
13. Off-loading at the retail outlet
14. Handling of packages by retailer
15. Handling of individual fruits at the counter display
16. Customer handling.

The consequences of poor handling practices obviously vary greatly from fruit to fruit. The fruit's susceptibility to damage when exposed to impact and vibration usually varies with time, increasing as the fruit becomes riper and softer. Some types of fruit (e.g. bananas) are susceptible to damage when unripe, but may not show the full evidence of that damage until ripe. With some fruits, the damage has the effect of spoiling the appearance, while not affecting the texture or taste, while with

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others textural damage occurs without obviously affecting the fruit's cosmetic appearance.

Not only do the consequences of poor handling practices vary from fruit to fruit, but it seems also that on some markets the purchaser's tolerance of external damage (where this damage does not affect internal quality) also varies from fruit to fruit. On export markets generally, however, cosmetic appearance is of vital importance right across the spectrum of products.

Engineering Aspects of the Damage Problem

In order to understand the causes and mechanisms of impact and vibration damage, it is necessary to study the following aspects (Fig. 1):

A. The source, magnitude, and nature of the impact or vibration input, for example:
   - single fruit impacting against single fruit, yielding surface, or unyielding surface.
   - single fruit subjected to compression with vibration, rubbing, etc.
   - fruit container subjected to drop impact or side impact, tipping, etc.
   - fruit container subjected to transport vibration.
   - vibration response of transport vehicle to road surface, and dynamics of payload.

B. The influence of the packaging material and the container itself, for example:
   - cushioning and damping properties of packaging material
   - dynamic response of the box or carton itself (especially the base)
   - dynamics of a stack of boxes or cartons
   - friction between the fruit and the container
   - friction between wrapping material and the container.

C. The influence of individual fruit and neighbouring fruit in modifying the impact or vibration input, for example:
   - cushioning effect of neighbouring fruit.
   - interaction between dynamics of fruit and packaging material.

D. The susceptibility of the fruit to damage, as a function of maturity, ambient temperature, previous cold storage time, storage temperature and atmosphere, etc.

To gain from such an understanding, it is then necessary to determine what the commercial cost of such damage is, and the cost and feasibility of putting into place measures to reduce damage to a certain target level.

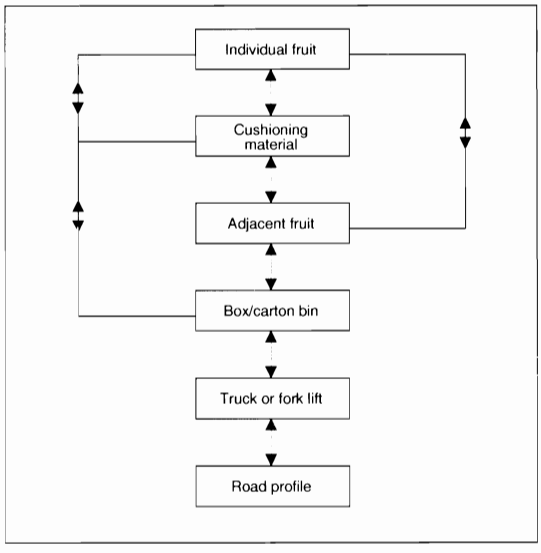

Figure 1. Diagram showing fruit–packaging–vehicle interactions.

Research into Impact and Vibration Damage

Most of the research into impact and vibration damage has been done not with tropical fruits, but with temperate fruits, principally pome fruits (mostly apples) and stone fruits (mostly peaches). A number of researchers have sought to quantify the damage problem in the commercial context. O'Brien et al. (1960, 1963, 1965, 1969) reported that in the case of loads of cling peaches, a particular road journey of 260 km produced significant damage in 40% of the fruit. They attributed between one-half and two-thirds of the transportation damage to the effects of vibration. Burton et al. (1989) studied bruising of apples resulting from picking and hauling operations. Schulte-Pason et al. (1990a) also examined apple damage occurring during interstate transportation. In this investigation, they used an instrumented sphere to record the magnitude, duration, and time of dynamic impacts. Armstrong et al. (1992) studied the damage caused in the transport of apples in bulk bins. Damage to fruit on apple packing lines has been studied by Brown et al.(1989) and Sarig et al. (1992), while Sargent et al. (1992) analysed impacts on tomato and bell pepper (*Capsicum annum* L.) packing lines. In their investigations, these researchers again used an instrumented sphere which passed through the packing line with the fruit. Brown et al. (1990) then describe ways of reducing impacts on apples in packing lines. Very little published work of a quantitative nature exists on damage incurred in picking operations or at the retail stage, though reference is made to the problem by Bardaie and Hitam (1979) and Suraphong (1983). Kunze et al. (1975) investigated bruising characteristics of peaches related

to mechanical harvesting, but little appears to have been done on damage arising from hand picking.

Laboratory studies into the susceptibility of fruit to impact loads have been carried out by a number of researchers in an attempt to determine an appropriate model by which bruise size can be predicted for a given impact (again mostly with apples). Set force conditions were mechanically applied or the fruit given a free fall onto selected surfaces (Garcia and Ruiz 1988; Brusewitz and Bartsch 1989; Schulte-Pason et al. 1990b; Hilton, unpublished data). The magnitude of impact loads is illustrated in Figure 2, which shows a force/time plot resulting from dropping an apple onto three different surfaces from a height of only 200 mm (Hilton, unpublished data). In the absence of packaging material, the peak force reached in the impact is equivalent to 250 times the apple's own weight. Schoorl and Holt (1974) studied the bruising caused by dropping wooden cases of apples and tray-packed cartons of apples from various heights onto a hard surface. Holt and Schoorl (1977) impacted the surface of an apple with a projectile and determined the energy absorbed in the impact. From these results they proposed a model in which bruise volume is related to the absorbed energy. Later they used this relationship in an attempt to predict the effects of truck suspension and road profile on bruising (Holt and Schoorl 1985). Holt et al. (1981) also studied the impact behaviour of columns of apples. Nelson and Mohsenin (1968) studied the effect of temperature on bruise susceptibility and postulated maximum allowable static and dynamic loads. Schulte et al. (1992) also studied apple bruising thresholds. Schoorl and Holt (1978) and Brusewitz and Bartsch (1989) have studied the effect of storage time and temperature on bruise susceptibility, while Kline (1987) and Brusewitz et al. (1992) looked also at the relationship between bruise susceptibility and harvest date. Pang et al. (1992) examined bruising damage in apple-to-apple impact. In work on papaya, Kumar and Wang (1971) investigated the effect of sinusoidal loading in the 0.25–0.7 Hz frequency range, while Hilton (unpublished data) investigated papaya impact loading.

The techniques for analysing stress in engineering materials when subjected to complex loading situations is well developed, and engineers and material scientists have attempted to apply the various rheological theories of stress/strain behaviour and material failure to fruit tissue, treating it as an elastic, elasto-plastic, or viscoelastic material (Miles and Rehkugler 1973; Mohsenin 1977; Diehl and Hamann 1979; Holt and Schoorl 1982). Hamann (1970) and Peleg (1984) produced mathematical models for deformation mechanisms using a relaxation modulus, the latter extending the Hertzian contact problem to non-linear viscoelastic spheres. Gan-Mor and Galili (1987) used upper and lower bound theorems of plasticity, suitably modified to include dynamic effects. In experiments on apple impacts, Siyami et al. (1988) explored a number of models employing Hertzian theory, adjusted Hertzian theory, plastic theory, and multiple linear regression analysis. In the experiments, apples were dropped-tested from three different heights onto surfaces representative of steel and wood (2 and 6 m sec impact duration, respectively). The results indicated relatively poor correlation between measured

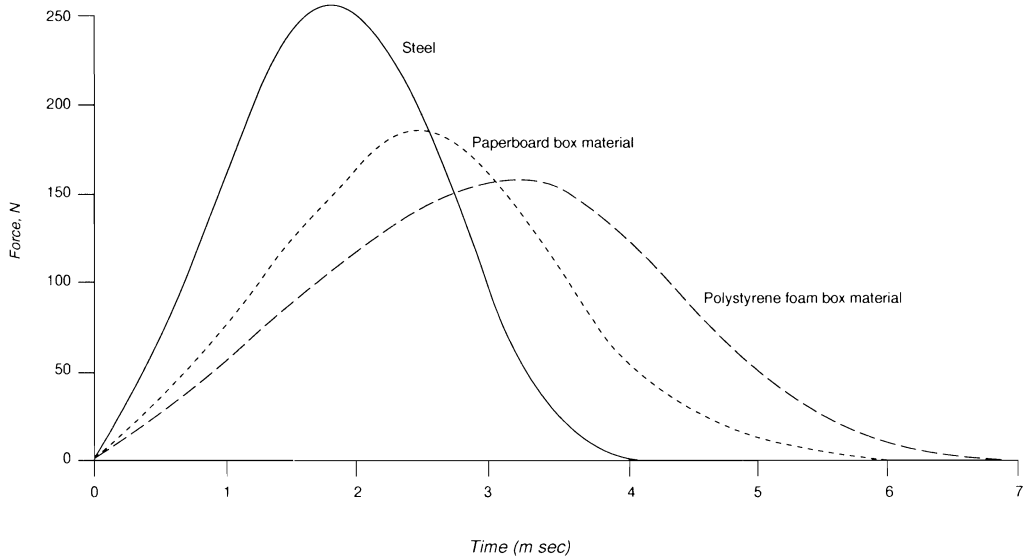

Figure 2. Impulsive force/time plot for apple dropped from 200 mm height onto hard and cushioned surfaces.

bruise diameter and that predicted from Hertzian contact stress theory or plastic theory, and the researchers concluded that the best model for predicting bruise diameter was to be found in a step-wise multiple linear regression analysis based on apple diameter, apple weight, resistance to an indentor probe (Magness–Taylor force), maximum acceleration, and total velocity change during impact as the independent variables. Srivastava et al. (1992) predicted bruising using a model derived from dimensional analysis.

The actual mechanism of failure in the bruising of fruit flesh has been discussed by a number of researchers. Holt and Schoorl (1977), Diehl et al. (1979), Pitt (1982), and Pitt and Chen (1983) considered the failure of fruit tissue under compression as a consequence of the propagation of cell wall ruptures, breaking of intercellular bonds, or cell deflation as a result of loss of cell fluid. In order to model these mechanisms, rather than treating the material as a continuum, Pitt (1982), Pitt and Chen (1983) and Pitt and Davis (1983) took their analysis down to a cellular level. They studied cell mechanical response to external load, modelling the fruit tissue as a cohesion of cells. A different approach was adopted by Roudot et al. (1991) who looked at the behaviour of apple flesh at the cellular level using imaging techniques, and based their model on the influence of maximum cell stress before collapsing, taking into account the effect of cell spatial distribution on mechanical properties.

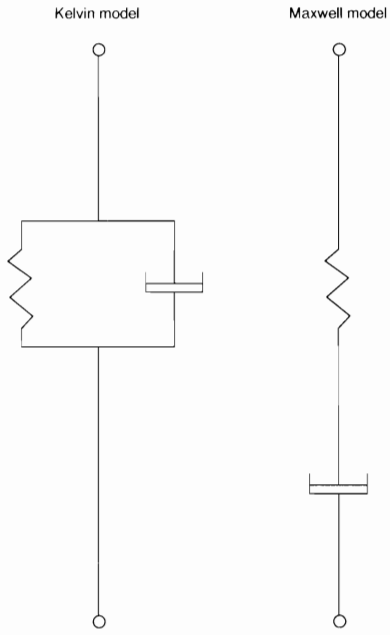

Figure 3. Dynamic two-element models of the Kelvin and Maxwell type.

While the latter approaches might ultimately yield the most rigorous method for predicting damage, other researchers have taken a more pragmatic approach of measuring impact behaviour of the whole fruit, and fitting this to one of a number of models, such as a Kelvin or Maxwell model (Fig. 3). These models are then used to represent the viscoelastic behaviour of a whole fruit during an impact. Lichtensteiger et al. (1988a,b) found that impact of tomatoes can be represented by a Kelvin model, and Hilton (unpublished data) found that a Kelvin model can also be used to describe the impact behaviour of apples against a hard surface.

As far as work on vibration damage is concerned, some of the most significant is still the early work of O'Brien et al. (1963) into transportation damage of fruit carried in bulk bins. They took acceleration and damage measurements with various depths of fruit, and observed an apparent resonant frequency which varied with the depth of the bed. They used a model of vibration behaviour represented by a single column of fruit excited at the base, the model predicting the frequency of the fundamental as:

$$f_n = [1/4d][\sqrt{(Eg/p)}]$$

where f_n = natural frequency (Hz)
d = depth of fruit column (m)
E = elastic modulus (Pa)
g = acceleration due to gravity (9.81 m/sec^2)
p = fruit density (kg/m^3)

Despite the simplistic form of the model, it was found to predict the natural frequency to a reasonable degree of accuracy. Table 1 shows the natural frequencies for four different fruits at depths of 300 and 600 mm (obtained by interpolation). The experiments of O'Brien et al. (1965) showed that with a bed of fruit 600 mm or more in depth, it was easy to excite resonance at frequencies in the same range as those encountered with transport vehicles. Figure 4 shows a typical road transport vehicle vibration spectrum, indicating significant levels of vibration in the range 3–25 Hz. Walker et al. (1978) vibrated single apples on a laboratory vibrating table at frequencies within the range 7–22 Hz. Provided

Table 1. Natural frequencies (Hz) of four fruits at 300 and 600 mm bed depths (by interpolation of curves taken from O'Brien et al. 1965)

Fruit	Depth (mm)	
	300	600
Tomatoes	16	9
Apricots	27	13
Cling peaches	–	20
Pears	54	28

the apples remained in contact with the table at all times, the vibration damage was confined to within 3 mm of the surface. When the vibration level was sufficient to cause loss of contact, the apple bounced against the table, resulting in damage from repeated impacts and giving rise to larger and deeper bruises more typical of impact bruising.

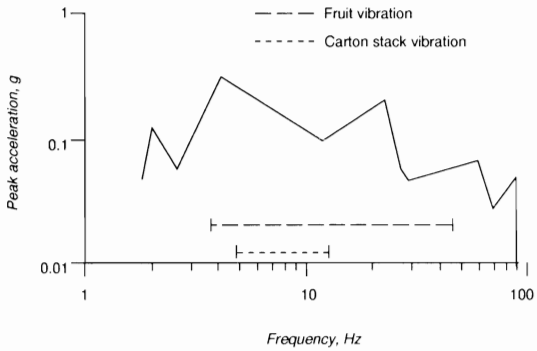

Figure 4. Typical peak acceleration spectrum for road truck.

McLaughlin and Pitt (1984) carried out a more detailed investigation into cyclic compression loading of apples and concluded that cyclic loads of magnitude insufficient to cause initial failure still eventually caused tissue failure. They also found that significant irreversible deformation accrued in the first few load cycles, even without cell wall rupture. Kimmel et al. (1992) investigated the natural vibration modes of oranges and apples subjected to unidirectional vibration, and identified three principal modes. Resonant frequencies in the case of the orange (navel) were at 88, 300, and 408 Hz whereas those for the apple (golden delicious) were at 495, 713, and 1045 Hz. They then represented the behaviour by means of a 6-element viscoelastic model. Kawano and Iwamoto (1979) studied the vibration of vertical stacks of fibreboard boxes filled with fruit and showed that they resonated at about 6 Hz, i.e. within the range of major excitation frequencies encountered during road and rail transport (Fig. 4).

A few researchers have attempted to devise a model for transportation damage using an integrated approach which includes fruit damage characteristics, truck suspension parameters, and road surface profile. Schoorl and Holt (1982) and Jones et al. (1991) proposed such a model of the road-vehicle-load system, and attempted to use it to predict mechanical damage. The model, which has yet to be rigorously tested, deals with bumps in the road, but ignores continuous vibration inputs. Timm and Brown (1992) suggest the use of a road surface profile classification as a component in fruit damage control.

Implications of the Research

The importance of defining a bruise threshold for impact loads

To be able to define an impact load threshold below which bruising is considered to be non-existent or negligible is commercially very desirable, since the concept provides the first step in a rational approach to specifying handling procedures and selecting packaging. Such a threshold may have both a biological component and a component based on commercial tolerance. In the commercial context, a few very small bruises may be tolerated as not detracting from the overall appearance or quality. (This is particularly the case with red apples.) Where such a tolerance exists, this effectively raises the allowable impact threshold. While some researchers have defined impact damage thresholds for a few varieties of apples, pears, and peaches, there is evidence that bruising susceptibility varies significantly between apparently identical fruits. This means that any threshold may have to be defined on a statistical basis, e.g. a level at which fewer than, say, 10% of fruit will show detectable damage. It must also be remembered that most of the research has been done with apples, and relatively little research into tropical fruits, and so care has to be taken before generalising.

The determination of bruise threshold in turn defines the maximum drop height which is allowable in respect of various surfaces against which a fruit impacts. In the case of some tropical fruits, the maximum allowable drop height onto a hard flat or convex surface or onto an adjacent fruit may be as little as 80–150 mm, depending on the degree of ripeness and fruit temperature. This has significant implications for harvesting operations, the design of packing house machinery, and the selection of appropriate packaging.

The importance of limiting the depth of the fruit layer, and the height of stacks of cartons during transport

Of the three mechanisms of vibration damage, potentially the most serious one arises where fruit in the top layer becomes momentarily airborne during transportation and impacts repeatedly against the fruit below. Thus, it is important to limit the vibration in such a way that the acceleration of the top layer is always below $0.9g$ or 9 m/sec^2. Alternatively, the fruit should be physically held down with soft packing material. Limiting the acceleration level at the topmost layer is assisted by keeping to shallow depths in bulk bins and by employing transport vehicles with soft suspensions (low natural frequency).

It is also important that stacks of fruit cartons should not exceed a height of around 1.5 m during road trans-

port, in order to avoid vibration amplification in the 5–10 Hz range.

The concept of damage threshold for vibratory loads

The other mechanisms arising from true vibratory loading involve damage at the point of contact and also damage throughout the fruit due to internal resonance. Since the frequencies involved in the latter are very high, it is considered that ensuing effects are relatively minor, and that the main problem arises around the area of contact. The concept of a threshold relating to vibratory or repeated impact loading is much harder to define than for impact loads, since comparatively little research has been carried out into the effects of pure vibration. In transport situations the vibration is semi-random, though it is often made up of a few predominant frequencies. Separating the effects of the regular frequency vibration from the effects of transients (bumps, jolting, etc.) is a difficult task. With our present knowledge, the cumulative effective of repeated loading below the single loading impact threshold is also very difficult to determine.

Design and selection of packaging and containers

In the case of fruits that are highly susceptible to damage, the ideal configuration is single-layer container packaging or multilayer containers using preformed cellular fibre trays to separate individual fruit and also to separate the layers. It is recognised, however, that the cost of such packaging can be high, and for some markets compromise might be necessary. Whatever type of container is used, the impact-absorbing properties of the packaging material at the bottom of the container can be critical. In the case of containers made from wood or hard plastic, the cushioning material should be capable of yielding to impacts without yielding to the point where the fruit is brought into contact with the hard surface underneath (Fig. 5). The effect of the cushioning material is two-fold. Firstly it reduces the peak impact load and extends the duration of the impact (see Fig. 2). But a far greater effect is by virtue of the fact that the packaging material itself yields, causing the load to be spread over a much larger contact area. Because of this, the contact stress (force per unit area) is greatly reduced, often by an order of magnitude. The cushioning material should also be energy-absorbing. Using a base cushioning material which is too elastic (i.e. with too little damping) can give rise to continual small movements, resulting in excessive rubbing between adjacent fruit. In the case of loose-filled fibreboard cartons, rubbing injury can also be caused as a result of the flexing of the carton base during shock and vibration loading. On rough roads when stacks of full fibreboard cartons 6–8 high tend to vibrate at 5–10 Hz frequency, this again causes internal movement of the contents. Individual wrapping of fruit serves to minimise any rubbing injury caused in this way, especially if the wrapping material is of the low-friction type. In the case of bananas, for instance, lining the carton with polyethylene has been found to be very beneficial in this regard.

Where transport vibration is likely to be excessive (i.e. greater than $1g$), the fruit should be packed within the container in such a way that the top layer is held down firmly. With some fruits it is common practice to pack the fruit to a level slightly higher than the top of the carton to achieve a small amount of pre-compression. In some cases, however, shrinkage due to water loss combined with settling due to vibration can soon result in the pre-compression being lost. Ideally a light pressure should be applied by a soft packaging material sandwiched between the fruit and the container lid.

Damage which occurs at the retail stage can be reduced by using the same packaging container also as a display container, assuming that the container is aesthetically pleasing. As an example, plastic transport crates are now being used on retail displays in some of the large supermarkets in Europe. (The plastic crates are

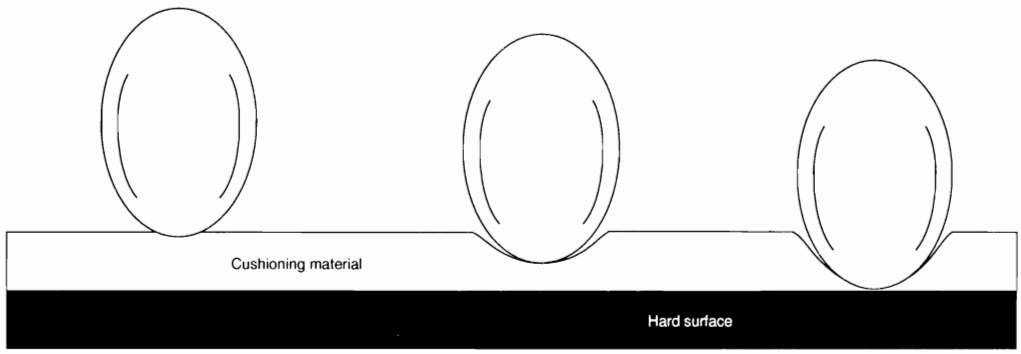

Figure 5. Diagram showing insufficient, correct, and excessive deformation of cushioning material.

owned by the supermarkets, and rented by the wholesalers.)

Fruit orientation within the container

Fruits shaped like a prolate spheroid (e.g. mangoes and smaller varieties of papaya) are normally packed with their major axis vertical, since in this position they are perceived as being more capable of taking vertical compressive loads. More importantly, in this orientation it is easier to pack the fruit in such a way as to make sure of a tight fit, thereby leaving little space for the commodity to move around in the container when it is shaken. It is likely, however, that some fruits packed in this way are more prone to impact bruising than when the fruit is laid flat.

Container rigidity and stackability

In order to protect the fruit, the container should ideally be rigid and capable of being stacked without transferring any vertical load through the fruit itself. Wooden boxes, styrofoam containers, and hard plastic crates usually satisfy these criteria very well. Fibreboard cartons are normally satisfactory when stacked up to 6 or 7 high (if dry) but sometimes when they are overfilled or held in high humidity environments significant loads may be passed through the fruit itself. Since fibreboard loses much of its strength in high humidity conditions (compression strength dropping by around 35% for a moisture content increase from 10 to 15%) waxing of cartons is to be recommended under these conditions. Cartons may have wax applied to both the inner and outer layers of the fibreboard as well as the core, or for economy may have the inner layer waxed only.

Cross-stacking of fibreboard cartons is sometimes practiced for the purposes of stability, but in-line vertical stacking is to be preferred, since cartons are much stronger and more rigid when stacked one directly above the other. Stability can be achieved by other means, such as the use of banding or netting.

Bamboo baskets of circular cross-section are less effective than rectangular boxes or cartons, especially when they are over-filled, as is frequently practiced throughout Asia. Although when used upright in single layers they may protect the fruit from vertical loads, their circular shape at the top end makes them quite flexible, thereby allowing lateral loads to be transmitted through the fruit, such as when baskets are squeezed into place in a transport vehicle. Baskets which are filled only to the top and and have strings tied across the top in two or three directions provide much better protection for the fruit (Fig. 6). It is recognised, however, that in some market situations this practice would be difficult to implement where the *over-full* basket is traditionally used as a volume measure.

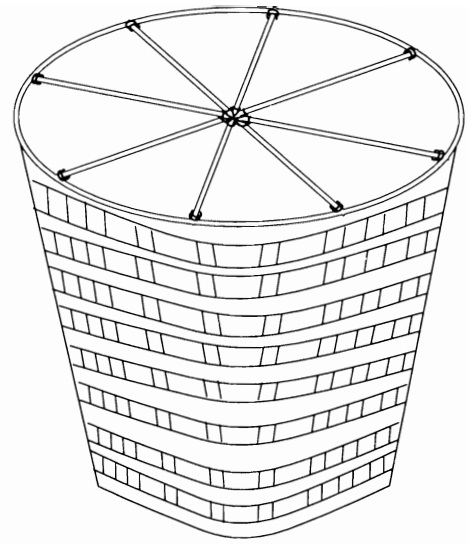

Figure 6. Sketch showing method of stiffening traditional bamboo basket.

Any lack of stiffness in the container bottom is usually less of a problem with small containers than with large bulk bins, where adequate stiffness is important. The weight of a full load of fruit has the tendency to make the bin bottom sag, which can result in vertical motion of the whole mass when bumps are encountered during transportation, causing rubbing and bruising. Bin design should therefore provide for ample stiffening cross-members at the base.

Loading/stacking patterns within vehicles

Where it is possible, palletising is to be strongly recommended not only for the sake of handling efficiency and quick turn-around, but also as a way of minimising the number of handling impacts. If possible, some packing material should be wedged in any gaps between the stack and the sides of the vehicle to prevent the stack swaying and hitting the sides when cornering or travelling on rough roads.

Where bamboo baskets are used, these should preferably be loaded onto the vehicle in the vertical position and not laid on their side. Rather than stacking baskets on top of one another, shelves should be provided within the vehicle to take the weight of individual layers of baskets (Fig. 7).

Vehicle suspension design

Road haulage vehicle suspension is normally designed to achieve a compromise between ride comfort and vehicle handling. (*Vehicle handling* is a term used

Figure 7. Baskets loaded onto shelf during transport.

by automotive engineers which refers to stability and safety in steering control and braking, and is not to be confused with fruit or container handling.) Since most goods carried are much less susceptible to shock and vibration than fruit, vehicle suspension is normally designed to be relatively hard in order to give good vehicle handling. In the case of transport of fruit, a better compromise would be to make some sacrifice in vehicle handling in favour of a softer suspension, thereby lowering the frequency and acceleration level of vibration, and reducing the effect of rough road surfaces. Incorporating a good, active suspension system in larger transport vehicles would further improve vehicle ride for the fruit, while maintaining good vehicle handling characteristics. Unless a vehicle is to be used exclusively to carry fruit, however, such suspension designs are not likely to be built. Needless to say, both these approaches would also increase the cost of the vehicle. As far as current truck suspensions are concerned, there is evidence that air suspension produces less damage than multi-leaf spring suspension.

Much of the fruit transported over short distances is still carried on small vehicles. Fortunately, vehicles of 1–3 tonne capacity generally have softer suspensions than the larger haulage vehicles, and give a reasonably good ride when heavily laden, provided the road surface is not too rough.

Vehicle routing

With the availability of the instrumented sphere, other ride vibration meters or road profile meters, different transport routes can be classified and a route specified which will minimise transport damage. Since transport vibration is a function of speed, damage can also be reduced by specifying the optimum vehicle speed over rough roads (in those cases where it is possible to exercise control.)

Possible Future Developments

More regular impact and vibration monitoring

The development of the instrumented sphere (IS) in the USA represents a significant development in the measurement and monitoring of the impact/vibration environment. At present, the IS is designed to record impacts as measured by the number of times the acceleration exceeds certain threshold values, recording them as single events. At this stage in its development, the IS's dynamic response is somewhat different from the fruit itself. What this means is that although what it records is a measure of the vibration environment and may be used to identify points in the handling chain that require the most urgent attention, the motion the IS measures does not represent the precise motion of the actual fruit. Studman and Pang (1992) acknowledge the considerable difficulty in relating the output to the level of fruit bruising. Clearly there would be considerable interest in developing the IS to the point where it comes closer to imitating the dynamic behaviour of different types of fruit.

In addition, there is perhaps scope for further development in this direction by measuring the frequency content of the vibration and by weighting the vibration frequency in accordance with the fruit's own particular response to various frequencies. From this it would then be possible to determine the severity of the vibration 'dose' the fruit has received. This approach has been used previously in the context of human exposure to whole body vibration in off-highway and tractor-driving operations (Hilton 1970). Before this can be done, however, more data must be gathered on the vibration response of various fruits, and their susceptibility to a combination of vibration and single load cycles.

Improved techniques for bruise detection and maturity determination

Non-destructive techniques for bruise detection such as ultrasonic scanning, specific gas detection, and vision system analysis, are likely to play an increasing role in future. Since susceptibility to damage is a function of fruit maturity, improved non-destructive techniques for measuring fruit maturity could also play an indirect role in damage prediction and reduction.

Improved computer packages for stress analysis

Using the finite element technique (in which a body is considered to be made up of a very large number of small elements), an individual fruit can be modelled, and a very detailed stress analysis carried out for the case where the fruit is subjected to contact loads at any point on its surface. As an example, Figure 8 shows the com-

puted stress field in a cross section representing that of a papaya subjected to a compressive load on two sides (in this case the top and bottom of the figure). The level of stress at any point is indicated by contour lines or by various bands of colour. As with most of the computer packages available, the analysis assumes that the material is purely elastic and shows a linear relationship between stress and strain.

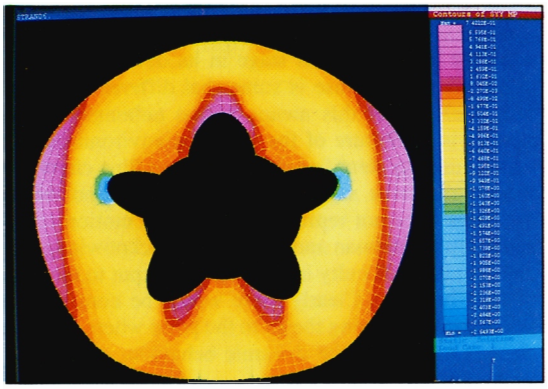

Figure 8. Output from finite element analysis of papaya cross-section, assuming linear elastic material behaviour. Red–pink areas show regions of highest stress.

Although fruit flesh tends to exhibit viscoelastic rather than elastic behaviour, the technique nevertheless is useful in highlighting regions within the section that are likely to be most susceptible to mechanical damage. In side impact tests carried out on semi-ripe papaya, for instance (Hilton, unpublished data), the regions where cracking and bruising were found to occur correlated very closely with those highly stressed internal regions indicated in Figure 8. Some of the more sophisticated finite element packages can already cater for nonlinear elements, and it is possible that in the next 5–10 years packages will emerge which cater for viscoelastic behaviour. Provided that the material behaviour can be adequately described, this will enable much greater precision to be reached in predicting damage arising from various loading situations.

Vehicle development

Provided the cost could be tolerated, there is scope for improving truck suspension specifically for loads of fruit. This can be done by lowering the suspension's natural frequency, or by employing an active suspension which is specially tailored to the task. Another possible development in the case of shipping container transport could be to keep the standard truck suspension and to provide a separate suspension for the container itself (Fig. 9).

Conclusions

Although a considerable amount of effort has been put into investigating damage problems and mechanisms in the case of apples and some stone fruit, very little published data exist regarding damage potential for any of the tropical fruits. Since tropical fruit represents a significant export growth industry for the Asia–Pacific Region, urgent work is required to establish *quantitatively* the impact and vibration damage susceptibility for many of the tropical fruits, particularly mango, papaya, carambola, and certain thin-skinned banana varieties. Where the market can bear the cost of expensive packaging, many of the post-packaging problems can be solved using existing technology. In future, however, more attention should perhaps be given to developing lower-cost packaging solutions, in order to provide a wider range of options. Data are also needed relating to transport and handling in rural areas using local transport on both highways and rural access roads, with a view to identifying the most serious sources of damage. Training is an essential part of any TQM system. Orchard operations, vehicle and fork lift truck driving, and retail handling are areas requiring more attention in this regard.

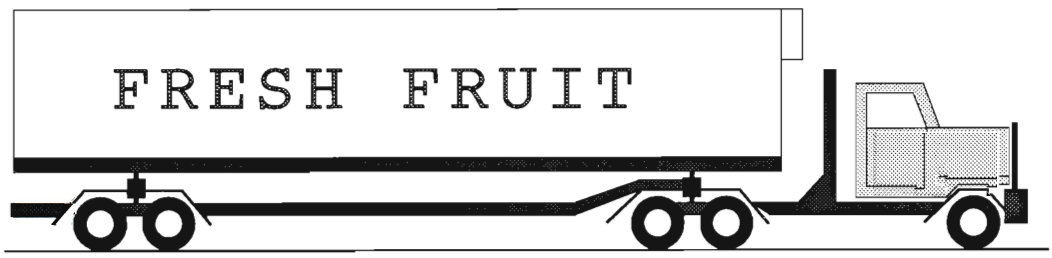

Figure 9. Sketch illustrating the concept of independent container suspension.

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Minimal Processing of Tropical Fruits

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Abstract

Minimally processed tropical fruit is becoming more common. Consumer demand for convenience has made it more popular. It is also being considered for export in place of whole intact fruit because of its advantages in reducing transportation cost, efficient use of cargo space, and avoiding plant quarantine. Minimally processed fruits are normally damaged during their preparation, to a degree dependent on their structure, e.g. separation of pulp tissue from the peel. Consequently, physiological responses, such as respiration, ethylene production, and chilling sensitivity differ amongst fruit types. Fruit must be very carefully processed to minimise injury. Packaging and storage conditions must be very specific to maximise shelf life. In addition, minimally processed fruits are vulnerable to microbial attack, even by organisms that do not normally attack fruit (e.g. *Listeria*). Little research has been done in these areas. Therefore, contamination by human pathogens is an important concern. More work needs to be done to understand physiological behaviour following minimal processing, which differs from that of intact fruits and to find a means to maintain good quality of the processed product for a longer period.

MINIMALLY processed fruits and vegetables can be defined as those fruits and vegetables that may have been cleaned, peeled, cut, sliced, packaged, or processed by any means short of killing the tissues (Shewfelt 1987). A wider definition (Huxsoll and Bolin 1989) might include fruits whose tissues have been killed during processing but have retained their fresh appearance. This review is limited to living tissues only. Such minimally processed fruits are very perishable and vulnerable. This is the opposite situation to that found under conventional processing such as drying, canning, or freezing, in which fruits are made stable, less perishable, and can be stored for long periods (Huxsoll and Bolin 1989). Minimally processed fruits, however, retain their flavour, aroma, and nutrition better than conventionally processed fruit (Klein 1987).

Minimal processing of fruit is not new. It has been done for a long time around the world. However, the distance and the time between the preparatory processes and consumption in the past might be short; e.g., a few minutes walk from the market to the consumer's home nearby. Today, however, the processing may be done thousands of miles from the place of consumption. In this case, care must be taken in selecting and preparing the fruit, to hold the finished product in good condition long enough to satisfy the consumer. The demand for minimally processed fruits is the result of the twin desires of consumers for convenience (King and Bolin 1989), and quality. Suppliers also benefit, since shipping costs can be reduced. Labeling can be easily done on the package, quality can be guaranteed, waste disposal cost can be minimised, price can be lowered and, eventually, more profit received. It was predicted that by the year 2000, the market value for minimally processed fruits and vegetables would grow to US$4000–8000 million a year (Hurst and Schuler 1992).

Most of the development of minimally processed fruit has been undertaken by people in the fruit business. Food scientists have paid little attention until recently. With this perspective, more research is needed to improve the technology for producing high quality, minimally processed fruit. This review examines criteria for fruits to be minimally processed, current practices, and associated problems, with the emphasis on tropical fruit.

Critera for Fruits to be Minimally Processed

Not all fruits are being minimally processed. Durian, jackfruit, mangosteen, papaya, pineapple, pummelo, and young coconut are among tropical fruit often seen available in this form. The reason these fruits are suitable for minimal processing can be summarised as follows:

Large fruit size. Several tropical fruits are quite large. A single fruit may weight more than 10 kg; e.g., durian, jackfruit, and papaya. It may not be convenient for the

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consumer to carry the whole fruit back home, or it may be too much to consume, particularly for smaller families.

High price. Prices for some fruits are very high, particularly early in the season. If the fruit is also large, then it is more economic to buy just enough for consumption.

The risk in obtaining poor quality pulp. In many fruits, the pulp quality varies greatly and cannot be determined from the outside. Several physiological disorders in tropical fruit severely reduce their quality; e.g., granulation in pummelo, internal browning in pineapple, and pulp necrosis and water soaking in durian. In addition, maturity of many tropical fruits cannot be determined easily. Minimally processed products allow consumers to inspect them closely and reassure themselves that they will get high quality products.

Difficulty in peeling. Durian has numerous sharp spines that are dangerous for consumers not skilled in the procedure for opening the fruit. Jackfruit is full of gummy material that stains clothes and sticks to the hands. The difficulty of accessing the flesh often results in an unsightly product.

Weight reduction for transportation. Many tropical fruits have thick rind with only a small portion being edible. Durian, jackfruit, mangosteen, pummelo, and pineapple are good examples. The extra weight not only increases transportation cost but also causes waste disposal problems (Garg et al. 1990) at the end of the market chain, which may be costly. To remove this inedible portion at the beginning greatly reduces the price to the consumer.

Avoiding plant quarantine. Most tropical fruits are subjected to infestation by fruit flies. Hence, they cannot be imported into some countries, such as Japan and the United States, from areas known to be infested with these insects. Minimal processing allows each fruit to be carefully examined right to the fruit centre. Nevertheless, one can argue that newly laid eggs and small larvae may escape detection during the peeling, cutting, and sorting process. Research must be conducted to verify that minimally processed fruits are free from the insects. Alternatively, minimal processing itself may be used as a quarantine treatment, or quarantine treatment may be imposed on minimally processed fruits. It must be cautioned, however, that minimally processed fruit may be classified by the authority as food or processed fruit instead of fresh fruit and must follow the rules and regulations of that category.

The above criteria are the main reasons that various fruits are minimally processed. There are still other minor reasons, such as to create new consumer products, to improve quality or make use of defective fruit, to increase shelf life, and to reduce the labour cost for processing fruit at processing plants, restaurants, or food centres in the city. These criteria are all aimed to satisfy the desire for convenience among customers.

In addition to the above criteria for fruit to be minimally processed, there are also questions of where and when the process should be done and what degree of processing is needed. The physiological nature of the fruit and the marketing channel are the two important considerations. Obviously, if the processed fruits do not quickly deteriorate, the processing can be done at the growing area. On the other hand, those which rapidly deteriorate must be dealt with at retail outlets, unless new techniques can be developed to preserve them close to their original condition. A survey on where the fruits are grown and consumed, how they are transported, distributed, and displayed must also be done to efficiently answer this question. In any case, it is known that a central processing facility is more economical than scattered ones (Huxsoll and Bolin 1989).

Current Practices and Their Development

There are marked differences in the structure and physiology among tropical fruits. Thus, the minimal processing methods for the seven fruits already mentioned are quite different, as detailed in the following sections.

Durian (*Durio zibethinus* Murr.)

Durian fruits are quite large, usually 2–4 kg in weight depending on cultivars, and are covered with numerous sharp spines. Thailand is the biggest producer and exporter of durian fruit. Chanee and Monthong are the two most popular cultivars. The pulp weight including seed varies between 30–50% of the total fruit weight. They can be very expensive at US$4–5/kg early in the season. Because of this high price, a large percentages of immature fruit was harvested. Consequently, repeated complaints were heard from both local and foreign customers. There are many maturity indices of durian but using a single index is not enough. Even experts must use a combination of indices to determine the maturity correctly. They also make mistakes particularly early in the season. Minimally processed durian looks very promising during this period.

As mentioned before, to open durian fruit is not an easy task. However, once harvested, the fruit will finally dehisce by itself At this dehiscence stage, durian pulp has already become very soft, which is not attractive to Thai consumers. They prefer durian in which the pulp is still relatively firm. At this stage the fruit is not easily opened or dehusked, since the separation zone on each locule has not been well developed. Durian must be opened with a knife, using considerable force. Consumers in Thailand prefer to ask retailers to open the fruit for them. In supermarkets, durian pulp is sold prepackaged on cling-wrapped styrofoam trays.

Praditduang (1986) reported that durian pulp could be

stored at 4°C for up to 40 days. Storage of vacuum–packed durian, however, was not successful since the bag expanded due to the production of gases from the pulp. Booncherm (1990) reported that the pulp could be kept for up to 8 weeks, and that ripening continued without chilling injury except for the appearance of a reddish patch on the funiculus tissue. Whole durian fruit however, showed visible chilling injury symptoms in less than a week at 5°C. These were discoloration of the husk, black colour groove between spines, and red patches on the inner white wall of the husk. In addition, the pulp never ripened.

Booncherm and Siriphanich (1991) demonstrated that the ripening processes of the pulp and husk are separate (Fig. 1). Respiration and ethylene production of the pulp were very low, about $^1/_5$ to $^1/_{100}$ of the husk. However, the climacteric peak of respiration and ethylene production was reached first in the pulp, about 2–3 days earlier than the husk. Presumably, the ripening process initiated first in the pulp induced the ripening of the husk. Chaiprasart (1993) confirmed this finding by showing that the activity of ACC synthase was initiated first in the pulp. The climacteric peak in the husk, however, coincided with its dehiscence. Sriyook (1990) showed that the dehiscence process of durian fruit depends on both water loss and the production of ethylene. Ethylene, however, appeared to be more important for the fruit to dehisce. The ripening process of durian pulp removed from the fruit appeared to proceed more slowly than in intact fruit (Booncherm and Siriphanich 1991). This phenomenon may be due to the low ethylene level in the pulp. Hence, the continued presence of ethylene may be necessary for the ripening process of durian to continue.

Dehiscence could be delayed by application of a gibberellic acid spray. With this treatment, the durian husk remained green, but other ripening processes of the pulp were not affected (Siriathwat 1989). On the other hand, attempts to enhance dehiscence without advancing pulp ripening have not been successful.

The removal of pulp from the husk of fully ripe durian is not difficult since the dehiscence zone of the husk is already weakened and the pulp has begun to separate

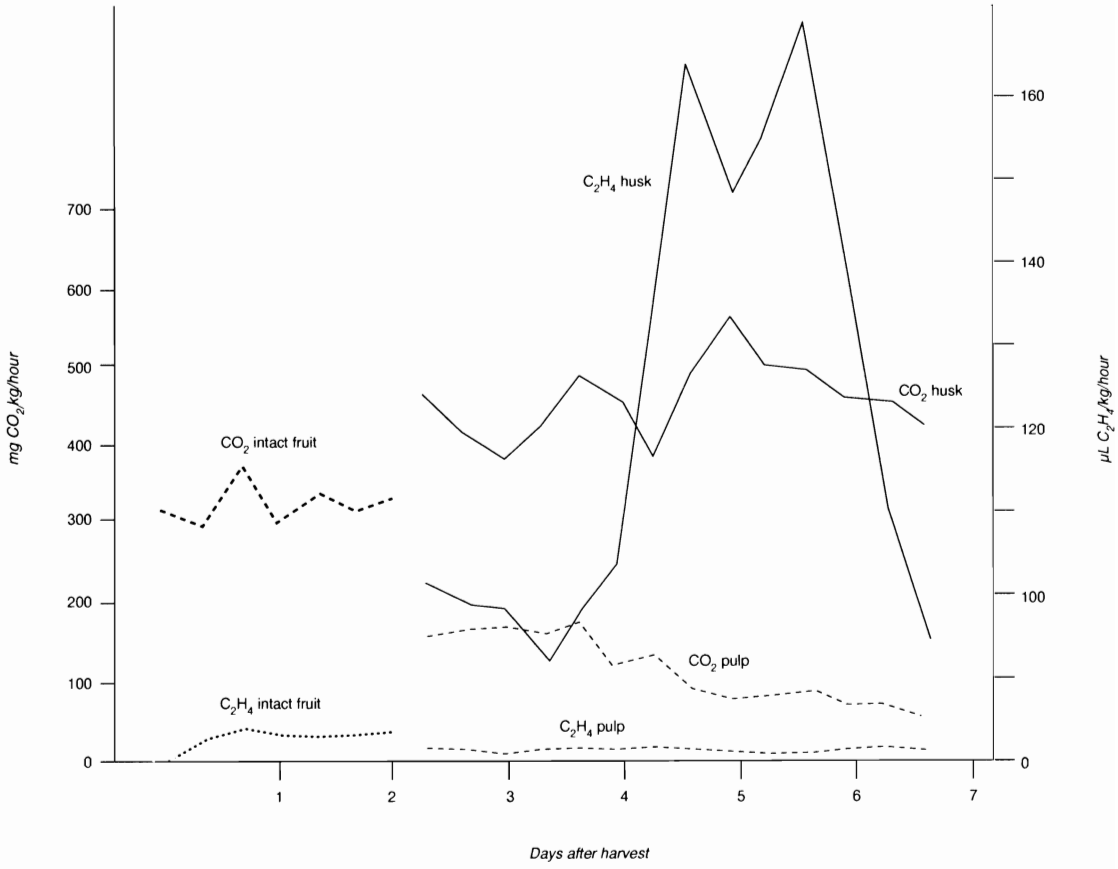

Figure 1. Respiration and ethylene production of Chanee durian (Booncherm and Siriphanich 1991)

from the fruit axis. The surface of the pulp is covered with epidermal cells and cuticle. Hence, attack by microorganisms is not normally a problem unless it is damaged. However, with the less–ripe durian which Thais prefer, the removal of the pulp might damage the pulp leaving it susceptible to microbial attack. The funiculus tissue that was once connecting the pulp and the fruit axis is another region prone to microbial attack. During storage, both mould and bacteria have been found in this region and the wounded surface (Boon-cherm 1990). The use of 10% CO_2 atmosphere balanced with air was found to inhibit fungal growth for a week at room temperature.

Jackfruit (*Artocarpus heterophyllus* Lank)

Jackfruit is the biggest of all fruits, weighing 5–20 kg or more. The surface is covered by small protuberances. The fruit is an aggregate fruit with numerous fruitlets each containing one seed. The pulp of each fruitlet is the perianth, covered with epidermal cells and cuticle, having waxy appearance. For eating the fruit must be divided into small pieces, or individual fruitlets extracted from the centre core (receptacle) and other surrounding tissue. Each fruitlet is then cut longitudinally to remove the seed. The process is quite unpleasant, since the fruit is full of gummy latex that sticks to the hands, and stains clothes. To facilitate the procedure, hands are rubbed with vegetable oil before dealing with the fruit. Retailers who prepare jackfruit pulp for sale usually produce cleaner jackfruit pulp with fewer defects than can most customers, making it more popular for consumers to buy minimally processed jackfruit, at least in urban areas (Fig. 2).

At room temperature, jackfruit pulp lasts only a day or two. Ploymerusmee (1990) reported that jackfruit pulp could be stored for 6 days at 1°C, and up to 9 days at 5°C. Later on, the pulp was dull in colour, and the tissue along the cut edge became translucent. However, Tonnanonta (1992) was able to store jackfruit pulp for up to 16 days at 1°C and 14 days at 5°C. In both cases, the fruit pulp was packed in cling–wrapped styrofoam trays. The discrepancies between their results may be the result of differences in cultivar and maturity of the jackfruit used in the experiments. The ability to prepare clean and less injured jackfruit pulp would also affect the shelf life. Singh and Mathur (1954), however, reported that whole jackfruit might be stored at about 12°C for 3–6 weeks.

In an attempt to extend the storage life of jackfruit pulp, Ploymerusmee (1990) also studied the storage of the pulp without removing the seed. The pulp with seed lasted for up to 12 days while the seeded one lasted only 9 days. However, the reduction in soluble solids content of the pulp with seed was more rapid than that in the seeded pulp. The colour of the pulp with seed was also paler than the pulp without seed. It appeared that there might be a translocation of nutrients from the pulp into the seed.

Figure 2. Preparing jackfruit pulp for sale at a street stall in Bangkok

Mangosteen (*Garcinia mangostana* L.)

The weight of mangosteen fruit is in the range 60–200 g. When ripe, it is easily cut open along the equator of the fruit revealing the white puffy pulp. Although the pulp weight is only about 30% of the whole fruit, there is no reason for this fruit to be minimally processed. Besides, the pulp can easily turn brown if exposed to the air, particularly if damaged.

Harvesting index of mangosteen is based on skin colour change, which normally progresses from green to pink, red, purple, and finally black. Harvesting is usually done from pink (some red patch on the green surface) through to the red colour stage (Tongdee and Suwanagul 1989). The fruit is edible from the purple stage onward. Immature mangosteens having few red patches on the skin are sometimes harvested. They ripen slowly and are sorted out. These fruits, together with defective fruits such as those having insect scar, can be minimally processed, before they turn red, into another product called mangkhut–cut (in Thai, mangosteen = mangkhut). This product is exclusively produced in Nakhon Sithammarat province in southern Thailand. The peel at the top and bottom of the fruit is cut out, but the pulp is not exposed.

The fruit is then soaked in 1% salt together with 1% alum (aluminium potassium sulfate) solution for about half an hour. The peel is then removed by knife and left in the solution before latex and other defects are removed, also with a knife. After cleaning, 3–4 fruits are held together by a wooden stick and are ready to be sold (Fig. 3). With the above procedure, mangosteen pulp remains white for about 5 hours, after which the colour becomes dull. The taste of this mangosteen is less sweet and less acidic than the normal ripe fruit. However, the texture is firm and crisp. Too much salt and alum during the preparation causes pulp discoloration, while with too little salt fruit cannot retain their firm and crisp texture for long.

Figure 3. Peeled and unripe mangosteen for sale in Nakhon Sithammarat, Thailand

Papaya (*Carica papaya* L.)

Papaya is a tropical fruit that is quite well known among people in other parts of the world. Hawaiian papaya dominates the international market, owing to their small size of about 500 g. In Southeast Asia, however, papayas normally weigh more than 2 kg and may be up to 10 kg It is popular as the fruit served in restaurants, along with pineapple. They are peeled, deseeded, then cut into small pieces. Unlike durian, jackfruit, mangosteen, and pummelo, minimally processed papaya is covered with damaged tissue. Unlike the other fruits there is no protection from epidermal cells. In addition, because of its soft texture, it is easily desiccated and becomes unattractive in a short time. The use of clingwrap reduces its shriveled look to some extent. An edible coating may be useful to minimise this problem.

Powrie et al. (1990) patented a preservation procedure for cut and segmented fruit pieces. They claimed to store papaya pieces in modified atmosphere packaging at 1°C for up to 16 weeks (Table 1), with little loss in taste and texture. The packaging was a high gas barrier; polyethylene/tie/ethylene vinyl alcohol/tie/polyethylene plastic laminated pouches (DuPont LP 920™). To achieve the exceptionally long storage period, papaya was cut into pieces weighing 10–25 g and dipped in 5% citric acid solution. The package was flushed with 15–20% oxygen and 3% helium balanced with nitrogen before sealing. The ratio of gas volume to fruit–piece volume was about 1:4. In addition it must be cold shocked to 1°C as soon as possible.

Pineapple [*Ananas comosus* (L.) Murr.]

Pineapple is very well known around the world, due to its availability in the form of canned pineapple, which retain aroma and flavour close to the fresh fruit. Fresh pineapple, however, is not as popular as canned pineapple. Only 5% of production is for export as fresh pineapple, due to the fragile nature of its flesh. Smooth cayenne is the most exported cultivar (Py et al. 1987). Pineapple suffers from chilling injury at its 8–12°C shipping temperature. The internal browning symptom develops in about 1–4 weeks, depending on cultivar and temperature during the growing season. Coating the fruit with waxes reduces the symptom to some extent (Paull and Rohrbach 1985). At higher transport temperatures, pineapples cannot be held longer than 2 weeks.

Pineapple is usually sold intact including the crown, but slices or segments are not uncommon. Powrie et al. (1990) claimed to store pineapple pieces for up to 10 weeks (Table 1) in modified atmosphere packaging at 1°C, without chilling injury and no loss in taste and texture. The pineapple was sliced and cut into pieces 6–15g each, packed in DuPont LP 920 plastic pouches, flushed with a gas mixture 15–20% oxygen and 3% argon before sealing, and immediately cooled to 1°C. The ratio of gas volume to fruitpieces volume was about 1:3.3.

Table 1. Storage life of sliced fruit pieces claimed by Powrie et al. 1990.

Fruit	Sliced fruit MAP at 1°C (weeks)	Whole fruit cold storage[a] (weeks)
Mango	12	2–3
Pineapple	10	4–5
Papaya	16	1–3
Apricot	10	2
Melon	12	3–4
Grapefruit	16	4–6
Tangerine	8	2–4
Apple	8	–

[a] Stored at an optimum refrigeration temperature for the specific fruit. Mango, pineapple, papaya, grapefruit and tangerine at 5–9°C, the others at 0–4°C.

Iversen et al. (1989) studied the metabolism of cut pineapple, using a microcalorimeter. The measurement

of heat production under different storage conditions revealed that the metabolism of cut pineapple was initially low. After a lag period, the heat production increased to reach a peak and then declined The lag period and the height of the peak depended on the size, the degree of wounding (Fig. 4a), and the atmosphere surrounding pineapple pieces. The increase in heat production was related to the development of undesirable odour and loss of colour. However, with the application of metabolic inhibitors and antibiotic chemicals, it was shown that the spoilage of cut pineapple was not due to the fruit itself. Microbial activity appeared to be the predominant factor causing spoilage (Fig. 4b).

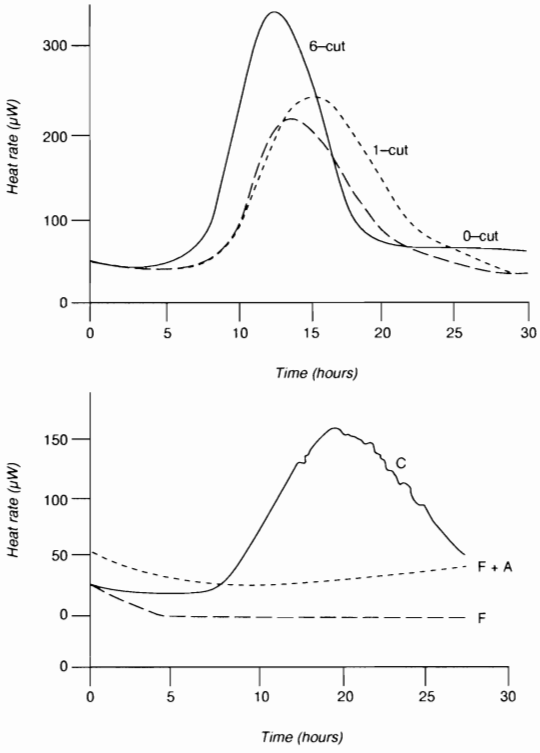

Figure 4. (a) Effects of tissue damage on the time course of measured heat rate of stored pineapple sections (Iversen et al. 1989); (b) Effects of inhibition of fungal growth on metabolic heat rate of stored pineapple sections: C = control, F = fungicide, A = antibiotic (Iversen et al. 1989)

Pummelo [*Citrus maxima* (Burm.) Merr]

Pummelo is the largest size citrus, weighing 0.5–2 kg. It is available all year round in Thailand but the main season is between August and November. Prices are quite stable all year, due to its long shelf life and year round availability. Even at room temperature, pummelo lasts for about a month. In fact, pummelo fruits are normally not consumed soon after harvest. Instead, they are usually left to 'forget the tree' for about 1–2 weeks before being consumed. This practice increases the soluble solids to acid ratio and thereby improves the taste.

Minimally processed pummelo is quite common. The peel, including the albedo is removed, then the peeled fruit is halved or divided into 2–4 wedges and sold around bus or railway stations. This peeled and segmented pummelo lasts for several days since the segment membrane becomes dry and forms a good protective layer. The exposed juice vesicles are also protected by their own epidermal tissue. In supermarkets the segment membrane is removed, and the pummelo segments are beautifully arranged on stryrofoam trays, covered with cling-wrap, and displayed on refrigerated shelves. These peeled segments are often wounded on their outer side, where juice vesicles were previously connected to the segment membrane. Contamination by airborne fungi such as *Penicillium* and *Aspergillus* is common on this product.

Jamjunya (1988) showed that benzoic acid, para–benzoic acid, and sodium bisulfite could prevent mould growth on pummelo halves for up to 6 days, at room temperature, but off–flavour was detected. At 5°C peeled pummelo wrapped with cling-wrap could be stored without chemical treatment for 2 weeks without mould or loss of taste. An experiment simulating air shipment to Japan was also undertaken (Poomchai 1988). Peeled pummelo were held for 2 days at 5°C then transferred to room temperature for 1 day, back to 5°C for another 2–5 days and returned to room temperature for another day before making quality evaluation. The peeled pummelo remained in good condition with no contamination. Off–flavour, however, increased with storage period (Fig. 5). Storage of pummelo segments at lower temperatures than 5°C should also be possible, since Chiraporn (1990) reported that storage of intact pummelo at 0–2°C for 2 weeks, as a fruit fly disinfestation treatment, did not injure the fruit. Although alcohol content in pummelo juice–sacs increased during the treatment, off–flavour was not detected by the taste panelists.

Currently, pummelo from Southeast Asia cannot be imported into Japan due to fruit fly infestation. If peeled and segmented pummelo could be imported into Japan or other countries which currently impose restrictions, it would open up a large new market. Nevertheless, to ensure high quality, pummelo must be very carefully prepared not to damage the juice–sac membrane. Modified atmosphere packaging must be studied to suppress mould growth and delay deterioration.

Young coconut (*Cocos nucifera* L.)

Coconut drink is very popular in tropical regions, particularly the liquid of young, fragrant coconuts. To

serve the juice with the whole fruit is quite attractive to consumers and tastes better than preserved or refrigerated coconut drinks. However, because of its semi-spherical shape and scars or defects on the fruit surface, the husk is often partially peeled off to make the coconut more attractive and convenient to serve (Fig. 6). After peeling, the remaining husk tissue quickly turns brown. Local retailers use many means to inhibit the browning, including salt solution and lime juice, but most use sodium metabisulfite. Sodium metabisulfite concentrations above 1% effectively inhibit browning, but 2–3% is recommended to get a consistent and long-lasting

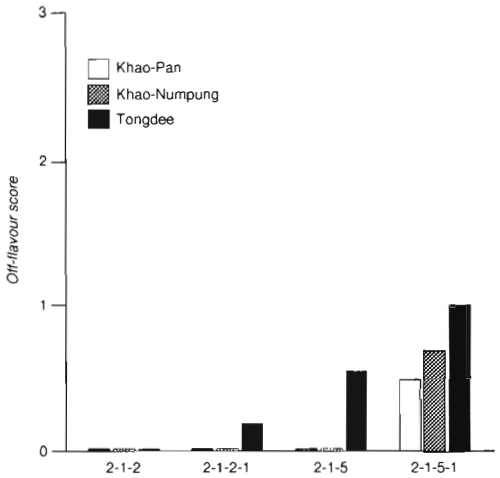

Figure 5. Off-flavour scores in peeled pummelo stored at alternate temperatures between 5°C for 2 or 5 days, and room temperautre for 1 day (Poomchai 1988)

Figure 6. Peeled and well-shaped young coconuts in a Bangkok market

effect (Tongdee et al. 1991). Harvesting of young coconut must be done carefully since even a short drop to the ground causes browning of the internal husk within a day or two. A 50 cm drop on a concrete floor causes browning deep into the shell within one day. Sodium bisulfite cannot eliminate this type of browning.

Peeled coconuts lose their soluble solid content quickly as compared with intact fruit, while titratable acidity increases, result in off–flavours in a few days at room temperature. Low temperatures delay the reduction in soluble solids and the increase in acidity. The recommended shipping temperature for peeled young coconut transported to Hongkong is 4–10°C. Intact fruit stored at 4, 7, or 10°C developed chilling symptoms, as surface discoloration, in 10, 20, and 30 days respectively. With the bisulfite dip, peeled young coconut remained in excellent appearance for up to 4 weeks at 4–10°C, but the quality of the juice was acceptable for only 3 weeks. Wrapping with PVC stretch film is also recommended to prevent desiccation of the peeled surface. When these treatments are combined, peeled young coconuts have 3–4 days additional shelf life at 20°C (Rattanachinnakorn et al. 1990a,b).

Problems Associated with Minimally Processed Fruit, and Possible Solutions

Fruit preparation

All minimally processed fruits are either cut or peeled more or less dependent on the structure of the fruit. Cutting and peeling allow many substances, including phenolic compounds normally compartmentalised within the cell, to come into contact with the atmosphere, resulting in browning of the fruit tissue. Sugar, acid, water, and other substances released from damaged tissue provide a good source of food for microorganisms to grow rapidly. These materials should be rinsed off with clean water; 200–300 ppm chlorine solution is recommended for this purpose. Rinsing water is removed by centrifugation in minimally processed vegetables, but too strong centrifugation will also desiccate the commodity (Bolin et al. 1977; Bolin and Huxsoll 1991b). For the soft fruit tissue, water might be removed using a fan. A conveyer belt is essential for rinsing and drying minimally processed fruits.

Besides the leakage of substances, metabolic processes of minimally processed fruit also change to cope with the new environment (Rolle and Chism 1987). Respiration and ethylene production rate may increase reflecting the defence mechanisms triggered by the wounding. The defence mechanisms include the synthesis of new compounds that serve as antimicrobial agents, the lignification of the cells adjacent to the wound, and the formation of new cell layers to heal the wound. With all these responses to minimal processing,

it is obvious that processing should be done very carefully. The knife used must be sharp. Bolin et al. (1977) and Bolin and Huxsoll (1991b) reported that a dull knife damages more tissue and results in faster deterioration of shredded lettuce. Bruised fruit should also be removed, and not used for minimal processing (Huxsoll and Bolin 1989)

To prevent browning reaction, sulfites have been used in the past; e.g. in apple (Ponting et al. 1972). Ascorbic acid can also be used together with sodium bisulfite with very satisfactory results on apple slices, reducing the need for sulfites by as much as 90% (Borenstein 1987). However, use of sulfite for this purpose is no longer permitted at least in the USA (Anon. 1986). The use of alternatives has been attempted. Ascorbic acid-2-phosphate was reported to be effective in preventing browning of peeled potato and apple (Sapers et al. 1989; Sapers and Miller 1992). It may also prove effective with minimally processed fruits.

Lignification of wounded tissue might cause customer rejection. For example, cut carrot sticks developed a whitish appearance due to lignin formation on their peeled surface, after a few days in storage. A 30 second dip with 2% citric acid retarded the formation of the material without flavour changes (Bolin and Huxsoll 1991a).

To prevent microbial growth on the surface of minimally processed fruits, a combination of temperature and atmospheric manipulation and chemical application are needed. Temperature should be kept as low as possible even before processing. The atmosphere surrounding the tissue should have low oxygen to inhibit growth of aerobic microbes, but anaerobic organisms still survive. High carbon dioxide and carbon monoxide is used in the shipment of strawberry and shredded lettuce to retard the growth of microorganism. However, the foremost step in preventing contamination is that the fruit must be cleaned before being processed. Food additives such as benzoate and sorbate have been attempted with limited success (Robinson and Hill 1959; Poomchai 1988; Heaton et al. 1969)

Fruits of pH lower than 4.6 are quite free from bacteria even though acidgrowing microorganism such as fungi could still proliferate. Organic acids such as citric acid can be added to the surface of fruits containing low acid by dipping in the acid solution for a few minutes to reduce the pH of the surface tissue (Powrie et al. 1990; Juliot et al. 1989). Other non–thermal processes to control microorganisms are being developed in various laboratories (Mertens and Knorr 1992). Although none is applicable at the present time, intense light pulses (UV + infrared) show promise.

Packaging

Minimally processed fruits must be carefully protected since their natural protection has been removed. It is common practice for minimally processed products to be packaged in plastic bags, on cling-wrapped styrofoam trays or in clear plastic baskets with lids so that the product can be displayed as well as stored or transported. One very important step before packaging (McGlasson 1992) is that the produce must be cooled before being packaged, to avoid condensation underneath the plastic overwrapping.

Selection of plastic for minimally processed fruit is very important, since the package will create specific atmospheres around the produce. It is generally accepted that the packaging material should provide enough gas exchange to minimise aerobic respiration and avoid anaerobic respiration. Under this condition, fruit tissues are kept at minimum metabolic activity without the development of off–flavour. (Brody 1992; McGlasson 1992). The anaerobic compensation point of minimally processed fruit should be determined so that the selection of plastic for packaging is made easier. Leshuk and Salveit (1990) describe a rapid method to determine the anaerobic compensation point of plant tissue. PVC plastic film is usually suitable for this purpose, but also allows relatively easy passage of water vapour. Polyethylene film is not suitable because of its low gas and water vapour permeability. However, polyethylene film can also be perforated to provide the required gas exchange. Polyethylene film can also be manufactured from a mixture of polyethylene and 6–18% ethylene vinyl acetate to provide relatively high gas but low water vapour permeability (Barmore 1987). However, one must keep in mind that there is no plastic that can keep pace, in terms of gas exchange properties, with the changing metabolic condition of the produce inside (McGlasson 1992). In addition, commercial packaging almost always contains gaps or holes especially at the sealing edge. These allow gas exchanges that may be more significant than gas permeation through the plastic itself (Brody 1992).

Plastic film could also be impregnated with chemicals such as ethylene absorbent and fungicide that help lengthen storage life of fruits and vegetables. Much attention has focused on improving the properties of plastics to lengthen storage life but little attention has been paid to the possible contamination of products by plastics. The adjuvant, the adhesive or even the polymer itself could contaminate the produce directly or by reactions between the plastic polymer or its components and substances from fruit tissues (Ronk et al. 1989).

Powrie et al. (1990) patented a procedure to preserve cut and segmented fresh fruit pieces. Their invention used plastic pouches with very low gas and water vapour permeability. Fresh fruits were prepared and packaged in these plastic pouches then flushed with gas containing 10–50% oxygen, a few percentages of inert gases and the rest nitrogen. The pouches were sealed

and quickly cooled to 1°C. Under these conditions the inventors claim that the CO_2 build up from aerobic respiration at the beginning would prevent anaerobic respiration. The cold shock also helped induce mechanisms against tissue deterioration. As a result, fresh fruit pieces could be stored up to 4 months with little loss in aroma and flavour, and no off–flavours and microbial growth detectable. However, no scientific evidence was given to support their claim. In addition, their technique may not reach commercial practice, since temperature fluctuations during transportation and distribution are quite high and may change all the conditions suitable for storage of fruit pieces. Hence, shelf life may be very limited.

Storage condition

Temperature is the most important factor governing the storage life of fruits. The lowest temperature that will not damage fruit tissue should be employed. For tropical fruit, minimum temperatures are 10–15°C, below which chilling injury symptoms usually develop. However, it has been demonstrated on many occasions that peeled fruit can tolerate lower temperatures. For example, Praditduang (1986) and Booncherm and Siriphanich (1991) reported that durian pulp could be stored for 6–8 weeks at 4–5°C while intact durian developed chilling symptoms in a few days below 15°C. Powrie et al. (1990) claimed that fresh pieces of mango, pineapple, papaya, and tangerine could be store at 1°C with their technique for up to 4 months while intact fruits lasted only a few weeks. The reason that peeled tissues tolerated lower temperatures may have been because they were usually already at the fully ripe stage, while the intact fruit might be mature but not yet ripe. Ripe fruit has been known to tolerate lower temperature than unripe fruit since the work by Kosiyachinda and Young (1976). The peel of fruits might also be naturally more susceptible to chilling injury than the pulp. The difference in atmospheric composition around the pulp tissue may also influence chilling susceptibility.

Nevertheless, most of the studies on minimally processed fruit have been made at a laboratory scale and rarely under simulated commercial conditions. In the real world circumstances are quite different. Fruit obtained is not so fresh, clean or uniform as that used in the laboratory. Time for preparation might take longer. Temperature fluctuations will be much higher, particularly at the end of the marketing chain where handlers are concerned more with cost cutting than with keeping fruits at optimum temperatures. Hence, simulation studies must be undertaken.

Health hazards

There have been reports of illness or even death due to, or associated with, the consumption of minimally processed fruit and vegetables. An outbreak of shigellosis in Texas involving 347 people was traced to the consumption of shredded lettuce contaminated with *Shigella sonnei* probably transmitted from a food hander (Davis et al. 1988). Another incident, due to surface contamination of melon by *Salmonella chester* resulted in two deaths (Ries et al. 1990). After the investigation, the US–FDA instructed retailers to wash all melons with chlorinated water before cutting, to keep the cut melon below 45°F (7°C), and not to display for more than 2 hours after cutting (Madden 1992).

These tragedies were the result of postharvest technology taking the storage period of fruit and vegetables beyond their normal shelf lives. Under optimum storage conditions, plant pathogens which normally serve as organoleptic warnings to the consumer were suppressed or eliminated. This condition allowed uncommon microorganisms including human pathogens to proliferate and produce toxins. The microorganisms of concern included *Salmonella, Clostridium, Listeria,* and *Shigella* as well as a virus and a parasite. The appearance of *Salmonella* has been reported in cantaloupe and tomato, *Clostridium* in tomato (but not found to be health hazardous), and *Listeria* in tomato, asparagus and cabbage (Brackett 1987; Doyle 1990; Hotchkiss et al. 1992; Hotchkiss and Banco 1992; Saguy 1992).

Since bacteria usually could not grow at pHs below 4.6, it seems that fruits with pH lower than 4.6 are safe from contamination by human pathogen. However, it must be pointed out that, after any rinsing, the pH of the cut surface might be higher than 4.6 because the acidic solution has been washed out. Pathogenic bacteria may survive on this surface. There have been reports that *Clostridium botulinum* could survive on intact but not on chopped tomato (ph below 4.5); and that *Listeria monocytogenes* could survive on both intact and chopped tomato (Hotchkiss et al. 1992). However, they pose no danger to the consumer since tomato is not a good substrate for them. Their population remained low and no toxin was found (Beuchat and Brackett 1991). Of the minimally processed tropical fruits discussed in this paper, durian, papaya and jackfruit have pHs above 4.6 (Table 2). Their preparation must thus be exceptionally clean to prevent contamination by the aforementioned pathogens. Mangostoeen, pineapple, and pummelo are relatively safe since their pHs are about 3. Young coco-

Table 2. The pH of some tropical fruits.

Durian	6.7
Jackfruit	4.6–5.2
Mangosteen	3.0–3.2
Pineapple	3.5–4.0
Papaya	5.3
Pummelo	3.7–3.8

nut has its hard shell to serve as a natural protection. To protect the consumer from illness due to the consumption of contaminated produce, Hazard Analysis and Critical Control Point (HACCP) procedures must be adopted for minimal processing of tropical fruit. All steps in the preparation should be outlined, critically evaluated to find critical points at which contamination might occur, and changes made to avoid contamination implemented in routine procedures (Corlett 1989). However, one must be aware that temperature abuse is common and can jeopardise all efforts to produce safe and sound minimally processed fruits.

Concluding remarks

Fruits are minimally processed in response to the consumer demand for convenience foods. The need for tropical fruits to be minimally processed is greater than subtropical or temperate fruits because of their large size, difficulty in peeling, and other factors. Minimally processed tropical fruit could become an important sector in the fruit industry in the future. Little research and development has been done in this field. Basic information on the physiology of minimally processed tropical fruit is available only for durian and pineapple. This does indicate however, that minimally processed fruits behave differently from intact fruits. Much has yet to be learnt. Preparatory techniques also need improvement to minimise injury and to avoid contamination. Packaging and storage conditions need to be detirmined for each commodity, in order to achieve highest quality and longest shelf life. The issue of safety of minimally processed fruit must be taken seriously since even a minor mistake could lead to disaster and the demise of an emerging industry.

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Harvesting, Processing, and Transportation—Session Summary

Chairman: Mr Abdullah Hassan, MARDI, Malaysia
Rapporteur: Dr Daryl Joyce, CSIRO, Australia

THIS session commenced, appropriately, with an overview on the subject of when to harvest. Dr Amos Blumenfeld pointed out that harvesting at the correct maturity can determine whether the grower gains or loses financially. In this regard, a market-driven approach to the determination of optimum harvest maturity was suggested. Key determinants of price for, or more specifically income from, any particular crop should be identified in line with this objective.

Mr Clive Murray then considered packhouse operations with a view to increasing returns. It was suggested that four important objectives are to:

1. increase the price;
2. decrease the cost;
3. increase demand; and
4. improve handling skills and systems for the product.

The need to tailor packhouse operations for specific products, and the benefits associated with mechanisation were discussed.

With regard to handling systems, Dr Connie Lizada considered those appropriate to the region. Important criteria include:

1. does it work?
2. does it pay? and
3. is it acceptable?

The importance of support infrastructure, relevant policy, and market information was promoted. It was concluded that improved fruit-handling systems must be developed in collaboration with those groups with vested interests, including growers, handlers, and traders.

In furthering the plea for better handling of harvested horticultural produce, Dr David Hilton described various types of physical injuries that commodities may suffer. Modern methods for monitoring physical injury were exampled (for instance, the instrumented sphere), and means for minimising such injuries were presented (for instance, air-bag truck suspension). An case was made for integration of concern about physical injury into total quality management (TQM) systems for the various commodities.

Finally in this session, Dr Jingtair Siriphanich described many advantages of minimal processing for fruits. It was suggested that rapid growth in this aspect of postharvest horticulture is inevitable. Examples were given of minimal processing of durian, jackfruit, and pomello, to name a few. In conclusion, Dr Jingtair pointed out that care has to be exercised in the development of minimal processing in order to avoid problems associated with wounding, desiccation, microbial breakdown, and the promotion of ripening and senescence.

This was a comprehensive session, and the topics were well presented and thought provoking.

Postharvest Diseases and Disorders

Control of Postharvest Diseases of Tropical Fruits: Challenges for the 21st Century

Greg I. Johnson* and Somsiri Sangchote†

Abstract

The fungal pathogens that attack tropical fruit appear to be non-selective in their choice of host. As a consequence, basic information about the biology and control of tropical fruit pathogens may be broadly applicable to a range of commodities. However, all the pathogens do not cause serious losses in all the fruit. Inter- and intra-generic differences in susceptibility of fruit to the major pathogens depend upon a range of host defences, as well as the availability of inoculum and ecological niche requirements. Definition of these factors is necessary for successful postharvest disease control.

The challenges for the 21st century are to increase storage life and extend the period of freedom-from-disease beyond the stage of optimum eating quality. Researchers on tropical fruits face greater obstacles than their colleagues working on temperate fruit. There are fewer of them, working in an information vacuum, with much greater evolutionary gaps between the existing and the desired fruit attributes, such as disease resistance and length of storage life. Opportunities to reduce disease losses and extend storage life need to be exploited to the full as they accrue from increasing knowledge of fruit and pathogen biology, from harnessing the benefits of molecular biology, and from improving handling, storage, and transportation technology.

FRUITS are designed by nature to nurture and protect the developing seed. Fruits have evolved effective mechanisms to prevent or restrict pathogen invasion and/or disease development during seed ontogeny. Once the seeds are mature the fruits may aid in seed dispersal by ripening, changing their appearance, chemical composition, and structure to become more attractive and palatable to seed dispersers. In temperate fruits, the evolution of specific secondary chemical patterns during ripening could have resulted from the need to provide enticing, nutritious, and non-toxic pulp for dispersers, while discouraging non-disperser fructivores, including seed predators and microorganisms that could affect seed viability (Cipollini and Stiles 1992). Fruit morphology could also reflect this need.

Similar selection criteria would apply in the evolution of tropical fruit species. However, an ability to survive cold (freezing) winters would not. Unlike seeds of temperate fruit which may overwinter before emerging, maturation of many tropical fruits coincides with the rainy season so that their seeds can disperse, germinate, and grow into seedlings before the onset of the dry season. For germination and establishment, the mature seeds need to be liberated from encasing flesh quickly. The rapid ripening and senescence of tropical fruits are a reflection of the need to quickly transform unpalatable, impenetrable, germination-inhibiting tissue into palatable, soft, germination-encouraging tissue. The fructivores which consume flesh, leaving seeds intact and viable, facilitate seed liberation and dispersal. Microorganisms that attack flesh but not seeds also aid seed release and could also discourage seed predators (Wicklaw 1988; Borowicz 1988; Buchholz and Levey 1990). The spectra of fungi that attack temperate and tropical fruits respectively (e.g. *Botrytis* and *Monilinia* vs. *Colletotrichum* and *Botryosphaeria*) could reflect the influences of contrasting climates on dispersal and survival strategies of the respective hosts, fructivores, and pathogens in the two regions.

A balance frequently evolves which allows seed development and dispersal and regulates sustenance of fructivores and microorganisms. For the human fructivore, the balance requires adjustment, favouring fruit production and human consumption over (i) seed production, (ii) fruit consumption and dispersal by other fructivores, and (iii) the provision of substrates for decay.

Over the last two centuries, this balance has been shifted by selective plant breeding, improvements in

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agronomic practices, handling and marketing technologies, and the introduction of pre- and postharvest disease and insect control strategies. Regional freedom from pests as a result of quarantine isolation has also eliminated the need for specific control measures against the excluded pests in the pest-free region.

Human involvement in the selection from primitive ancestors of the fruits that we consume today would have been to favour thick flesh, thin rind, small seeds, low levels of unpleasant tasting chemicals, early bearing, high yields, and good taste, and not necessarily disease resistance. Decayed fruit would be discarded and the seed dispersed, while healthy fruit, and possibly the seed, consumed. Early selection for disease resistance could have occurred by favouring palatability at the mature-green stage, before pathogen defence mechanisms broke down, rather than extension of defence mechanism activity past the full-ripe stage.

Steps in the development of current disease control recommendations have included:

- determination and documentation of the microorganisms involved and the environmental and host factors that facilitate development and spread of fruit pathogens;
- the introduction of field management practices and fungicide treatments and postharvest disinfectant, fungicide and heat treatments to eradicate or prevent infections; and
- the utilisation of sturdy packaging, swift transportation and refrigerated storage to maximise fruit vitality and temporal disease resistance.

Modern marketing of fruit has arisen as a consequence of the improvements in packaging, transportation, storage, and disease control methods. In some cases the 'capture' of consumers has been achieved and maintained by the implementation of quality Assurance Programs. What is the consumer conception of Quality? Consumers rate fruit quality in terms of appearance, flavour, texture, durability, and increasingly, freedom from chemicals.

The Challenge

In this last decade of the twentieth century we are faced with the challenge of increasing the storage life of fruit to extend export prospects and satisfy the demands of 'once-a-week-shoppers'. At the same time, socio-economic pressures and the emergence of fungicide-resistant strains of pathogens are reducing opportunities to devise fungicide-based control strategies. There is an urgent need to to develop alternatives to fungicides that do not compromise community expectations of fruit quality. This paper discusses some of the options.

While the tropics produce a remarkable diversity of fruit, relatively few (those that store and transport easily) have become widely known by consumers living in temperate climates. Until recently the 'orphan' commodities, those that don't store and transport well, have not received the attention they deserve from exporters, importers, and scientists (Persley 1989). Disease, together with rapid ripening, are the major limiting factors to successful marketing of tropical fruit to temperate regions. Losses may occur in spite of the use of cool-chain handling and provision of adequate transportation systems (Cappellini and Ceponis 1984).

For many fruits, basic information such as the causes of disease losses is poorly documented, and recommendations for effective disease control are inadequate. Postharvest losses in fruit and vegetables from all causes have been estimated at 20–40% in tropical countries, with individual commodity losses in less developed countries ranging from 20% for apples to 40–90% for papaya (Daniels 1990). Unfortunately, data collected at the wholesale market indicates only a portion of total losses. Although disease losses in mangoes in the New York markets over a 14-year period were low, with less than 10% of fruit affected in most consignments (Cappellini and Ceponis 1988b), the data reflect the fact that mangoes are generally marketed mature but unripe. Greater losses may occur in the retail and domestic sectors.

Looking to the future, we need to determine: which postharvest diseases occur on many tropical fruits; how genetically diverse are the species of microorganisms that attack those fruits, and how closely are they related to temperate fruit isolates and others of the same species; and how do the pathogens infect the fruits, what regulates pathogen quiescence, and what factors affect the interplay between fruit, fructosphere microflora, environment, and disease? Accumulation of this knowledge must underpin the development of control measures.

Know Your Enemy

Correct identification of the causal pathogen is the key to published information which can provide the basis of control strategies. Table 1 lists the genera of postharvest pathogens and their tropical and subtropical host families. Of the pathogens listed, the fungi causing anthracnose *(Colletotrichum* spp.) and stem-end rot *(Botryosphaeria* spp. and *Diaporthe* spp. and their anamorphs) are the major causes of disease in most subtropical and tropical fruit, with pineapple *(Ananas comosus* (L.) Merr.), citrus, and durian *(Durio zibethinus* Murr.) being notable exceptions. For the aforementioned fruit, water blister caused by *Thielaviopsis paradoxa* (de Seyn.) Hoehn, green and blue mould caused by *Penicillium* spp., and phytophthora fruit rot caused by *Phytophthora palmivora* (Butler) Butler are the most serious fruit diseases. In addition, transit rot caused by *Rhizopus* spp. and yeasty rot caused by *Geotrichum candidum* Link are sporadically serious on

Table 1. A host list of pathogens of tropical and subtropical fruit.

Pathogen genus (*teleomorph/**anamorph)	Host family
Major fungal pathogens	
• *Alternaria*** Q	• Anacardiaceae , Caricaceae, Cucurbitaceae, Ebonaceae, Lauraceae, Musaceae, Oxalidaceae, Passifloraceae, Rutaceae, Sapindaceae, Solanaceae
• *Botryosphaeria** *Lasiodiplodia*** W/Q *Dothiorella*** Q *Fusicoccum*** Q	• Anacardiaceae , Annonaceae, Bombacaceae, Bromeliaceae, Rosaceae, Caricaceae, Cucurbitaceae, Guttiferae ,Lauraceae, Moraceae, Musaceae, Myrtaceae, Oxalidaceae, Rutaceae, Sapindaceae, Sapotaceae
• *Ceratocystis*/Thielaviopsis*** W	• Bromeliaceae , Cucurbitaceae, Musaceae, Myrtaceae
• *Diaporthe*/Phomopsis***Q	• Anacardaceae , Annonaceae, Caricaceae, Cucurbitaceae, Guttiferae, Lauraceae, Musaceae, Oxalidaceae, Passifloraceae, Punicaceae, Rutaceae, Sapindaceae, Sapotaceae, Solanaceae
• *Geotrichum*** W	• Rutaceae, Sapindaceae, Solanaceae
• *Glomerella*/Colletotrichum***Q	• Anacardiaceae , Annonaceae, Bombacaceae, Caricaceae, Cucurbitaceae, Lauraceae, Moraceae, Musaceae, Myrtaceae, Oxalidaceae, Passifloraceae, Rutaceae, Sapindaceae, Solanaceae
• *Penicillium*** W	• Anacardaceae, Bromeliaceae, Cucurbitaceae, Ebonaceae, Lauraceae, Moraceae, Passifloraceae, Rutaceae, Sapindaceae, Solanaceae
• *Phytophthora* Q/P	• Anacardiaceae, Annonaceae, Bombacaceae, Caricaceae, Cucurbitaceae, Lauraceae, Moraceae, Musaceae,Myrtaceae, Passifloraceae, Punicaceae, Rutaceae, Sapotaceae, Solanaceae
• *Rhizopus* W	• Anacardiaceae, Annonaceae, Bombacaceae, Bromeliaceae, Caricaceae, Cucurbitaceae, Ebonaceae, Lauraceae, Moraceae, Musaceae, Myrtaceae, Passifloraceae, Punicaceae, Rutaceae, Sapindaceae, Solanaceae
• *Botryotinia*/Botrytis*** Q/P	• Anacardiaceae , Cucurbitaceae, Ebonaceae, Moraceae, Musaceae, Myrtaceae, Punicaceae, Solanaceae
Minor fungal pathogens	
• *Asperisporium* P	• Caricaceae
• *Aspergillus*** W	• Anacardiaceae, Bromeliaceae, Caricaceae, Cucurbitaceae, Ebonaceae, Myrtaceae, Punicaceae, Rutaceae, Sapindaceae, Sapotaceae, Solanaceae
• *Cladosporium*** Q	• Caricaceae, Cucurbitaceae, Ebonaceae, Oxalidaceae, Palmae, Passifloraceae
• *Corynespora* P	• Caricaceae
• *Cylindrocladium*** P	• Annonaceae, Myrtaceae
• *Deightoniella* P	• Musaceae
• *Didymella*/Ascochyta*** Q	• Caricaceae, Cucurbitaceae
• *Elsinoe*/Sphaceloma*** P	• Anacardiaceae, Lauraceae, Rutaceae
• *Fusarium*** P/W	• Bromeliaceae, Caricaceae, Cucurbitaceae, Moraceae, Musaceae, Myrtaceae, Passifloraceae, Rutaceae, Solanaceae
• *Gliocephalotrichum* W	• Sapindaceae
• *Guignardia*/Phyllosticta*** P	• Anacardiaceae , Rutaceae, Musaceae, Myrtaceae
• *Macrophomina*** W	• Cucurbitaceae
• *Mucor* W	• Anacardiaceae, Bombacaceae, Cucurbitaceae, Ebonaceae
• *Mycosphaerella** /Cercospora*** P or /Pseudocercospora*** P	• Annonaceae , Caricaceae, Lauraceae, Musaceae, Rutaceae
• *Nigrospora*** W	• Musaceae
• *Peronophythora* W	• Sapindaceae
• *Pestalotiopsis* Q	• Anacardiaceae, Lauraceae, Myrtaceae, Punicaceae, Sapindaceae, Sapotaceae
• *Phoma*** Q	• Caricaceae , Cucurbitaceae, Myrtaceae, Punicaceae, Sapindaceae, Solanaceae
• Powdery mildews P	• Anacardiaceae, Caricaceae

Continued on next page.

Table 1. Cont'd.

Pathogen genus (*teleomorph/**anamorph)	Host family
• *Pythium* W	• Cucurbitaceae, Solanaceae
• *Rhizoctonia*** W	• Cucurbitaceae, Solanaceae
• *Sclerotium*** W	• Bombacaceae, Cucurbitaceae, Myrtaceae, Solanaceae
• *Septoria*** P	• Passifloraceae, Rutaceae
• *Stemphylium*** Q	• Anacardiaceae, Caricaceae, Cucurbitaceae, Solanaceae
• *Thyronectria*/Stilbella*** W	• Lauraceae
• *Trichothecium* W	• Annonaceae, Caricaceae, Cucurbitaceae, Lauraceae, Musaceae, Rutaceae, Solanaceae
• *Verticillium*** Q	• Musaceae
Bacterial pathogens	
• *Enterobacter* W	• Caricaceae
• *Erwinia* W	• Bromeliaceae, Caricaceae, Cucurbitaceae, Lauraceae, Myrtaceae, Solanaceae
• *Pseudomonas* P	• Bromeliaceae, Cucurbitaceae, Lauraceae, Solanaceae
• *Xanthomonas* P	• Anacardiaceae, Cucurbitaceae, Musaceae, Passifloraceae, Rutaceae, Solanaceae

Q = quiescent infection; W = wound infection; P = preharvest symptoms produced. (Simmonds 1966; Cook 1975; Snowdon 1990; Persley 1993)

some fruit. Table 2 lists key references describing the postharvest diseases of some tropical and subtropical fruit and/or the losses they cause, while Table 3 lists key references to the pathogen genera regardless of the host involved. Such information can be extrapolated to develop disease control strategies for less known (researched) fruit.

One deficiency of some published research on tropical fruit has been failure to identify the causes of the 'diseases' which have been assessed. For example, without confirmatory isolations, stem-end anthracnose caused by *Colletotrichum* spp. could be confused or included in ratings with stem-end rot lesions of similar appearance caused by *Lasiodiplodia theobromae* (Pat.) Griff. & Maubl. and *Dothiorella* spp., making it impossible to interpret treatment differences. Johnson and Coates (1993) note that misidentification of pathogens may exacerbate the problem. *L. theobromae* and *Dothiorella* spp. have similar mycelial growth habits, and *L. theobromae* sporulates earlier, and more reliably in culture than *Dothiorella* spp., so that while both genera can be associated with lesions, only the former may be recognised. Molecular based identification procedures and other rapid tests similar to those widely available for bacterial genera would reduce such mistakes (Bailey and Thompson 1992).

For example, lectin cytochemistry may be useful for identification of fungal fruit pathogens. O'Connell *et al.* (1992) concluded that lectin cytochemistry revealed differences in the surface carbohydrate of conidia of *Colletotrichum* spp. that correlated well with differences in morphology, host specificity, and mode of infection, and as such had potential for disease diagnosis. However, they also noted that results could be difficult to interpret.

Molecular biology

Molecular analysis of both the pathogens and the fruit species they attack will provide information on species variability and the genetic basis of infection, pathogenicity, and host resistance. Mills et al. (1992) reported that avocado and papaya isolates of *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. from around the world produced a number of restriction fragment length polymorphisms (RFLPs) when probed with an rDNA clone, while no variation was apparent amongst mango isolates from around the world. Polymerase chain reaction (PCR) amplification of internal transcribed spacer (ITS) and intergenic spacer (IGS) regions of the rDNA genes produced similar results; limited variation amongst mango isolates compared with extensive variation amongst avocado and papaya isolates (Mills et al. 1992). The results may reflect the fact that mycelium of *C. gloeosporioides* was distributed easily along with large-seeded mango (Johnson et al. 1993b) or mango budwood, while simultaneous distribution with papaya and avocado seed did not occur so readily.

Dispersal by water- or air-borne conidial inoculum rather than by seed-borne or budwood-borne hyphae may lead to more rapid genetic divergence in a pathogen. Alahakoon et al. (1992) demonstrated the ease with which a genetic variant within *C. gloeosporioides* isolates (pathogenic on mango) could be obtained using single conidium isolates and another host (tomato). Pathogen diversity could also reflect multiple centres of origin of the avocado and papaya varieties of commerce, and/or their associated strains of *C. gloeosporioides*, as appears to be the case with the pasture legumes, *Stylosanthes* spp., and associated isolates of

Table 2. Diseases of tropical and subtropical fruit: recent reviews or assessments of loss

Host – Genus – Minimum storage temperature[a] for unripe fruit, °C and time	Host family	References
Avocado – *Persea* – 5–12 for 2–4 weeks	Lauraceae	Cappellini and Ceponis 1988b; Snowdon 1990; Persley 1993; Ploetz et al. 1993
Banana – *Musa* – 15 for 2–4 weeks)	Musaceae	Wardlaw 1972; Slabaugh and Grove 1982; Snowdon 1990; Persley 1993
Breadfruit – *Artocarpus* – 13 for 1–3 weeks	Moraceae	Thompson et al. 1974; Snowdon 1990
Carambola – *Averrhoa* – 10 for 3–5 weeks	Oxalidaceae	Johnson et al. 1992; Persley 1993
Cherimoya – *Annona* – 12–20 for 2–3 weeks	Annonaceae	Purss 1953; Persley 1993
Citrus – *Citrus* – varies from 4–14 for 2–12 weeks depending on species (Kader and Arpaia 1992)	Rutaceae	Cook 1975; Ceponis et al. 1986a; Whiteside et al. 1988; Snowdon 1990; Persley 1993
Coconut – *Cocos* – 25 for 1 week; date - *Phoenix* – 0 for 1–2 months	Arecaceae	Cook 1975; Snowdon 1990
Durian – *Durio* – 15 for 2 weeks	Bombacaceae	Lim 1990
Guava – *Psidium* – 7–10 for 2 weeks	Myrtaceae	Lim and Khoo 1990; Snowdon 1990
Jackfruit – *Artocarpus* – 15 for 2 weeks	Moraceae	
Longan – *Euphoria* – 10 for 2 weeks	Sapindaceae	
Lychee – *Litchi* – 5 for 2 weeks	Sapindaceae	Lonsdale 1988; Johnson 1989; Snowdon 1990
Mango – *Mangifera* – 13 for 2 weeks	Anacardiaceae	Lim and Khoo 1985; Prakash and Srivastava 1987; Cappellini and Ceponis 1988b; Johnson 1989; Johnson 1992; Ploetz et al. 1993
Mangosteen – *Garcinia* – 13 for 4 weeks	Guttiferae	Snowdon 1990
Melon – *Cucumis* – 5 for 3 weeks; *Citrullus* – 10–15 for 2–3 weeks	Cucurbitaceae	Ceponis et al. 1986b; Snowdon 1990, 1992; Persley 1993
Papaya – *Carica* – 10–15 for 2–3 weeks	Caricaceae	Alvarez and Nishijima 1987; Cappellini and Ceponis 1988a; Snowdon 1990; Persley 1993
Passionfruit – *Passiflora* – 6–10 for 3–5 weeks	Passifloraceae	Inch 1978; Snowdon 1990; Persley 1993
Pineapple – *Ananas* – 15 for 2–4 weeks	Bromeliaceae	Cappellini and Ceponis 1988b; Snowdon 1990; Persley 1993
Pomegranate – *Punica* – 5 for 3 months	Punicaceae	Snowdon 1990
Rambutan – *Nephelium* – 10 for 2 weeks	Sapindaceae	Visarathanonth and Ilag 1987; Persley 1993
Roseapple, Lillipilli – *Eugenia, Syzgium*	Myrtaceae	
Sapodilla – *Manilkara*	Sapotaceae	Cook 1975; Snowdon 1990

[a] Temperatures listed are a guide only. Also see Kader, these proceedings.

Table 3. Major genera of fungi causing postharvest diseases of tropical and subtropical fruit: Key literature references on taxonomy, genetics, and biology regardless of host(s), and minimum temperature below which fruit isolates are unlikely to cause disease.

Genera of fungi	Minimum temperature (°C) required for disease development[a]	References[b]
Alternaria	– 3	Simmons 1967, 1976; Ellis 1971
Aspergillus	+ 16	Raper and Fennell 1965; Domsch et al. 1980; Pitt and Hocking 1985
Botryosphaeria/	–[c]	Pennycook and Samuels 1985; Hartill 1991
Lasiodiplodia	+ 8	Sutton 1980; Sivanesan 1984
Dothiorella	+ 2	Maas and Uecker 1984
Fusicoccum	+ 2	
Botryotinia	–[c]	
Botrytis	– 2	Jarvis 1977; Coley-Smith et al. 1980
Ceratocystis	–[c]	Hunt 1956; Hoog and Scheffer 1984
Thielaviopsis	+ 5	
Diaporthe/Phomopsis	– 2	Sutton 1980; Uecker 1988
Geotrichum	+ 2	Carmichael 1957; Butler and Petersen 1972; Gueho et al. 1985
Glomerella/Colletotrichum	+ 3–9	Sutton 1980, 1992
Penicillium	– 2	Pitt 1979, 1985
Phytophthora	+ 10	Waterhouse 1963; Newhook et al. 1978; Ho 1981; Gerretson-Cornell 1985.
Rhizopus	0–4	Domsch et al. 1980; Schipper 1984

[a] Sommer (1985), Sommer et al. (1992)
[b] General references: Rossman et al. (1987), Snowdon (1990)
[c] – = not known.

C. gloeosporioides (Manners et al. 1992). The lack of diversity within mango strains could be due as well to vegetative incompatibility between mango and other fruit strains of *C. gloeosporioides*.

Know Where the Foe Comes from and How It Arrives

Development of successful control strategies depends upon determining the form of inoculum, how it is spread and the mode of infection, the times at which infection occurs, the nature of the infection structures formed by the pathogen, and the mechanisms that hosts implement to regulate pathogen invasion.

Many postharvest pathogens establish limited infections on or beneath the cuticle, or within the fruit exocarp or peduncle, pedicel, or floral remnant tissues at any time during fruit development. Invasion frequently remains restricted by host defence mechanisms until after the fruit are harvested, wounded, or begin to ripen. The phenomenon of limited preharvest invasion followed by a period of quiescence that extends until fruit maturation and ripening has been reviewed previously (Swinburne 1983; Jeffries et al. 1990; Prusky and Keen 1993). The time between initial infection and disease symptom appearance is known as the latent or quiescent period (Berger and Bartz 1982; Swinburne 1983).

Table 1 indicates whether fruit pathogens are considered to form preharvest quiescent infections, invade fruit through wounds after harvest, or produce symptoms on fruit before harvest. Table 4 lists the sources of inoculum, and modes of transmission and infection for fruit pathogens. Such information is host specific and can only guide researchers investigating other hosts. Distribution of spores by water or air, and spore germination followed by host infection (with and without appressorium formation) via direct penetration of the cuticle, or entry through stomata, lenticels, wounds, or abscission scar tissue are commonly recognised modes of transmission and infection for fruit pathogens (Kubo and Furusawa 1991). However, other sources of inoculum and modes of infection warrant consideration.

Endophytic colonisation

Johnson et al. (1991, 1992) showed that mango fruit were infected about 6 weeks after flowering by the endophytic colonisation of the inflorescence, peduncle, and pedicels of fruit by *Dothiorella* spp., *Phomopsis mangiferae* Ahmad, and other stem-end rot fungi harboured in stem tissue, whereas earlier colonisation of floral remnants by *Dothiorella* spp. may have favoured fruitlet abortion. They speculated that management procedures which slowed colonisation of the inflorescence and pedicel could reduce the incidence of infected fruit at harvest, and suggested that water stress and low levels of stored carbohydrates could favour colonisation. It is likely that infection of citrus fruit by stem-end rot fungi

Table 4. Sources of inoculum, modes of transmission and infection for postharvest pathogens of tropical and subtropical fruit. (Holliday 1980; Pena and Duncan 1989; Snowdon 1990, Johnson et al. 1992, 1993b).

Pathogen	Form of inoculum	Mode of transmission	Mode of infection
Alternaria	conidia	airborne	direct
Aspergillus	conidia, hyphae	air-borne, soil-borne, water-borne	wound
Botryosphaeria	ascospores	air-borne	direct?
/*Dothiorella*	conidia	water-borne	direct
/*Fusicoccum*	hyphae	hyphal colonisation of inflorescence (endophytic)	internal colonisation of pedicel
		fruit to fruit	contact
		seed-borne hyphae	internal colonisation of stems etc.
Botryotinia	ascospores	air-borne	necrotic tissue
/*Botrytis*	conidia	air-borne	necrotic tissue
		arthropod-borne	colonisation of floral parts
		fruit to fruit	
Diaporthe	ascospores	as for *Botryosphaeria*	as for *Botryosphaeria*
/*Phomopsis*	conidia		
	hyphae		
Geotrichum	conidia	water-borne, soil-borne,	wound, water or soil/debris infiltration
		fruit to fruit	contact
Glomerella	ascospore	air-borne	direct
Colletotrichum	conidia	water-borne	
		arthropod-borne	
		seed-borne hyphae	internal colonisation of stems
Lasiodiplodia	conidia, hyphae	air-borne, water-borne, soil-borne (endophytic?)	wound, colonisation of cut pedicel or floral remnants
Penicillium	conidia, hyphae	air-borne, water-borne, soil-borne	wound, water or soil/debris
		fruit to fruit	infiltration, contact
Phytophthora	zoospores	water-borne	direct,wound
	hyphae	soil-borne, fruit to fruit	
Rhizopus	sporangio-spores	air-borne, water-borne, soil-borne,	wound, water or soil/debris
	hyphae	fruit to fruit, mycelium to fruit	infiltration, contact

occurs in a similar way. Homma et al. (1989) also showed that *Phomopsis citri* Fawcett causing stem-end rot of citrus colonised fruit via the stem and pedicel.

Soil-borne inoculum

Johnson et al. (1993a) reported that mango fruit could also be infected by *Lasiodiplodia theobromae* causing stem-end rot when the fruit were inverted in the soil after harvest to drain sap from the fruit. Soil-borne inoculum is an important source of infection for fruit diseases caused by *Phytophthora*. Following harvest, durian fruit can be infected by soil-borne inoculum of *Phytophthora palmivora* through wounds at the juncture of the spines (Pongpisuta and Sangchote, these proceedings), although insects and snails may also serve as vectors for pathogen on developing fruit (Lim 1990).

Other propagules

Hyphal segments and fragments of colonised host tissue may be important additional sources of inoculum for many pathogens, particularly those which produce melanised hyphae. As well, spores that are generally

distributed in water may also be distributed in air (e.g. as spore tendrils) and other spore forms (ascospores, chlamydospores) may supplement conidial inoculum.

Animal vectors

Animal vectors of pathogens could be an underestimated means of inter-tree and inter-orchard dispersal of tropical fruit pathogens. Pena and Duncan (1989) found conidia of *C. gloeosporioides* on the bodies of vinegar fly *(Drosophila melanogaster* L.) and bees *(Apis mellifera* L.), and speculated that they could be involved in inter-tree spread of inoculum causing postbloom fruit drop of lime *(Citrus latifolia).* Honeybees have been shown to transmit *Monilinia vaccinii-corymbosi* to blueberry flowers (*Vaccinium* spp.) from sporulating lesions that mimicked the UV reflectance patterns of the flowers (Batra 1983; Batra and Batra 1985; Batra 1987), while larvae of the grape berry moth *(Lobesia botrana* Pers.:Fr.) carried viable conidia of *Botrytis cinerea* Pers. to developing grapes in the field (Fermaud and Le Menn 1992), leading to postharvest brown rot and grey mould. Fruit pathogens may also be spread in animal (bird, rodent, mammal) faeces (Pirozynski and Malloch 1988).

Moser et al. (1989) reported that beetle-associated mites were vectors of blue-stain fungi of the ascomycete family Ophiostomataceae (Bridges and Moser 1986) which cause damage to sawn timber and logs. *Botryosphaeria* spp. (and their *Fusicoccum/Dothiorella* spp. anamorphs) and *L. theobromae* which cause stem-end rot diseases of tropical fruit are also blue-stain fungi (family Botryosphaeriaceae) (J. Tierney, personal communication; Shaw 1984).

Ascospores of one blue-stain fungus, *Ophiostoma minus* (Hedgcock) H. & P. Syd., were carried by the mites inside a special spore-carrying structure called a sporotheca (Moser 1985). Mites would be ideal vectors for introducing spores of a fungus into spaces (such as beneath sepals) that would be less accessible to air- or water-borne spores. The role of mites and beetles in the dissemination of stem-end rot and anthracnose pathogens has not been examined. However, Grossenbacher and Duggar (1911) noted that a small beetle, *Psenocerus supernotatus* (Say) Le Conte, occurred in blighted canes of *Rubus vulgare* L. and fed on stromata of *Botryosphaeria ribis* Gross. and Dugg. (syn. *Botryosphaeria dothidea* (Moug.) Ces. et. de Not.). Grossenbacher and Duggar (1911) also considered that the blighted canes were host to the larvae of *P. supernotatus.* In addition, the fungi inhabiting galls on several plant hosts in a mutualistic association with larvae of ambrosia gall midges (family Cecidomyiidae) are probably anamorphs of *Botryosphaeria,* and are transported and inoculated into the host by adult midges (Bissett and Borkent 1988).

Floral infection

McNicol and Williamson (1988) showed that symptomless or quiescent infections of black currant flowers by *B. cinerea* could develop when conidia germinated in the stigmatic fluid (in the absence of free water) and the hyphae spread symptomlessly throughout the style to infect the pericarp and the ovule. Dashwood and Fox (1988) found that symptomless infections of *B. cinerea* developed in the stamens and gynoecia of raspberry flowers and later initiated the development of grey mould in fruit. Infection via floral parts has also been reported for *Monilinia laxa* on plums (Schagbauer and Holz 1990) and *L. theobromae* on citrus fruit (Nadel 1944; Minz 1946). In mangoes, stem-end anthracnose is more difficult to control than side lesions caused by the same pathogen. This could reflect the presence of quiescent infections in floral scar tissue and endophytic infections in the peduncle, but it remains possible that additional fruit infections could arise from spores germinating in the stigmatic fluid during flowering, with hyphae forming quiescent infections at the base of the ovary.

Know Where the Enemy Sleeps

Adhesion

Once the pathogen propagule has arrived on the host, it must remain attached until conditions favour infection (usually free water or high (>95%) humidity). There is no evidence that fungi share a common adhesive compound or common mechanism of adhesion (Nicholson and Epstein 1991). A hemicellulose is involved in adhesion of *Colletotrichum graminicola* (Ces.) Wilson (Lapp and Skoropad 1978) and a protein or glycoprotein is involved in adherence of *Phytophthora palmivora* zoospores (Sing and Bartnicki-Garcia 1975). Hydrophobic binding may be involved in attachment of conidia of *Colletotrichum lindemuthanium* (Sacc. and Magnus) Briosi and Cav. (Young and Kauss 1984). Scientists studying attachment mechanisms of *Actinomyces viscosus,* the cause of gingivitis and root decay and a major component of plaque on human teeth, have found that the enzyme trypsin interferes with the mechanism by which *A. viscosus* attaches to teeth, and they are now evaluating trypsin's use in prevention of plaque formation and tooth decay (Pain 1993). Similar simple solutions could arise from determining adhesion mechanisms for fungal infection structures. Treatments which interfere with the mechanisms by which fungi attach to their host, could prevent or eradicate infections by facilitating the physical removal of propagules or infection structures by water, gravity, and fructifauna.

Germination

Spore germination is the most vulnerable stage in the life cycle of many pathogens. Treatments, environmental variables, or host attributes which interfere with germination can significantly reduce the incidence of postharvest disease. Hoch and Staples (1991) have reviewed several aspects of germination and infection structure formation. Basic research on the process of spore germination and the factors affecting it could reduce the need for post-infection control measures.

Melanisation

In addition to depending upon favourable conditions for infection, inoculum which is dispersed within a tree externally to the host is prone to environmental degradation, interference from other microorganisms, and consumption by fungivores. Melanisation of spores, hyphae, and appressoria provides protection from UV light and may also discourage microbial and fungivore threats (Emmett and Parbery 1975; Kubo and Furusawa 1991). Studies on the role and process of melanisation could yield novel control methods.

Preharvest infection

Coates and Gowanlock (these proceedings) review infection of tropical fruit by *C. gloeosporioides,* and discuss the formation of the symptomless quiescent structures and limited (restricted) lesions under conditions of high inoculum pressure. While great emphasis has been placed on control strategies to eradicate symptomless quiescent structures, there has been less attention to the eradication of visible but arrested lesions which represent a greater control challenge. The threat such lesions represent could be determined by the stage of fruit development at which they are formed, with late-formed arrested lesions more likely to recommence development during fruit ripening. This may be because the extent of periderm formation around the lesion may be greatest when infections are initiated during the fruit growth stage, and least or absent from lesions initiated on mature green fruit, as occurs for infections of apricot fruit by *Monilinia fructicola* (Wint.) Honey (Jenkins and Reinganum 1965; Wade and Cruickshank 1992). *C. gloeosporioides* was reisolated from a greater proportion of avocados inoculated in the field late, as compared with early in their development. (Coates et al. 1993), suggesting that the development of a larger proportion of early infections failed or was limited, possibly in the same way as described for *M. fructicola* on apricot.

Stem-end infection

While Johnson et al. (1992) demonstrated endophytic colonisation of the inflorescence as an important mode of infection for mango fruit by *Dothiorella dominicana,* and Peterson (1978) and Darvas et al. (1987) showed that avocado fruit could be infected by *D. aromatica* before harvest, the form and location of the quiescent infection structures produced were not determined.

In detached fruit studies, colonisation by stem-end rot fungi (*L. theobromae* and *P. citri*) of the peduncle and pedicel of citrus fruit was restricted by wound periderm and the cuticle, and the fungi could not enter fruit until abscission occurred (Brown and Wilson, 1968). Homma and Yamada (1969) reported a similar result from field inoculation studies on citrus. *Phomopsis citri* colonised the inner tissues of pedicels via (i) scars of defoliation, (ii) pedicel wounds and unwounded pedicels, and (iii) bearing shoots and branches, and reached the disk at the stem-end button via the vascular tissue. *P. citri* was then restricted from entering the fruit by an abscission zone barrier (Homma et al. 1989). Postharvest treatment with the growth hormone 2,4-dichlorophenoxyacetic acid (2,4-D) was introduced, to prevent abscission of the button and hence the development of stem-end rot (Weyer 1969; Eckert and Eak 1989). Halos and Divinagracia (1970) found that *L. theobromae* could directly penetrate the cuticle or invade the mango pedicel through wounds on detached mature-green and ripe fruit, with invasion of fruit occurring without any apparent quiescent stage. Whether infection could occur on unharvested fruit was not investigated.

G. Johnson (unpublished data) observed subcuticular colonisation by *D. dominicana* of mango inflorescence and pedicel tissue inoculated before harvest. Vascular colonisation as reported for *P. citri* on citrus (Homma et al. 1989) could occur for *D. dominicana* on mango and other fruit. Colonisation of vascular tissue by this pathogen causing stem cankers (as the teleomorph *Botryosphaeria dothidea)* has been reported in temperate tree studies (McPartland and Schoeneweiss 1984). Elucidation of the mode of infection and form of quiescent structures for any pathogen-host combination reveals when and where control measures should be targeted. Considerable primary research is required to determine the infection events for many tropical fruit/pathogen combinations.

Transmission and infection by the above mentioned mechanisms may be less vulnerable to postharvest fungicide and heat treatments than subcuticular infections originating from air- or water-borne spores. In situations where postharvest disease control treatments are less effective than expected, pathogen modes of transmission and infection may need to be reassessed.

Prevention Is Better Than Cure

Control of postharvest diseases may be achieved by preventing infection, eradicating infection, or delaying

symptom development so that the fruit can be marketed and consumed before disease appears.

Preharvest management

Thompson (these proceedings) discusses fungicides for preharvest control of postharvest diseases of mango, Dodd et al. (1992) reviewed the value of epidemiological studies and spray forecasting based on environmental data for control of anthracnose, while Jeffries and Koomen (1992) and Korsten et al. (these proceedings) have covered the use of biological control agents for control of anthracnose. Mayers and Owen Turner (1989) integrated field management and infection assessment procedures to successfully control black spot caused by *Guignardia citricarpa* Kiely in export citrus for the Japanese market. Selection of growing regions where dry weather coincides with flowering and fruit development can further reduce the need for preharvest control measures. In Israel, preharvest assessment of fruit infection levels has been used to determine the need for postharvest treatments to control alternaria rot of mango caused by *A. alternata* (Prusky et al. 1983), while Prusky et al. (1993) subsequently found that the disease risk could be assessed by monitoring relative humidity during flowering and fruit development. In the long term, global warming effects could disrupt seasonal weather patterns, with increased rainfall occurring in some regions that currently enjoy a dry fruiting season and vice versa, thus increasing or decreasing the need for pre- and postharvest control measures.

Fruit bagging

Fruit bagging (Kitagawa et al. 1992) creates a dry microenvironment in which fruit can develop with comparative freedom from air- and water-borne inocula, free water to facilitate infection, infestation by fruit fly, and damage by fruit-piercing insects (although scale insects and mealybugs can proliferate). Bagging is one option for regulating fruit surface wetness and deposition of inoculum in regions not blessed with dry weather during fruit development. G. Johnson, T. Campbell and A. Cooke (unpublished data) found that enclosure of mango cvs Kensington and Kiett in bags manufactured from paper or Tyvek®, respectively, reduced the incidence and severity of stem-end rot and anthracnose. Conversely, Lim and Razak (1986) reported that fruit bagging was associated with an increase in stylar-end ring rot caused by *Phomopsis psidii* Nag Raj & Ponnappa on guava fruit, in the zone of contact between fruit and bag.

Preharvest effects

Hofman and Smith (these proceedings) discussed the role of preharvest nutrition and other management factors on postharvest quality, and such factors can directly affect the mechanisms of fruit resistance to infection and the ripening-associated decline in fruit regulation of pathogen quiescence. Host vitality may also affect the infection potential of inoculum produced on the host.

Silicon

Bowen et al. (1992) found that soluble silicon sprays inhibited the development of powdery mildews on grasses, and noted that silicon was implicated in disease resistance of sorghum *(Sorghum vulgare* L.) to anthracnose caused by *Colletotrichum graminicola*. Preharvest silicon sprays for control of tropical fruit anthracnose and other diseases should be assessed. The effects of silicon sprays on fruit palatability would also need to be evaluated.

Wound invaders

While many pathogens infect fruit before harvest, some infect fruit via wounds or by direct penetration of the cuticle after harvest (Table 1). Processes that protect wounds from invasion, or promote wound healing, can reduce disease losses caused by wound pathogens. While fruit washing can improve appearance, fruit may become infected by wound pathogens during treatment, especially when recirculated, unfiltered water dips are used. Fruit brushing can cause abrasion wounds that enable the entry of wound pathogens, or induce physiological browning reactions.

Disinfectants and washing

The addition of disinfectants, fungicides, in-line filters, and sterilising systems, and the use of non-recirculating sprays can reduce the risks associated with fruit washing. Sugar and Spotts (1986) demonstrated that sodium lignin sulphonate (a by-product of paper manufacture) used to improve flotation of pears in postharvest treatment lines inhibited spore germination by spores of *B. cinerea, Penicillium expansum* Link. ex Thom., *Mucor piriformis* Fischer, and *Phialophora malorum* (Kidd & Beaum.) McCulloch and, in combination with sodium ortho phenylphenate (SOPP), improved control of decay caused by *P. malorum*, compared with SOPP alone. Flotation salts and other dip additives or dip decontamination procedures could reduce the impact of dip tank water as a source of inoculum for tropical fruit pathogens.

Johnson and Cooke (1989) noted that the time between harvest and disinfection of wounds was critical. Disinfection with sodium hypochlorite controlled yeasty rot on tomato when applied within 3 hours of wound inoculation with *G. candidum*, whereas the treatment failed when applied 6 hours after wound inoculation.

G. Johnson and A. Cooke (unpublished data) have also found that the temperature of the fruit for 24 hours before inoculation affected the susceptibility of winter-grown tomatoes to yeasty rot. Those held at 30°C for 24 hours remained resistant to wound infection by *G. candidum*, while those held at 36°C were susceptible. This result offers an explanation for the prevalence of yeasty rot in summer-grown tomatoes, and its absence in winter-grown crops, and suggests that harvesting in the early morning or at night when the fruit are cooler could reduce losses from this disease. Hershenhorn et al. (1989) found that when lemons were treated at 80°C for 2 minutes, active lesions were produced by avirulent strains of *G. candidum* that produced only dry, limited lesions in unheated lemons. Susceptibility of lemons to *G. candidum* also increased with physiological age, treatment with ethylene, and water potential of the lemon peel (Baudoin and Eckert 1982; Davis and Baudoin 1986).

Packing and coating

Muirhead and Grattidge (1986) reported that wood wool, a by-product of the timber industry, used when packing mangoes, harboured *Rhizopus stolonifer* (Ehrenb. Fr.) Lind which causes transit rot. Elimination of the packaging material controlled the disease. Transit rot is a serious disease of papaya and can also cause losses in sulphur dioxide-fumigated lychees. El Ghaouth et al. (1992) found that chitosan, an ingredient of some fruit waxes, reduced the growth in vitro of *R. stolonifer, C. gloeosporioides, Botrytis cinerea,* and *Alternaria alternata* and suggested that it had potential for post-harvest disease control. Chitosan has elicited phytoalexin production in some hosts (Kendra and Hadwiger 1984; Kendra et al. 1989).

Immunisation

Immunisation, the inoculation of the host with heat-killed or mild strain pathogens to promote the formation of antibodies, has controlled many human and animal pathogens. Kuc (1983; 1987) and Madamanchi and Kuc (1991) have reviewed this approach for the control of plant pathogens, notably tobacco downy mildew caused by *Peronospora hycscyami* De Bary (Tuzun and Kuc 1989). Davis et al. (1988) and Brown and Davis (1992) have explored systemic protection of *Stylosanthes* spp. against *C. gloeosporioides*. Caruso and Kuc (1979) found that systemic resistance induced in cucumbers, muskmelon, and watermelon by foliar inoculation, was transferable to the fruit. In citrus and other commodities, ethylene induces activity in phenyl ammonia-lysase (PAL). PAL catalyses the branch-point step reactions of the shikimic acid pathway, leading to the biosynthesis of phenols, phytoalexins, and lignins which are associated with induced resistance to disease (Kuc 1982).

The concentration of preformed antifungal compounds in fruit may also be increased by challenge treatments. Prusky et al. (1990) found that, in unharvested avocado fruit, the concentration of a preformed antifungal diene was almost doubled for a period of 3 days following inoculation with *C. gloeosporioides*. Induction of resistance to tropical fruit pathogens using avirulent or non-host strains of fruit pathogens deserves further research.

Hypovirulence

Another possible means of preventing fruit infection is to reduce pathogen virulence. Griffin (1986) and Nuss and Koltin (1990) reviewed the prospects for using transmissible hypovirulence to control chestnut blight, a serious disease of American chestnut trees (*Castanea dentata* (Marsh.) Borkh.) caused by *Endothia parasitica* (Murr.) And. & And. A mycovirus was found to be naturally present at sites where isolates of *E. parasitica* were associated with trees recovering from chestnut blight. The hypovirulence was transmitted to virulent strains of *E. parasitica* that were vegetatively compatible (Griffin 1986; Glass and Kuldau 1992). Transmissible hypovirulence could be an effective option for slowing pedicel colonisation by stem-end rot pathogens.

Eradication

Culling

The postharvest impact of diseases that develop on fruit before harvest can be reduced by culling affected fruit in the field, or on the packing line. The incidence of black spot of citrus can be reduced in this way. However, additional infections are quiescent at harvest and symptoms can appear during transportation and marketing (Mayers and Owen-Turner 1989). A combination of control procedures may be required, a reflection of the range of infection and symptom development patterns exhibited by a particular pathogen.

Minimal processing

Siriphanich (these proceedings) reviews minimal processing of tropical fruit, a procedure that eliminates quiescent infections of pathogens in the peel and other non-edible parts, and thus the need to control them. Care must be taken to prevent infection of the processed fruit by wound pathogens such as *Rhizopus* spp. which can quickly destroy fruit flesh. Despite washing, pectolytic enzymes in the juice from decayed fruit can remain active and cause fruit softening after minimal processing or canning. A sodium hydroxide wash inactivates the enzyme (Sommer et al. 1992).

Mycotoxins

The salvage of edible flesh portions from partly decayed or damaged fruit for processing introduces another risk, mycotoxin contamination. Mycotoxin production by some genera of fungi that also cause fruit rots has been documented (e.g. *Penicillium, Alternaria, Aspergillus, Fusarium, Phomopsis),* and the toxins have been associated with processed fruit products such as apple juice (Phillips 1984; Bills et al. 1992). Secondary invasion of fruit products (e.g. fruit pastes) during drying represents an additional risk. Further work is needed to determine the extent of mycotoxin production by fruit pathogens, and to establish protocols for monitoring their presence in processed fruit products.

Systemic fungicides

Despite the implementation of comprehensive protective control measures, some infections establish on fruit, particularly when rain falls before harvest. Some systemic fungicides have a 'kick-back' effect: they can eradicate infections that were initiated one or more days prior to treatment. Their ability to eradicate infections will depend upon the time between infection and application of the fungicide, the location of quiescent infection structures, and the penetration and covering properties of the fungicide formulation. Cuticle thickness will influence fungicide penetration, and treatments which soften or strip fruit cuticle will increase fungicide efficacy. Information on the kick-back effect of a particular fungicide is sometimes available from the manufacturer and may be printed on the product label. Eckert and Ogawa (1985) and Eckert (1990) have reviewed the chemical control of postharvest diseases of subtropical and tropical fruit, and summarise information about effective fungicide–pathogen–fruit combinations. Fungicide choice will also be influenced by whether the product-use is permitted in the target market for the commodity.

Hot benomyl and prochloraz are effective against anthracnose and alternaria rot and the former treatment also controls stem-end rot of mangoes during storage at 13°C (Johnson et al. 1990b; Lonsdale et al. 1991), and either or both of the treatments are also effective on other hosts (cucurbits, lychee, papaya) (Eckert 1990). Imazalil has also been widely evaluated and is effective against anthracnose, while iprodione provides good control of transit rot caused by *Rhizopus* spp. (Eckert 1990). The future prospects for these treatments is uncertain.

Fungicide resistance

In Florida, Spalding (1982) isolated benzimidazole-resistant strains of *Colletotrichum, Lasiodiplodia*, and *Phomopsis* from diseased mangoes, a result of the widespread use of preharvest sprays of benomyl. Benomyl-resistant strains of *Colletotrichum* have been reported also from mangoes in Thailand (Farungsang and Farungsang 1992). In Australia, benomyl sprays have never been recommended for preharvest use on mangoes, a strategy designed to prevent the development of benomyl-resistant strains of *Colletotrichum* spp. The risk of loss of efficacy associated with preharvest application of any of the modern systemic fungicides threatens the long-term viability of that fungicide for postharvest use. Preharvest application of effective postharvest fungicides should be discouraged.

Regulatory constraints

Of greater concern for the continuing availability of postharvest fungicides are the socioeconomic pressures that have persuaded chemical manufacturers to withdraw postharvest registrations for fungicides. The European Parliament has voted to ban totally the postharvest treatment of fruit and vegetables with pesticides within the European Community (E.C.). The ban will come into effect only after it is possible to withdraw pesticides without seriously impeding the marketing of fruits and vegetables in the community. Some members of the European Parliament demanded that E.C. limits on residues apply to imports from non-E.C. countries and to exports from the community (Anon. 1991). In the USA, Du Pont Ltd withdrew all postharvest registrations for benomyl (Vaux, pers. comm. 1989). The decision by Du Pont (USA) has not yet extended to important tropical fruit producing countries, e.g. the banana trade in South America, however the treatment has never been acceptable in some other markets.

One of the problems in achieving registration for postharvest fungicides is the fact that postharvest uses represent small markets. The returns to manufacturers often do not justify the costs of establishing efficacy and taint data, and payment of government charges associated with registration or label extension.

Multiple infections

At harvest, tropical fruit may harbour infections of several pathogens with differing quiescent phases. Control of those with longer quiescent phases (e.g. *A. alternata* on mango [Schiffmann-Nadel et al. 1985; Johnson and Coates 1993]) will be necessary only if long storage is anticipated. A cascade of diseases can develop in tropical fruit, with successive invaders being revealed only when those with shorter quiescent periods are eradicated or absent. Johnson et al. (1990b) found that a prochloraz spray needed to follow a hot benomyl dip treatment of mangoes to control alternaria rot which developed when anthracnose and stem-end rot were

successfully controlled by hot benomyl. Alternatively, several diseases can develop simultaneously (e.g. on papaya), and combination treatments may be required to control them all.

Fumigants

Tongdee (these proceedings) reviews the use of sulphur dioxide (SO_2) for control of postharvest diseases and to improve the appearance of lychee and longan, and noted that the treatment has had a long history of human use for food preservation. Tongdee (these proceedings) also stresses the need for careful and precise application of SO_2 to ensure that residue levels are not exceeded and for incorporation of a scrubbing system into the treatment facility to prevent atmospheric pollution. Sulphur dioxide is also widely used to control grey mould and other postharvest diseases of grapes (Cappellini et al. 1986). One constraint on the use of SO_2 for disease control is its bleaching effect; red fruit turn white initially, but the colour returns with exposure to oxygen or dilute hydrochloric acid (Keetsa and Leelawatana 1992; Underhill et al. 1992). The application of sulphur dioxide by the use of sodium metabisulphite slow-release pads reduces the environmental risk and residue hazards, and has been adopted for disease control in grapes during export. Slow-release pads are also being developed for lychee and longan (Zauberman et al. 1990; Underhill et al. 1992; Kremer-Kohne 1993; Tongdee, these proceedings). Slow-release application ensures that fruit are protected from new infections during transport and storage, but does not allow for a post-fumigation treatment to restore fruit colour.

Other non-residual fumigants have also been assessed for control of fruit pathogens, including acetylene (Avissar and Pesis 1991) and hinokitiol, a volatile oil extracted from Japanese cypress *(Hiba arboruitae)* (Fallik and Grinberg 1992; Aharoni et al. 1993), but the toxicity of the former to humans precludes its use. Volatile compounds are an attractive option for control of disease during storage. The active agent can be slow-released to extend control, while once the package is opened, any residue dissipates readily.

Heat

Heat treatments are a 'clean' means of eradicating infections of postharvest pathogens provided the thermal death point of the pathogen is lower than the damage threshold of the fruit (Barkai-Golan and Phillips 1991). Hot water dips have been widely used for control of postharvest diseases of mango, usually in combination with the fungicide benomyl. Johnson and Coates (1993) summarise recently evaluated regimes for mango. The use of heat in combination with fungicides additional to benomyl has been assessed most extensively in South Africa (Lonsdale et al. 1991; Pelser and Lesar 1990, 1991).

Disinfestation

Recently, heat disinfestation treatments for fruit fly have received considerable attention (Paull 1990; Armstrong 1992; Heather, these proceedings) and their use influences disease control strategies (Coates and Johnson 1993; Jacobi et al., these proceedings). Coates and Johnson (1993) reviewed disease control obtained using heat disinfestation treatments, and summarised the commercial and experimental heat treatments for control of postharvest diseases of temperate, subtropical, and tropical fruit. Jacobi et al. (these proceedings) review the disease control and fruit quality benefits and disadvantages of fruit fly disinfestation regimes for mango. The limitations of current disinfestation regimes for disease control could be overcome by (i) targeting pathogen quiescent structures more effectively or increasing their sensitivity to heat; (ii) increasing heat-fungicide treatment synergism; and (iii) increasing the tolerance of fruit to both heat treatments and post-treatment handling and storage. Coates and Johnson (1993) note the opportunity for post-heat-treatment application of biological control agents to occupy the biological vacuum created by the heat treatment, a situation which may also exist following SO_2 and acid treatment of lychee.

Irradiation

In the quest for clean disinfestation treatments, considerable research has been undertaken on gamma irradiation (Thomas 1985). As part of this research, its potential for disease control has been examined (Moy 1983; Johnson et al. 1990a). Many published reports on irradiation do not distinguish benefits conferred by eradicating infections from those conferred by delaying ripening or senescence, which can themselves delay (rather than eliminate) disease. Dose rates required to eradicate infections range from 2000–3000 Gy, but can be as low as 1000 Gy or as high as 6000 Gy, far higher than the doses required for disinfestation (75–300 Gy). For most fruit-pathogen associations, the radiation dose required for successful disease control is deleterious to fruit quality, although some workers have reported a synergism between the disease control effects of irradiation, hot water, and fungicide treatments (Moy 1983).

While irradiation may provide a measure of control of quiescent infections in fruit at the time of treatment, it provides no residual protection against attack by wound pathogens and necrotrophs. Successful control of one pathogen could reveal additional problems. Johnson et al. (1990a) found that irradiation of strawberries at doses of 600–2000 Gy reduced the incidence of grey mould

caused by *B. cinerea* during storage at 0–2°C for 4 weeks, however during subsequent storage for 24 hours at 18°C, a high incidence of rot caused by *A. alternata* developed in irradiated fruit. Alternaria rot is not a problem encountered in strawberries, probably because fruit are usually eaten, processed, or destroyed by grey mould and other pathogens (e.g *Rhizopus* spp.) long before the quiescent period of *A. alternata* ends.

Delaying Symptom Appearance

For the postharvest pathogens that can infect fruit between flowering and harvest but do not develop further until after harvest (for example *C. gloeosporioides, Dothiorella* spp., *A. alternata),* the quiescent period can vary from a few days to many weeks (Simmonds 1941; Horne and Palmer 1935; Peterson 1978; Dodd and Jefferies 1989). For such postharvest pathogens, the critical quiescent period (CQP) should be defined as the time between harvest and disease appearance, during which the produce remains free of symptoms and thus marketable and fit for consumption (Johnson 1992).

The breaking of quiescence for particular postharvest pathogens can result from a decline in the concentration of antifungal compounds associated with fruit ripening (Prusky et al. 1988; Droby et al. 1987; Prusky and Keen 1993), or anatomical changes in fruit structure (Brown and Wilson 1968). Such changes often occur in parallel with the commencement of ripening and the respiratory climacteric (Simmonds 1941; Schiffmann-Nadel et al. 1985). Throughout Southeast Asia, culinary practice exploits the critical quiescent period of many tropical fruit pathogens. Many fruit are consumed at the mature-green stage, with full-ripe fruit considered inferior. Expansion of export markets and demands by the expatriate community and western tourists for ripe fruit require a greater degree of disease control than is necessary when fruit are consumed mature-green.

Regulation of ripening

Brady (these proceeedings) reviews the regulation of ripening in tropical and subtropical fruit. The development of slow-ripening cultivars of tropical fruit, and management practices to 'turn off' and 'turn on' ripening when required would facilitate long storage and delay disease development, particularly if other factors affecting postharvest fruit quality such as water loss (Joyce and Patterson, these proceedings) were regulated. When ethylene fumigation to promote ripening and colour development is incorporated into the handling system, either intentionally or by mixed stowage of ethylene-sensitive produce with high ethylene producers (such as ripe bananas or senescing leafy vegetables), an earlier appearance of disease may be an unwanted consequence (Kader 1985), affecting the saleability of fruit that in a less-ripe state might appear quite sound. The effects of ethylene treatment of tropical fruit on disease development needs to be assessed in advance of commercial introduction, especially if fruit are to be cool-stored for some time after treatment. Stowage practices for transportation also require consideration of the relative ethylene sensitivity of individual products. Use of effective ethylene scrubbing devices in transport and storage containers could help to regulate the problem.

Temperature

Sommer (1985) considered that all other methods of disease control should be considered as supplements to refrigeration. Cool storage offers great potential for immediate and future improvements in fruit quality and disease control. Low temperature storage slows the physiological processes associated with ripening and the growth of fungi (alternatively, a different suite of low temperature pathogens may be favoured). Susceptibility to chilling injury is a major impediment to full exploitation of cool storage. Enhancement of host tolerance of low temperature storage by (i) selection within (and outside) the host gene pool, (ii) development of 'conditioning' treatments that increase fruit tolerance of low temperatures, and (iii) development of storage regimes in which periods of low temperature fluctuate with periods of high temperature all offer potential for reducing disease losses.

What constitutes a 'long' storage period varies with commodity, decreasing with increasing storage temperature and the relative 'tropicalness' and low temperature intolerance of the commodity. Minimum temperatures tolerated by subtropical and tropical fruit are summarised in Table 2, while minimum temperatures below which a pathogen is unlikely to cause disease are summarised in Table 3.

Although cool storage effectively extends the marketing period for many tropical fruit, the post-storage vigour of the fruit may decline rapidly. Jones (1991) showed that the need for postharvest application of prochloraz to control crown rot of bananas caused by *Fusarium* spp. depended upon the length of the preripening storage period. Postharvest treatment with prochloraz was unnecessary when fruit were ripened immediately after treatment, but significantly reduced crown losses compared with untreated fruit, when the bananas were held at 13°C for 2 weeks before ripening.

In developing storage temperature schedules to slow fruit ripening and disease development, consideration must also be given to prevention of water vapour condensation. Free water on the fruit surface can favour infection by wound pathogens and the development of superficial fungal growth. Unforeseen off-loading of wrapped fruit on an airport tarmac can dramatically

increase disease development en route, the effects being due to water vapour condensation favouring superficial mould growth and higher temperatures favouring ripening.

Storage atmosphere

Kader (these proceedings) and Ben-Yehoshua et al. (these proceedings) review the use of modified and controlled atmospheres and surface coatings for extension of storage life. Extension of the critical quiescent phase for postharvest pathogens can be concomitant with storage atmosphere effects that delay ripening.

Host regulation of pathogen quiescence

In parallel with research on gene regulation of ripening and chilling injury and the exploitation of atmosphere, temperature, water-loss, and nutritional effects on fruit storage potential and disease resistance, studies are being undertaken on host mechanisms that regulate the pathogen quiescence. Nicholson and Hammerschmidt (1992) reviewed the role of phenolic compounds in disease resistance and noted their universal presence in plants, with some constitutively present which functioned as preformed inhibitors associated with non-host resistance, and others formed in response to pathogen ingress, their appearance being part of an active defence response. Matern and Kneusel (1988) and others proposed that plant defence occurred in two stages. The first involved rapid accumulation of phenols at the infection site to slow (or stop) invasion and allow activation of secondary strategies that would more thoroughly restrict the pathogen. Secondary responses included the de novo synthesis of phytoalexins or other stress-related substances. Defence events could include (in order) host cell death and necrosis, accumulation of toxic phenols, modification of cell walls by phenolic substituents or physical barriers such as appositions of papillae and, finally, the synthesis of specific antibiotics such as phytoalexins (Nicholson and Hammerschmidt 1992).

The impact of host defences can be illustrated by considering brown etch, a superficial skin-blemishing disease produced by several fungi on butternut gramma fruit *(Cucurbita moschata* Duchesne). Johnson (1976) found that symptoms of brown etch of mature butternut gramma caused by *Fusarium* spp. and *Ascochyta cucumis* Fautr. & Roum. appeared during fruit development, and that the fungi causing the symptoms could be isolated and pathogenicity proven only in immature fruit. In very young fruit, sunken lesions developed, while in half-grown to near-mature fruit, typical brown etch symptoms restricted to the fruit skin developed. In half-grown fruit, host defences may restrict invasion to the skin. In mature fruit showing symptoms, the fungi could not be isolated, and symptoms could not be induced in healthy, mature fruit by inoculation. Presumably, host defence mechanisms progressively restrict invasion and subsequently kill the fungi in the invaded tissue. Elucidation of the biochemical and genetic basis of the response could have potential for the control of ground rots caused by the same fungi in other cucurbits such as cantaloupe *(Cucumis melo* L.).

In investigating host defences with a view to their more effective regulation or modification, consideration needs to be given to the location (spatial and temporal) of the mechanisms in relation to the part of the fruit that is consumed. Prusky and Keen (1993) note the potential toxicity of antifungal compounds to human and animal consumers, citing the toxicity or carcinogenicity of compounds in potato, celery, and sweet potatoes. If the activity (or enhanced presence) of compounds were restricted to the non-edible peel and pedicel, their presence or altered activity would be acceptable. If present in the fruit flesh, critical levels may need to decline at fruit ripening or, in the case of vegetables that are always cooked, with heating above 100°C.

Considerable potential for control exists from studies on the biochemistry of quiescence for individual fruit-pathogen associations. Prusky and Keen (1993) reviewed the role of preformed antifungal compounds in the resistance of subtropical fruit to decay, and noted the difficulty in determining the role of preformed compounds in disease resistance. They considered that a functional role for preformed antifungal compounds was supported by studies that used genetically related pathogen strains with differing abilities to circumvent plant defences, whereas mere correlation of changes in the level of a preformed compound with resistance could be 'serendipitous' and needed to be interpreted cautiously. If the mechanisms accounting for the in vivo concentration of the preformed inhibitory compound were determined, then it would be possible to (i) modulate the systems exogenously and (ii) observe whether an altered level of the inhibitory compound and disease resistance were linked (Prusky and Keen 1993). Examples cited by Prusky and Keen (1993) were exogenous application of DL-phenylalanine to alter the levels of phenolic compounds and disease resistance of fruit to scab caused by *Venturia inaequalis* (Holowezak et al. 1962), and exogenous application of inhibitors of lipoxygenase (e.g. butylated hydroxy anisole) to avocado to increase the level of antifungal diene and delay development of anthracnose caused by *C. gloeosporioides* (Prusky et al. 1985; Prusky 1988).

How such information could be exploited to develop practical control measures was illustrated by the finding that freshly harvested avocados, when exposed to an atmosphere of 30% CO_2, contained higher levels of antifungal dienes and reduced decay compared with untreated fruit. However, the treatment needed to be applied for more than 24 hours, as soon as possible after

harvest, and to less- rather than more-mature fruit (Prusky et al. 1991; Prusky and Keen 1993). The work also demonstrated how the interplay between storage environment and handling regimes may influence the length of the critical quiescence period.

Prusky and Keen (1993) also noted that antifungal resorcinols had been isolated from mango fruit peel at fungitoxic concentrations in eight mango cultivars, that the concentration of one declined more quickly in a disease-susceptible cultivar than in resistant cultivars, that delayed reduction in the levels of the compounds was linked to delayed decay development, and that the flesh of unripe mangoes contained subfungitoxic concentrations of the antifungal compounds and was susceptible to fungal attack. These observations suggested, but did not prove, that the resistance of unripe mangoes resulted from the presence of the antifungal resorcinols in the peel acting on pathogen quiescent structures. Additional research was required to evaluate their role. Prusky and Gat (1992) reported that treatment of mangoes with high concentrations of CO_2 after harvest in the manner described for avocado (Prusky et al., 1991) enhanced the levels of antifungal resorcinols and delayed the development of decay caused by *A. alternata*. Other antifungal compounds isolated from avocado by Adikaram et al. (1992) and Prusky et al., (1991) need to be investigated in the manner proposed by Prusky and Keen (1993) to confirm their putative role in regulation of quiescence of *C. gloeosporioides*. Similarly, the impact of the abovementioned compounds on the development of other fruit pathogens needs to be clarified.

It is likely that several mechanisms of disease resistance operate simultaneously in fruit. Ben-Yehoshua et al. (1992) investigated the roles of both preformed and induced antifungal materials in the resistance of citrus fruit to decay caused by *Penicillium digitatum*. The flavedo tissue of lemon fruit contained four antifungal materials which acted as the first line of defence against pathogens, and exogenous application of one, citral, to lemons inoculated with *P. expansum* prevented decay. Subjecting fruit to fungal challenge and/or abiotic stress (heat or UV illumination) induced the production of the phytoalexin scoparone, which was more fungitoxic to *P. digitatum* than the preformed antifungal compounds, while citrus species differed in their ability to produce scoparone. Wild (1991) exploited the induction by potassium phosphonate of scoparone production in oranges, to enhance resistance to *P. digitatum* obtained when curing (at 35°C for 2–3 days at > 75% humidity) to stimulate the formation of lignin and antifungal coumarin compounds .

Another antifungal compound, identified as an hesperetin 7 rhamnoglucoside-like substance, has been reported from the stem-end tissues of mature, but not of immature, citrus fruit (Homma et al. 1989). The compound disappears in the terminal period of storage, suggesting a role in the regulation of quiescence of *P. citri* causing stem-end rot of citrus fruits (Homma et al. 1989).

Genetic manipulation

To incorporate genetic coding for disease resistance characters into fruit, transformation systems are required. Hammerschlag and Litz (1991) have reviewed the biotechnology of perennial fruit crops, providing overviews of the history, genetics and breeding, somatic cell genetics, and molecular approaches for several tropical and subtropical crops, including mango. In reviewing progress on mango, Matthews and Litz (1991) note that the polyembryonic mangoes from Southeast Asia evolved under constant disease pressure, and were generally more resistant to diseases than monoembryonic Indian cultivars. Stimulating somaclonal variation could unmask useful genes, while broadening the genetic base for resistance to mango pathogens could significantly improve productivity. Postharvest storage life and the critical quiescent period for pathogens might be extended by genetic transformation of the mango genome to express either ACC synthase RNA, or antisense polygalacturonase RNA (Smith et al. 1990; Oeller et al. 1991; Matthews and Litz 1991).

Conclusions

Early in this paper, we referred to the dearth of accurate data on the extent of postharvest disease losses. There is an urgent need to assess the extent of losses in tropical fruit on both local and export markets in the wholesale, retail, and domestic sectors.

In developing integrated pest management strategies, entomologists undertake intensive field observations to construct insect life-tables which trace the fate of the target insects' eggs, larvae, and adults. This information summarises the activity of natural or introduced predators, and identifies the stage at which most mortality occurs. Insecticide and predator release strategies can then be manipulated in the light of the improved knowledge of the insect's life-cycle. Insect life-stages are easier to see than those of fungal pathogens, and the fate of individual eggs easier to follow than the fate of individual spores or infection sites, but such an approach would increase the effectiveness of our current control measures and highlight 'windows of opportunity' for novel control measures. Investigations covering the aspects of pathogen biology reviewed here provide in part the information contained in insect life-tables.

In many cases, postharvest disease research has been a subsidiary of postharvest physiology or disinfestation research, emphasising 'band-aid cures' so that disease does not interfere with assessment of disinfestation

treatments or storage regimes. Such an approach favours fungicide, heat treatment, and storage technology, and limits attention to underlying issues such as pathogen diversity, dispersal and infection processes, and pathogen resistance mechanisms. An immediate challenge for postharvest pathologists is to ensure that the prerogative to undertake the primary research reviewed here is recognised by their colleagues in other disciplines, and by the institutes and agencies that regulate their activities.

There are several key aspects of the biology of tropical fruit pathogens on which research has the potential to revolutionise options for disease control: (i) the mechanics and the gene regulation of sexual and asexual reproduction, (ii) spore production, dispersal, survival and predation, (iii) adherence of propagules to the host, (iv) interactions with fructosphere organisms, (v) infection and invasion processes, and (vi) the responses of the host at all stages of pathogen life cycles. The ecology, physiology, biochemistry, and genetics of the pathogen need to be investigated with the same rigour as traditionally accorded to studies of the host. Such activity will interface with host-biology and handling-systems research to increase storage life while preserving the flavour, texture, and temptation of the tropics.

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Infection Processes of *Colletotrichum* Species in Subtropical and Tropical Fruits

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Abstract

Anthracnose caused by *Colletotrichum* spp. is the most serious postharvest disease of subtropical and tropical fruit. Initial stages of infection by *Colletotrichum* occur before harvest and typically remain quiescent until fruit ripening. Many studies have sought to determine the form and location of quiescent infection structures of *Colletotrichum* spp. in fruit. While some studies suggest that ungerminated appressoria represent the quiescent phase, others have shown that infection pegs and/or subcuticular hyphae may also be involved. In part, this confusion stems from the use of detached fruit by some workers, and the difficulty of locating infection pegs in histopathology studies.

In studies of the infection process of *C. gloeosporioides* on unharvested avocado fruit, we found that the appressorium produced a short infection peg in the cuticle of unripe fruit. Further growth of the infection peg was arrested until fruit ripening. Subcuticular hyphae were not observed in unripe fruit. The development of subcuticular hyphae in studies by others could have been an artefact resulting from the inoculation of harvested fruit. Our studies have also shown that infections of *C. gloeosporioides* established on fruit in the field do not always remain quiescent until ripening. The development of limited lesions up to 5 mm in diameter sometimes followed the field inoculation of avocado fruit with conidia of *C. gloeosporioides*. The implications of these findings for control of anthracnose are discussed.

SPECIES of the genus *Colletotrichum* are commonly encountered in subtropical and tropical regions of the world and attack a very wide range of plants including cereals, grasses, legumes, fruits, and vegetables. Diseases caused by *Colletotrichum* are generally referred to as anthracnose and can result in damage to leaves, stems, flowers, and fruit. In tropical and subtropical fruit, anthracnose causes serious postharvest losses.

Infection of tropical and subtropical fruit by *Colletotrichum* spp. commonly involves a period of up to several months where the fungus remains inactive or 'quiescent' after initial establishment in or on the fruit surface. Resumption of fungal activity occurs during the fruit ripening process when the physiological state of the host changes such that fungal development can proceed (Swinburne 1983). Although this period of quiescence has been the subject of numerous investigations in the past, some questions remain unanswered. One major uncertainty concerns the stage at which fungal development is arrested during the infection process. Resolving this issue will aid in the development of practical disease control strategies for anthracnose in tropical fruit.

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The aim of this paper is to review current knowledge of quiescent infection structures of *Colletotrichum* spp. in tropical and subtropical fruit.

Stages in the Infection Process of *Colletotrichum* spp.

Infection of fruit by *Colletotrichum* spp. involves a number of stages. Early stages of infection include: (1) arrival of inoculum (in the form of water-borne conidia) on the fruit surface; (2) adhesion of conidia to the fruit surface; (3) germination of conidia in the presence of free water; (4) germ tube elongation; and (5) appressorium formation (Jeffries et al. 1990). It is generally agreed that this sequence of events does not vary with the species of *Colletotrichum* or fruit in question.

Events occurring after the formation of appressoria are, however, not entirely clear. In some *Colletotrichum*–fruit interactions, it has been reported that once the appressorium has formed, no further development occurs until fruit ripening; i.e. the appressorium remains quiescent. In these interactions it is claimed that the appressorium germinates during fruit ripening to produce an infection peg that penetrates the cuticle and underlying epidermal cells. In other *Colletotrichum*–fruit interactions, however, it appears that the appressorium germinates in unripe fruit to produce an infection

peg and, in some cases, a subcuticular hypha. In these interactions, it is claimed that the infection peg or subcuticular hypha remains quiescent until fruit ripening.

Regardless of the form the fungus takes during the quiescent phase, further development of the pathogen during fruit ripening usually involves the production of both intracellular and intercellular hyphae. Cellular disruption and eventually death results from this hyphal invasion. In advanced stages of lesion development, a compact mycelial stroma is formed between the cuticle and necrotic tissue from which acervuli are produced (Chau and Alvarez 1983; Daykin and Milholland 1984a). Conidia are released upon rupture of the cuticle.

Demonstrating Quiescence of *Colletotrichum* Infections

Various techniques have been used to demonstrate quiescence of *Colletotrichum* infections in tropical and subtropical fruit. Wardlaw (1931) demonstrated quiescence of *C. musae* in banana by isolating the fungus from the surface-sterilised peel of symptomless fruit. Quiescence of *C. gloeosporioides* was also demonstrated in avocado, mango, and citrus fruit using this technique (Baker 1938). Although these studies established that *Colletotrichum* could remain in a quiescent state without losing viability, they did not demonstrate that the fungus was capable of resuming activity and inciting disease when conditions became more favourable for disease development.

Several studies have reported the use of an inoculation technique to demonstrate quiescence of *Colletotrichum* infections in fruit. In this technique, fruit at various stages of development are inoculated in the field with conidia of *Colletotrichum*. When the inoculated fruit reach maturity, they are harvested, ripened, and examined for lesion development within inoculated areas. The development of anthracnose lesions within inoculated areas is taken as evidence for quiescent infection, although an assumption must be made that such lesions have not arisen from natural infection. The inclusion of uninoculated control fruit in such studies is imperative for making this assumption. This technique has been used to demonstrate quiescence of *C. musae* in banana (Simmonds 1941) and *C. gloeosporioides* in avocado (Binyamini and Schiffmann-Nadel 1972) and papaw (Dickman and Alvarez 1983). Quiescent periods of up to several months were established in these studies.

An alternative to this approach for demonstrating quiescence is to use a genetic marker. The main advantage of using a genetic marker is that natural and induced infections can be clearly distinguished. Coates et al. (1993a) used a benomyl-resistant mutant to demonstrate quiescence of *C. gloeosporioides* in avocado fruit. Fruit were inoculated with the mutant at various stages of development, harvested at maturity, and ripened. Isolation of the mutant from lesions within inoculated areas confirmed that the fungus was able to remain in a quiescent state for periods of at least 6 months before resuming activity during the ripening process.

The Form of Quiescent Infection Structures in Host Tissue

The investigation of quiescent infections is often based on the histopathological examination of artificially inoculated fruit tissue (Table 1). Although such studies give direct evidence of the form of infection structures during the quiescent period, care must be taken in the interpretation of results. One aspect requiring special consideration is the method used to inoculate fruit. Most histopathological studies are based on the inoculation of detached fruit in the laboratory. Fruit inoculated in this way are incubated under optimum conditions for infection and are sampled at various stages during ripening. Alternatively, some studies are based on the inoculation of fruit in the field. Although field inoculation is the preferred method because it reflects the process of natural infection more accurately, both methods of inoculation need to be viewed with some degree of caution.

Another important consideration when interpreting results of histopathological studies is the consistency of observations made, i.e. at what frequency is a particular infection structure produced? Ideally, conclusions should be based on a large number of observations. Where possible, histopathological observations should be quantified in some way, although this can be very difficult to do when observations are based on the examination of thin tissue sections.

Method of tissue preparation also varies considerably between different histopathological studies. For light microscopy, there is a choice of using either thin sections (usually 1–15 μm thick) or cleared excised segments of peel tissue. The main disadvantage of using sections is that it is difficult to build up a complete picture unless numerous serial sections are examined. Structures such as infection pegs can easily be missed because of their extremely narrow diameter. Although excised peel segments have the advantage of allowing the three-dimensional development of hyphae to be traced, it still remains difficult to locate narrow hyphal structures which are produced directly beneath appressoria. In addition to this, some types of fruit tissue may not be suitable for clearing.

Simmonds (1941) was among the first to make a detailed histopathological study of quiescent infection structures of *C. musae* in banana fruit and of *C. gloeosporioides* in mango and papaw fruit. In each of the interactions examined in this study (which was based on the inoculation of detached fruit), it was found that appressoria germinated on the surface of unripe fruit to produce infection pegs that penetrated the cuticle before

Table 1. Quiescent infection structures of *Colletotrichum* spp. in various fruit crops

Fruit host	Pathogen	Inoculation method	Form of quiescent structure	Reference
Avocado	*C. gloeosporioides*	Attached fruit	Appressorium	Binyamini and Schiffmann-Nadel 1972
		Detached fruit	Subcuticular hypha	Prusky et al. 1991a
		Attached fruit	Appressorium and short infection peg	Coates et al. 1993b
		Detached fruit	Appressorium and long infection peg	Coates et al. 1993b
Banana	*C. musae*	Detached fruit	Subcuticular hypha	Simmonds 1941
		Detached fruit	Subcuticular hypha	Chakravarty 1957
		Detached fruit	Appressorium	Muirhead and Deverall 1981
Blueberry	*C. gloeosporioides*	Attached fruit	Appressorium and infection peg	Daykin and Milholland 1984b
Capsicum	*C. capsici* and *Glomerella cingulata*	Detached fruit	Appressorium	Adikaram et al. 1983
Citrus	*C. gloeosporioides*	Detached fruit and naturally-infected fruit	Appressorium	Brown 1975
Grape	*C. gloeosporioides*	Attached fruit	Appressorium and infection peg	Daykin and Milholland 1984a
Mango	*C. gloeosporioides*	Detached fruit	Subcuticular hypha	Simmonds, 1941
Orange	*C. gloeosporioides*	Detached fruit	Subcuticular hypha	Adam et al. 1949
Papaya	*C. gloeosporioides*	Detached fruit	Subcuticular hypha	Simmonds 1941

broadening within or near the wall of underlying epidermal cells. Because there was no further development of these subcuticular hyphal structures in unripe fruit, Simmonds (1941) concluded that they represented the quiescent phase of *C. musae* in banana and of *C. gloeosporioides* in mango and papaw.

Simmonds (1941) findings were confirmed in a number of subsequent studies. Fulton (1948) reported the production of subcuticular hyphae in green tomato fruit inoculated with *C. phomoides*. Similarly, subcuticular hyphae were observed in unripe orange fruit inoculated with *C. gloeosporioides* (Adam et al. 1949), and also in unripe banana fruit inoculated with *C. musae* (Chakravarty 1957).

During the 1970s and 80s, new evidence highlighted the importance of appressoria in the quiescence of *Colletotrichum* in subtropical and tropical fruit. In avocado fruit inoculated with *C. gloeosporioides* in the field, appressoria were reported to represent the quiescent phase rather than subcuticular hyphae (Binyamini and Schiffmann-Nadel 1972). Further support for appressorial quiescence was given by Brown (1975). In citrus fruit naturally infected by *C. gloeosporioides*, relatively few appressoria had produced infection pegs. When infection pegs did form, they were located within or beneath the cuticle, intercellularly in the epidermis, or inter- and intracellularly in the upper 2–4 cell layers of the flavedo. No further development of these infection pegs was observed during ripening.

Further evidence that appressoria represent the quiescent phase of *Colletotrichum* came from a reexamination of the banana–*C. musae* interaction by Muirhead and Deverall (1981). In their study, it was found that both hyaline and dark appressoria were produced following inoculation of detached, green banana fruit. Hyaline appressoria produced subcuticular hyphae in the peel of green fruit causing a hypersensitive reaction in neighbouring cells. No further development of these subcuticular hyphae was observed during ripening. On the other hand, dark appressoria remained quiescent on the surface of unripe fruit, producing subcuticular hyphae only during ripening. It was these subcuticular hyphae which led to the colonisation of underlying tissues and eventual formation of anthracnose lesions.

In detached, immature capsicum fruit inoculated with *Glomerella cingulata*, only a small proportion of appressoria produced infection pegs which penetrated the cuticle and outer epidermal cell wall before ceasing growth in the lumen (Adikaram et al. 1983). Most appressoria remained quiescent on the surface of fruit. All appressoria produced following inoculation of detached, immature capsicum fruit with *C. capsici* remained quiescent on the fruit surface.

Histopathological studies of *C. gloeosporioides* infection in field-inoculated grape and blueberry fruit revealed that infection pegs were produced in the peel of unripe fruit within one week of inoculation (Daykin and Milholland 1984a,b). In grape, approximately 35% of appressoria germinated to produce infection pegs which ceased growth in the cuticle until fruit ripened. In blueberry, only 3–11% of appressoria were observed to produce infection pegs, although it was acknowledged that a higher percentage of infection pegs may have been present but not observed due to the thinness of the cuticle and the fineness of infection pegs.

Most of the latest research on quiescent structures of *Colletotrichum* has been conducted on avocado. In contrast to the findings of Binyamini and Schiffmann-Nadel (1972), recent evidence suggests that germinated rather than ungerminated appressoria represent the quiescent phase of *C. gloeosporioides* in avocado. Prusky et al. (1991a) found that within 72 hours of inoculation of detached avocado fruit with *C. gloeosporioides*, appressoria had germinated to produce infection pegs which penetrated the cuticle and reached epidermal cells before ceasing growth. This finding was confirmed in a similar study of laboratory-inoculated avocado fruit by Coates et al. (1993b), although in field-inoculated avocado fruit it was found that appressoria produced only a short infection peg (less than 1.5 μm long) in the cuticle of unripe, attached fruit before ceasing growth (see Figs 1 and 2). From these studies, it is apparent that there is a difference between field-inoculated and laboratory-inoculated fruit in terms of the development of infection pegs. The possible cause of this difference is discussed in the next section.

Although most studies aiming to determine the form of quiescent infection structures have been based on histopathological observations, some evidence supporting the theory that subcuticular hyphae are the quiescent structures has come from studies based on the effect of surface sterilants. Simmonds (1941) used mercuric chloride to surface sterilise banana fruit which had been field-inoculated with *C. musae* 6 days previously. He found that anthracnose levels in ripe fruit which were previously inoculated and surface-sterilised were similar to those in fruit which were inoculated but not surface-sterilised, indicating that the quiescent infection structures were present below the fruit surface. A subsequent study, however, raised some questions on the effectiveness of mercuric chloride as a surface sterilant (Muirhead and Deverall 1981). Hyaline appressoria

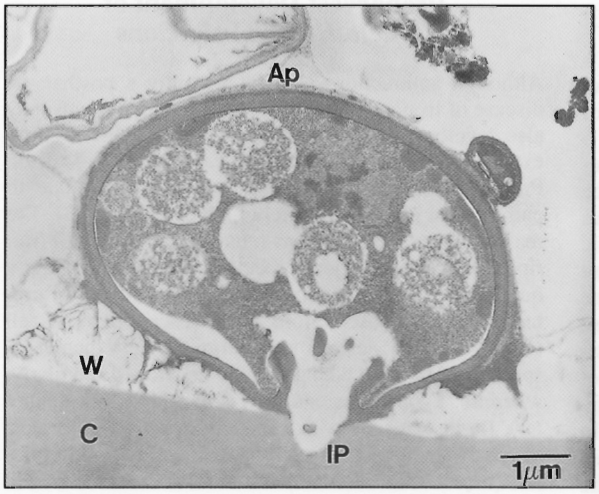

Figure 1. (Above) TEM of the quiescent infection structure of *C. gloeosporioides* in avocado: a germinated appressorium

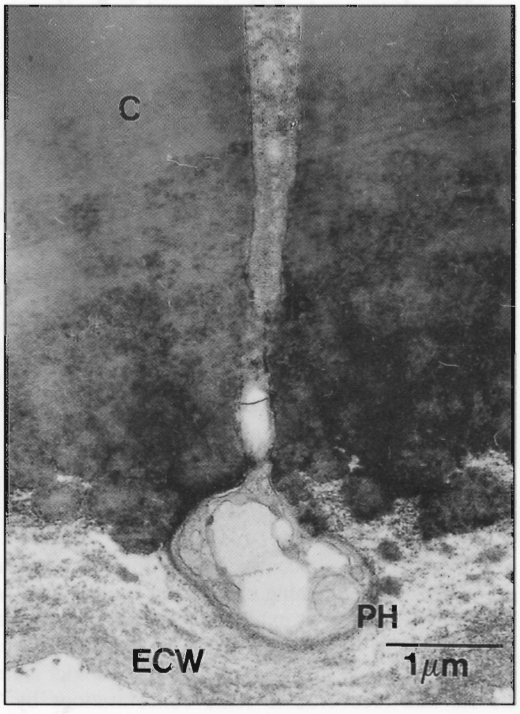

Figure 2. (Right) TEM of infection peg development (*C. gloeosporioides*) during ripening of avocado fruit. Legend: Ap = appressorium; IP = infection peg; PH = primary hypha; W = wax layer; C = cuticle; ECW = epidermal cell wall

produced on glass slides were killed by mercuric chloride, whereas the germination of dark appressoria on glass slides was merely delayed. In addition, mercuric chloride failed to kill dark appressoria on the surface of banana fruit.

Given the considerable variation in conclusions drawn by different researchers studying the same host/pathogen interactions, it is apparent that the issue of quiescent infection structures of *Colletotrichum* is still not completely resolved. In our own studies, we found that infection pegs produced in the cuticle of unripe field-inoculated avocado fruit were both short (less than 1.5 μm) and narrow (ca. 0.5 μm), making them very difficult to discern despite having access to the latest microscopy and microtomy equipment. It is not difficult to imagine how some of the early studies may have overlooked the existence of such structures. Given the inconsistencies reported in the literature, it would be appropriate to reexamine the infection process of *Colletotrichum* spp. in other fruit hosts. In an effort to standardise procedures used in the study of quiescent structures, it is proposed that future studies be based on the inoculation of attached rather than detached fruit. Fruit tissue sampled in the field should be fixed without delay, and sampling of field-inoculated fruit after harvest should be related to fruit ripening rather than to time after harvest.

The Relationship between the Production of Antifungal Compounds and the Development of Quiescent Infection Structures

Antifungal compounds, both preformed and induced, have been implicated in the regulation of quiescence of *Colletotrichum* spp. in subtropical and tropical fruit.

There is considerable evidence to suggest that preformed antifungal compounds are involved in the quiescence of *C. gloeosporioides* in avocado fruit. An antifungal diene was shown to be present in fungitoxic concentrations in the peel of unripe avocado fruit (Prusky et al. 1982). The concentration of this diene decreased to sub-fungitoxic levels by the time disease symptoms first appeared during fruit ripening. In resistant cultivars such as Hass, levels of the diene did not decline as rapidly during ripening as they did in susceptible cultivars such as Fuerte (Prusky et al. 1988). In addition, treatments which delayed the degradation of this compound during fruit ripening also delayed the onset of symptom development (Prusky 1988; Prusky et al. 1991b).

Although diene concentration was found to decrease gradually during ripening of avocado fruit, a sharp yet temporary decline was exhibited immediately after harvest (Prusky et al. 1991a). Within 16 hours of harvest, diene levels had declined to sub-fungitoxic levels. Levels had recovered to toxic concentrations by 72 hours after harvest. This finding may help to explain why the inoculation of freshly harvested avocado fruit with *C. gloeosporioides* results in the production of long infection pegs (Prusky et al. 1991a ; Coates et al. 1993b), whereas the inoculation of attached fruit results in the production of short infection pegs only (Coates et al. 1993b). This highlights the importance of inoculation method in the study of quiescent infections.

It was also found that time elapsed between harvest and recovery of toxic diene levels decreased with increasing fruit maturity (Prusky and Plumbley 1992), indicating that fruit maturity and ripeness stage should also be taken into account when interpreting results of histopathological studies.

Links between the production of phytoalexins and quiescent infections of *Colletotrichum* have been demonstrated in some fruit such as banana (Muirhead 1979; Brown and Swinburne 1980) and capsicum (Adikaram et al. 1982), although further studies are needed to clarify their role in other fruit hosts. In avocado, it appears that the preformed antifungal diene shows some of the characteristics of a phytoalexin in that its concentration can be enhanced by infection or challenge inoculation with *C. gloeosporioides* (Prusky and Keen 1993). Diene levels can also be enhanced by certain abiotic treatments such as exposure to high concentrations of CO_2. These findings will have important implications for the development of practical control measures for anthracnose.

Preharvest Development of *Colletotrichum* Infections

Although anthracnose is predominantly a postharvest disease of tropical and subtropical fruit, symptoms may also develop before harvest in some hosts. This has been extensively documented in the case of avocado fruit. Preharvest losses of immature avocado fruit due to anthracnose can be extremely high (Fitzell, 1983). The reason why some infections remain quiescent until fruit ripening whereas others proceed to develop without a quiescent period is not entirely clear. Two types of preharvest anthracnose lesions were described by Fitzell (1987). 'Type 1' lesions were large (1–4 cm diameter), spreading lesions which generally developed singularly, whereas 'Type 2' lesions were small (1–5 mm diameter), limited lesions which usually occurred in groups. 'Type 1' lesions were usually associated with skin injuries (insect or mechanical) and in most cases resulted in premature fruit fall. Fitzell (1987) proposed that wounding the fruit surface may cause localised fruit ripening and hence a reduction in antifungal diene levels, enabling conidia washed into the damaged tissue to germinate and colonise the flesh. It was acknowledged, however, that this theory does not explain why artificially inoculating fruit with *C. gloeosporioides* prior to wounding (caused by insects) did not result in

symptom development. 'Type 2' lesions, on the other hand, were usually associated with lenticels rather than skin injuries and in most cases did not result in premature fruit fall. Fitzell (1987) was unable to reproduce these lesions by artificially inoculating fruit, although in a subsequent study Coates (1991) reported the production of similar lesions in unwounded field-inoculated avocado fruit. Within 10 days, some fruit inoculated with *C. gloeosporioides* at a rate of 10^6 conidia/mL developed limited lesions, whereas no fruit inoculated at a rate of 10^4 conidia/mL developed these symptoms. Clearly, inoculum concentration was an important factor in the development of these lesions. The relationship between inoculum concentration, diene concentration and symptom development should be examined in future studies.

Future directions

Although there has been considerable research into quiescent infections of *Colletotrichum* in tropical and subtropical fruit, a number of areas still warrant further investigation:

1. Detection of quiescent infections — Quiescent infections are not visible at the time of harvest. The development of a simple method to estimate levels of quiescent infections in unripe fruit would allow postharvest losses due to anthracnose to be dramatically reduced. Such a method would be particularly useful for export fruit where reliable quality is critical.
2. Preharvest changes in antifungal compounds — Little information is available on what influences the concentration of antifungal compounds in fruit tissue before harvest. Such information may aid in our understanding of the causes of preharvest anthracnose development in some fruit hosts.
3. Antifungal compounds — The production of antifungal compounds in fruit other than avocado need to be examined in more detail.
4. Quiescent infection structures — As highlighted in this review, many histopathological studies have been based on the inoculation of detached fruit. Given the potential problems associated with this method, some *Colletotrichum*–fruit interactions should be reexamined using field-inoculated fruit. In addition, where observations lead to the conclusion that infection pegs and/or subcuticular hyphae are involved in quiescence, it would be useful to know whether such structures are still dependent on the appressorium for survival.

It is important that the whole issue of quiescent infection structures of *Colletotrichum* in fruit tissue be finally resolved so that effective new disease control measures can be developed on the basis of a thorough understanding of the infection process.

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Preharvest Fungicidal Sprays for Postharvest Disease Control in Fruits

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Abstract

This paper reviews the results of studies of the effectiveness of preharvest fungicidal sprays in controlling various postharvest rot diseases. Results from a number of temperate and tropical fruits are discussed, including apples, strawberries, raspberries, lychees, mangoes, and bananas. It is concluded that field spraying crops with chemical fungicides can reduce postharvest diseases but results will not always be consistent. Integrated control procedures, coupled with a knowledge of the causal organism, are crucial to effective disease control.

MANY postharvest diseases of fresh fruits and vegetables begin during production. Microorganisms may well be on or in the crop at harvest and be taken into storage or through the marketing chain and continue to develop and cause disease. The time between infection and the symptoms of the disease developing may be lengthy as, for example, in anthracnose in bananas, which can take over 5 months (Simmonds 1941).

Routes of Infection

Fungal and bacterial infections can occur through mechanical injuries and cut surfaces of the crop, growth cracks, or pest or disease damage. They also infect through natural openings in the surface tissue of the crop, such as stomata, lenticels, and hydrathodes. Many fungal species are able to penetrate the intact skin of fruit. The spores may germinate on the surface of the fruit, often as a response to specific chemicals released from the host, producing a hypha. With some species of fungi this terminates in a swelling called an appressorium as, for example, in *Colletotrichium* spp. In other cases, e.g. *Plasmodiophora brassicae*, the spore germinates and produces an adhesorium through which the fungus penetrates the host directly. *C. musae* conidia were shown to germinate more readily and appressoria production was greater on the surface of banana fruit than in water (Swinburne 1976).

Appressoria are resistant to adverse environmental conditions and are difficult to control with chemical fungicides. They may remain dormant for several weeks before the hypha begins to grow and penetrate the cuticle of the host and infect the tissue below. The mode of penetration is still being investigated but it is probable that penetration occurs by hyphal growth pushing into the cells by sheer force using the appressorium as an anchor. When the fungus has penetrated the host it breaks down cells by excreting enzymes which attack and dissolve the host's cells forming a liquid which is transmitted osmotically into the fungal hyphae. In some species of fungi the hyphae grow between the host's cells and penetrate the cells with haustoria which feed on the cell contents.

Preharvest fungal infections which cause postharvest rots can occur on most crops. In mangoes the fungus which causes anthracnose disease (*Glomerella cingulata*, conidial stage *Colletotrichum gloeosporiodes*) is a field infection that usually only develops as the fruit ripens. Therefore fruits which look perfectly healthy at harvest may develop the disease symptoms after harvest (Thompson 1987).

Crop hygiene can be important in reducing field infections and infestations which may be carried into storage or the marketing chain. This usually involves removal of rotting material from the field, especially fruit windfalls or tree prunings. It can also involve efficient weed control of species which might be alternative hosts for disease-causing organisms.

Preharvest Spraying Strategies

Miscellaneous fruits

Preharvest sprays with chemical fungicides have been shown to reduce postharvest diseases but the effects have not always been consistent. In Britain single sprays of apples with 0.025% benomyl in either June, July, or

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August controlled rots caused by infection with *Gloeosporium* spp., which developed in subsequent storage from September onwards at 3.3°C in unsprayed fruit. The observations were made over two seasons and the fungicide applied at 1120 L/ha (Edney et al. 1977). Application of benomyl and dichlofluanid to strawberries and raspberries, from early flowering to 14 days before the first harvest, gave mixed results in terms of disease levels on the fruit during subsequent storage (Dennis 1975). In the first year both treatments reduced rotting in storage in the early part of the season, but in the second year only the dichlofluanid treatment was effective at this time. In the latter part of the season there was little difference between sprayed and unsprayed fruit on storage rots. In the early part of the season most of the rotting was caused by *Botrytis cinerea* while in the latter part it was mainly due to *Mucor mucedo*. Strains of *B. cinerea* resistant to the benzimidazole fungicide were detected (Jordan and Richmond 1974), which restricted its use on soft fruit. Fruit rots on lychees caused by a range of fungi were not controlled by preharvest sprays with lime, sulfur, or copper compounds but postharvest treatment with 0.05% benomyl at 52°C for 2 minutes was found to be effective (Scott et al. 1982). Control of fruit rots in cucumber caused by *Didymella bryoniae* were reported after the growing crop was sprayed with either benomyl, chlorothalonil, or triforine (Van Steekelenburg 1982).

Mangoes

Thompson (1987) reviewed preharvest sprays of mangoes to control anthracnose. Recommendations are for field application of chemical fungicides often followed by postharvest hot water treatment usually combined with a fungicide. In Florida, cupric hydroxide at 2.4 g/L or tribasic copper sulfate at 3.6 g/L plus the organic sticker Nu-Film 17 at 0.125% applied at monthly intervals at 57 L/tree from flowering to harvest gave good anthracnose control (McMillan 1972). Benomyl at 0.3 g/L plus Triton B1956 at 0.15 mL/L at 57 L/tree at monthly intervals from flowering to 30 days before harvesting was shown to be very effective against anthracnose on mangoes (McMillan 1973). Mancozeb, chlorothalonil, and ferbam were shown to be equally effective as field sprays against mango anthracnose in Florida (Spalding 1982).

Trials carried out on Kett mangoes in South Africa showed that two pre-flowering applications of copper oxychloride and two applications of Bayfidan (triadimenol) during flowering, followed by monthly applications of copper oxychloride from fruit set, ensured effective control of anthracnose (Lonsdale 1992). Sprays were applied to run-off at about 20 L/tree.

In Australia, mancozeb applied at 1.6 g/L active ingredient as a weekly spray during flowering then as a monthly spray until just before harvesting gave good control of mango anthracnose (Grattidge 1980). In studies in the Philippines field sprays with mancozeb or copper were effective in controlling mango anthracnose and superior to either captan or zineb (Quimio and Quimio 1974).

Soft brown rot of mangoes in South Africa, caused by *Nattassia mangiferae*, is due to field infections, which were shown to be controlled by applications of copper oxychloride in June (pre-flowering) and January. Further applications after fruit set (between June and January) did not enhance control of the disease (Lonsdale 1992).

Papaya and guava

In the Yemen, the control of anthracnose in papaya, also caused by *C. gloeosporiodes*, was achieved by preharvest sprays with metiram 80% wettable powder at 200 g/100 L of water, or propineb 70% at 200 g/100 L of water, or copper oxychloride 50% wettable powder at 400 g/100 L of water, applied at 7–10-day intervals (Kamal and Agbari 1985). They also recommended the same treatments with either metiram or propineb for control of fruit canker caused by *Pestalotiopsis psidii* in guava. Snowdon (1990) also recommends orchard application of chemical fungicides as well as postharvest dips and low-temperature storage for *P. psidii* control in guava.

Bananas

Premature fruit ripening is a common problem of bananas, particularly those which enter international trade. This can be manifest on the crop before harvesting or it may only be observed as a 'physiological disorder' after harvest. Fungicide applications in the field to control Sigatoka leaf spot (*Micosphaerella musicola*) were shown to reduce premature ripening. Application of propiconazole at 50 g active ingredient per ha plus 4 litres of mineral oil per ha, or propiconazole at 100 g active ingredient per ha alone, reduced premature ripening from 100% on controls to 0% on treated fruit (Ramsey et al. 1987). An explanation for this effect is that the disease puts the banana plant under strain and premature ripening is a response to that strain.

Contraindications

It has been shown that preharvest chemical fungicide application can actually result in an increase in postharvest disease. Stem-end rot of mangoes in Australia was shown to be caused by preharvest infections with *Dothiorella dominicana, D. mangiferae, Phomopsis mangiferae, Lasiodiplodia theobromae Cytosphaera mangiferae*, and *Pestaloptiopsis* spp. (Johnson et al.

1992). They also showed that these fungi occur widely on mature branches and, in certain conditions, colonise the inflorescence tissue as it matures thus reaching the stem end of fruit through the pedicel. These infections remain latent until after the fruit has been harvested or until the fruit on the tree becomes senescent. However, Johnson et al. (1992) found a higher level of stem-end rot caused by *Dothiorella dominicana* in a mango orchard that had been regularly sprayed with a copper fungicide than at another site which had not been sprayed. At the unsprayed site the mangoes were extensively diseased with anthracnose which may have prevented *Dothiorella dominicana* infecting the fruit from the pedicel where it was detected.

Conclusion

It can be concluded that field spraying crops with chemical fungicides can reduce postharvest diseases but results will not always be consistent. Integrated control procedures coupled with a knowledge of the causal organism is crucial to effective disease control.

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A Review of Biological Control of Postharvest Diseases of Subtropical Fruits

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Abstract

Biological control of subtropical crops has been investigated for the past seven years at the University of Pretoria, South Africa. This article reviews the results and discusses the findings in relation to related studies on temperate crops. Various *Bacillus* spp. originally isolated from leaf and fruit surfaces effectively controlled anthracnose of mango and avocado, *Dothiorella/Colletotrichum* fruit rot complex of avocado, stem-end rot of avocado and mango, soft brown rot on mango and postharvest decay and secondary infections on lychee. Control was achieved with semicommercial packhouse dips, sprays, ultralow volume, or wax applications. Integrated treatments involving antagonists combined with quarter to recommended dosage of fungicides such as prochloraz, benomyl, or sodium hypochlorite also effectively suppressed postharvest diseases of avocado and mango. Enhanced control of mango postharvest diseases could be achieved by incorporating the antagonists in commercial warm water dips (52°C). Using a mixture of antagonists was not necessarily more effective than using the antagonists on their own. Consistent control of avocado postharvest diseases could be achieved on four different avocado cultivars viz. Fuerté, Hass, Ryan, and Edranol.

BECAUSE of long transit periods, postharvest losses due to disease are often greater in export shipments of tropical and subtropical fruits than in domestic consignments (Harvey 1978). Conservative estimates place U.S. and Asian losses of fruit and vegetables at around 25% of the harvested crop, whereas losses as high as 50% have been recorded from Africa (Wilson and Wisniewski 1989; Jeffries and Jeger 1990). These losses are generally assessed at a single point in the postharvest food chain. Losses in grocery stores, restaurants, kitchens, etc. are seldom calculated (Wilson and Wisniewski 1989).

Fungicides are a primary means of controlling postharvest fruit diseases (Eckert and Ogawa 1985). Although normally applied after harvest, preharvest fungicide applications are equally important in reducing postharvest losses (Jeffries and Jeger 1990; Thompson, these proceedings). However, protective preharvest fungicides often leave unacceptable residues on fruit. These residues can result in rejection of export consignments unless removed in the packhouse, thus unavoidably adding to production costs (Korsten et al. 1989). In addition, buildup of pathogen resistance has been reported for fungicides such as benomyl (Delp 1980; Spotts and Cervantes,1986; Darvas and Kotzé 1987). Added to this, registration of new chemicals for economically less-important crops such as lychee, is often hampered by the smaller return on investment perceived by chemical companies. Therefore, with growing international concern over the often indiscriminate use of fungicides, and the potential detrimental effect on the environment and human health, alternative disease control measures are urgently required.

One such alternative is biological control (Droby et al. 1991a). Biological control in its various forms has been known to man long before scientists utilised the concept to purposefully control disease. Since Stanford and Broadfoot used the term to describe their work on 'take-all' of wheat in 1916 (Sharma and Sankaran 1988), pioneering work has been done on soil-borne diseases (Leben 1965; Cook and Baker 1983). Although research on biocontrol of air-borne diseases started to gain momentum in the second half of the twentieth century, only in the last decade has it shown real progress (Wilson and Wisniewski 1989; Wisniewski and Wilson 1992).

Several antagonistic microorganisms capable of controlling a wide spectrum of fruit pathogens on a variety of crops are known (Table 1). The history of biocontrol research on fruit crops has largely been successful in the laboratory, but a failure in the field (Wilson et al. 1991). A few notable exceptions have progressed to field or packhouse experiments (Table 1). Of these, only Hofstein et al. (1991) and Droby et al. (1991b) with citrus,

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Korsten et al. (1991a), Korsten and Kotzé (1992) with avocado, and Korsten et al. (1991b) and Koomen and Jeffries (1993) with mango have succeeded in controlling natural infections of postharvest pathogens under commercial packhouse conditions. In some instances, disease control was equal or better than that achieved with commercial fungicides. Nevertheless, commercial application of biocontrol agents for control of fruit diseases is, as far as can be determined, limited to the use of *Trichoderma* spp. (trichodermin) against grey mould on strawberry (Lynch 1988). *B. subtilis* (MBI 600) has also been developed commercially and preliminary formulations were effective in controlling *Botrytis cinerea* Pers. ex Nocca and Balb. on strawberry (Rodgers 1989).

This paper gives an overview of the status of research and development on biological control of subtropical fruit crops in South Africa over the past seven years.

Subtropical Crops

Avocado (*Persea americana* Mill.) is the fourth most important subtropical crop cultivated in South Africa (Garbers 1987), while mango (*Mangifera indica* L.) and lychee (*Litchi chinensis* Sonn.) are gaining in significance (Milne, these proceedings). Fuerté is the most widely cultivated avocado cultivar in South Africa, representing 43% of the total plantings (South African Avocado Growers' Association 1991 Avocado tree census), with other important cultivars including Hass, Ryan, and Edranol. Although several mango cultivars are cultivated in South Africa, the most important for export are Sensation, Tommy Atkins, and Kent. More than 60% of the lychee cultivars grown in South Africa represent HLH Mauritius (Tai So), followed by the Madras group (Oosthuizen 1989). The majority of fruit is exported to Europe by sea. Extended storage conditions of up to 30 days place these crops under considerable physiological stress, which can result in significant losses due to postharvest decay (Swarts 1989). On the overseas markets, high incidences of anthracnose (29%) and stem-end rot (15%) have been recorded in some avocado consignments from South Africa (Bezuidenhout and Kuschke 1983).

Commercial control of avocado and mango fruit diseases in South Africa mainly involves preharvest sprays with copper oxychloride (Vermeulen et al. 1992). Postharvest hot water dip treatments (52°C for 5 min) with benomyl is currently used on mango fruit (Vermeulen et al. 1992). Although prochloraz and thiabendazole are at present registered for use on avocado in South Africa (Vermeulen et al. 1992), they are not used commercially on export fruit. Lychee postharvest diseases are mainly controlled with postharvest sulfur dioxide (SO_2) fumigation (Swarts 1989) and by postharvest temperature management (Kremer-Köhne and Lonsdale 1991). However, Botha et al. (1988) reported an increase in postharvest decay when the Mauritius cultivar was treated with SO_2.

Research Strategies

Biological control can be defined as the manipulation of natural processes to reduce losses to crops. A number of potential biological control avenues are open for controlling postharvest diseases of fruits (Wilson and Wisniewski 1989). Among these are: (1) manipulation of the host, which include approaches such as induced resistance, phytoalexins, resistance breeding, and genetic manipulation; (2) modification of the environment (temperature, humidity, and gaseous atmosphere); (3) reduction of the inoculum by sanitation principles and physical approaches such as hot-water dipping and irradiation; and (4) by direct or indirect use of antagonistic microorganisms (Wilson and Wisniewski 1989; Jeffries and Jeger 1990). The last-mentioned biological strategy can be achieved by stimulating indigenous organisms to prevent the establishment of the pathogen, or by direct application of antagonists to the plant surface (bioaugmentation) (Jeffries and Jeger 1990).

Our research strategies routinely included an initial ecological study of the leaf and fruit microflora of the particular crop, and in vitro and in vivo screening of potential antagonists against the full spectrum of postharvest pathogens. This was followed by field or packhouse application of potential antagonists, and eventually by investigating the mode of action, as well as antagonist attachment and survival. Our current research centres around first-tier toxicological tests and continued semi-commercial evaluation of antagonists (Fig. 1). A patent (SA patent no. 290-3764) has been granted as a result of this work.

Preharvest vs Postharvest Biological Control

Eckert and Ogawa (1985) outlined four strategies for control of postharvest disease, viz. reduction in inoculum, prevention, or eradication of field infection, inactivation of wound infection and suppression of disease development and spread. Implementation of the first two of these strategies can most effectively be achieved preharvest, and postharvest with the latter two. Korsten et al. (1989) controlled the avocado postharvest diseases anthracnose, stem-end rot (SE), and *Dothiorella*/*Colletotrichum* fruit rot complex (DCC) with *Bacillus subtilis* (Ehrenberg) Cohn sprayed onto trees at intervals during fruit development, or applied as a postharvest dip or wax treatment. Korsten et al. (1991b; 1992) also succeeded in reducing anthracnose of mango with either preharvest *Bacillus licheniformis* (Weigman) Chester sprays or postharvest dips.

Table 1. Published reports on biological control of fruit diseases

Commodity	Disease	Pathogen	Antagonist	Status of research[a]	Reference
Apple (*Malus sylvestris* Mill.)	Blue mould	*Penicillium expansum* Link ex Gray	*Pseudomonas* sp.; yeast	In vivo; AI; EC	Janisiewicz 1987
		P. expansum	*Pseudomonas cepacia* Palleroni and Holmes	In vivo; EC	Janisiewicz 1988
		P. expansum	*P. cepacia*	In vivo; EC	Janisiewicz and Roitman 1988
		P. expansum	*Candida* sp.	In vivo; EC	McLaughlin et al. 1990
		P. expansum	*Kloeckera apiculata* (Reess emend. Klöcker) Janke	In vivo; AI; LC	McLaughlin et al. 1992
	Grey mould	*Botrytis cinerea* Pers. ex Nocca and Balb.	*Acremonium breve* (Sucapure and Thirumalachar) W. Gams.	In vivo; EC	Janisiewicz 1988
		B. cinerea	*P. cepacia*	In vivo; EC	Janisiewicz and Roitman 1988
		B. cinerea	*Pichia guilliermondii* Wickerham[b]	In vivo; AI; EC	Wisniewski et al. 1988
		B. cinerea	*Candida* sp.[b]	In vivo; EC	McLaughlin et al. 1990
		B. cinerea	*Cryptococcus laurentii* (Kuff.) Skinner	In vivo; AI; BEF	Roberts 1990a
		B. cinerea	*K. apiculata*	In vivo; AI; LC	McLaughlin et al. 1992
	Mucor rot	*Mucor piriformis* Fisher	*P. cepacia*	In vivo; AI; EC	Janisiewicz and Roitman 1987
	Dry eye rot	*B. cinerea*	*Trichoderma harzianum* Rifai	Field sprays; NI; BEF	Tronsmo and Ystaas 1980
		B. cinerea	*Trichoderma pseudokoningii* Rifai	Field sprays; EC	Tronsmo and Raa 1977
	Scab	*Venturia inaequalis* (Cke.) Wint.	*Chaetomium globosum* Kunze and Stend.; *Athelia bombacina* Pers.	In vivo on leaves; EC	Heye and Andrews 1983
		V. inaequalis	*C. globosum*	Growth chamber; field; NC	Boudreau and Andrews 1987
	Fireblight	*Erwinia amylovora* (Burrill) Winslow, Broadhurst, Buchanan, Krumwiede, Rogers and Smith	*E. amylovora*; *Pseudomonas . syringae* pv *tabaci* (Wolf and Foster) Young et al.	In vivo; AI; EC	Wrather et al. 1973
Apricot (*Prunus armeniaca* L.)	Brown rot	*Monilinia fructicola* (Wint.) Honey	*Bacillus subtilis* (Ehrenberg) Cohn	In vivo; AI; EC	Pusey and Wilson 1984
Avocado (*Persea americana* Mill.)	Anthracnose *Dothiorella*/ *Colletotrichum* fruit rot complex (DCC)	*Colletotrichum gloeosporioides* Penzig *C. gloeosporioides* and *Dothiorella aromatica* (Sacc.) Petrak and Sydow	*B. subtilis*; *Bacillus cereus* Frankland and Frankland; *Bacillus licheniformis* (Weigmann) Chester	Preharvest field sprays; Postharvest dips; NI; IC; EC; ECC	Korsten et al. 1989
	Stem-end rot (SE)	*C. gloeosporioides; D. aromatica; Thyronectria pseudotrichia* (Schw.) Seeler; *Phomopsis perseae* Zerova; *Lasiodiplodia theobromae* (Pat.) Giffon and Maubl.; *Fusarium solani* (Mart.) Appel and Wr. emend. Snyd. and Hans.			

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Table 1. Continued.

Commodity	Disease	Pathogen	Antagonist	Status of research[a]	Reference
Avocado (*Persea americana* Mill.) (cont'd)	Anthracnose DCC SE	*C. gloeopsporioides* *C. gloeosporioides*; *D. aromatica* *C. gloeosporioides*; *D. aromatica*; *T. pseudotrichia*; *P. perseae*; *L. theobromae*; *F. solani*	*B. subtilis*	Postharvest dip; NI; IC; EC; ECC; PT	Korsten et al. 1991a
	Anthracnose DCC SE	*C. gloeopsporioides* *C. gloeosporioides*; *D. aromatica* *C. gloeosporioides*; *D. aromatica*; *T. pseudotrichia*; *P. perseae*; *L. theobromae*; *F. solani*	*B. subtilis*; *B. cereus* *B. licheniformis*	Postharvest dip; NI; IC; EC; ECC; PT	Korsten and Kotzé 1992
Blueberry (*Vaccinium corymbosum* L.)	Alternaria rot	*Alternaria alternata* (Fr.) Keissler; *Alternaria tenuissima* (Kunze ex Pers.) Witts.	*P. cepacia*	In vivo; AI; EC	Stretch 1989
Cherry (*Prunus avium* L. X *P. cerasus* L.)	Alternaria rot	*A. alternata*	*B. subtilis*	In vivo; AI; BEF	Utkhede and Scholberg 1986
	Brown rot	*M. fructicola*	*B. subtilis*	In vivo; AI; BEF	Utkhede and Scholberg 1986
Citrus spp.	Blue mould	*Penicillium italicum* Wehmer	*P. cepacia*	In vivo; AI; EC	Wilson and Chalutz 1989
		P. italicum	*P. cepacia*; *Aureobasidium pullulans* (De Bary) Arnaud; *Pseudomonas syringae* Van Hall; *Debaryomyces hansenii* (Zopf) Van Rij[b]	In vivo; AI; EC	Wilson and Chalutz 1989
		P. italicum	*P. guilliermondii*[b]	In vivo; AI; EC	Droby et al. 1991b
		P. italicum	*D. hansenii*[b]	In vivo; AI; EC	Chalutz and Wilson 1992
	Green mould	*Penicillium digitatum* (Pers. ex St.-Am.) Sacc.	*B. subtilis*	In vivo; AI; EC	Singh and Deverall 1984
		P. digitatum	*Myrothecium roridum* Tode ex Steudel; *Myrothecium verrucaria* (Alb. and Schw.) Ditm. ex Steudel	In vivo; AI; EC	Appel et al. 1988
		P. digitatum	*P. syringae*; *D. hansenii*; *A. pullulans*; *P. cepacia*	In vivo; AI; EC	Wilson and Chalutz 1989
		P. digitatum	*Trichoderma viride* Pers. ex Gray	In vivo; AI; EC	De Matos 1983
		P. digitatum	*T. viride*	In vivo; AI; EC	Borrás and Aguilar 1990
		P. digitatum	*D. hansenii*[b]	In vivo; AI; NI; EC	Chalutz and Wilson 1990
		P. digitatum	*P. cepacia*; *Pseudomonas corrugata* Roberts and Scarlett; *Pseudomonas fluorescens* Migula	In vivo; AI; EC; CF	Smilanick and Dennis-Arrue 1992

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Table 1. Continued.

Commodity	Disease	Pathogen	Antagonist	Status of research[a]	Reference
Citrus spp. (cont'd)	Green mould (cont'd)	*P. digitatum*	*Bacillus pumilus* Meyer and Gottheil	In vivo; EC	Huang et al. 1992
		P. digitatum	*P. guilliermondii*[b]	In vivo; AI; EC	Droby et al. 1991b
		P. digitatum	*P. guilliermondii*[b]	Packhouse; PT; NI; BEF	Hofstein et al. 1991; Droby et al. 1991b
	Sour rot	*Geotrichum candidum* Link ex Leman	*T. viride*	In vivo; AI; EC	De Matos 1983
		G. candidum	*B. subtilis*	In vivo; AI; EC	Singh and Deverall 1984
		G. candidum	*D. hansenii*[b]	In vivo; AI; EC	Chalutz and Wilson 1990
		G. candidum	*P. guilliermondii*[b]	In vivo; AI; EC	Droby et al. 1991b
	Alternaria rot	*Alternaria citri* Ellis and Pierce	*B. subtilis*	In vivo; NI; EC	Singh and Deverall 1984
Cranberry (*Vaccinium macrocarpon* AIT)	Black rot	*Apostrasseria lunata* (Shear) Nag Raj *Strasseria oxycocci* Shear	Bacteria; *A. pullulans*	In vivo; AI, EC	Stretch 1989
Grape (*Vitis vinifera* L.)	Grey mould	*B. cinerea*	*T. harzianum*	Field sprays; EC	Dubos 1984
		B. cinerea	*P. guilliermondii*[c]	In vivo; AI; EC	Chalutz et al. 1988
		B. cinerea	Bacteria; *Bacillus* sp.	In vivo; AI; EC	Ferreira 1990
		B. cinerea	*P. guilliermondii*[b]; *Hanseniaspora uvarum* (Niehaus) Shehata et al.	In vivo; AI; NI; EC	Ben-Arie et al. 1991
		B. cinerea	*P. guilliermondii*[b]; *H. uvarum*	Field sprays; NI; EC	Ben-Arie et al. 1991
	Rhizopus rot	*Rhizopus stolonifer* (Ehrenb. ex Link) Lind	*P. guilliermondii*[b]	In vivo; AI; EC	Chalutz et al. 1988
		Rhizopus stolonifer	*Candida guilliermondii*[b] (Castalani) Langeron et Guerra; *K. apiculata*	In vivo; NI; EC	McLaughlin et al. 1992
	Black storage rot	*Aspergillus niger* Van Tieghem	*C. guilliermondii*[b]; *K. apiculata*	In vivo; NI; NC	McLaughlin et al. 1992
Lychee (*Litchi chinensis* Sonn.)	Postharvest rot	*Phomopsis* sp.; *Penicillium* sp.; *Pestalotia* sp.; *C. gloeosporioides*	*Bacillus stearothermophilus* Donk; *Bacillus megaterium* de Bary; *B. licheniformis*	Postharvest dip; NI; IC; ECC	Korsten et al. 1993[b]
Mango (*Mangifera indica* L.)	Anthracnose	*C. gloeosporioides*	Bacteria; yeasts; *Pseudomonas* sp.	Postharvest dip; AI; EC	Koomen et al. 1990; Jeffries and Jeger 1990
		C. gloeosporioides	*B. licheniformis*	Postharvest dip; NI; IC; ECC	Korsten et al. 1991[b]
		C. gloeosporioides	*B. licheniformis*	Preharvest sprays; NI; IC; EC	Korsten et al. 1992
		C. gloeosporioides	*B. cereus; P. fluorescens*	Postharvest dip; NI; EC	Koomen and Jeffries 1993
	Soft brown rot	*Nattrassia mangiferae* (Sydow and Sydow, Sutton and Dyks)	*B. licheniformis*	Field sprays; NI; IC; BEF	Korsten et al. 1992
	Black spot	*Xanthomonas campestris* pv *mangiferaeindicae* Rbbs, Ribeira Kumura	*B. licheniformis*	Field sprays; NI; EC	Visser et al. 1990
		X. campestris pv. *mangiferaeindicae*	*B. subtilis; Bacillus amyloliquefaciens* Priest, Goodfellow, Shute and Berkeley	In vivo; AI; EC	Pruvost and Luisetti 1991

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Table 1. Continued.

Commodity	Disease	Pathogen	Antagonist	Status of research[a]	Reference
Nectarine (*Prunus persica* var. *nucipersica* Schneid.)	Brown rot	*M. fructicola*	*B. subtilis*; *Pseudomonas* spp.	In vivo; AI; LC	Pusey and Wilson 1984
Peach (*Prunus persica* Sieb. and Zucc.)	Brown rot	*M. fructicola*	*B. subtilis*	In vivo; AI; EC	Pusey and Wilson 1984
		M. fructicola	*B. subtilis*	In vivo; AI; EC	Pusey et al. 1986
		M. fructicola	*B. subtilis*	Packhouse wax; AI; BEF; PT	Pusey et al. 1988
	Rhizopus rot	*R. stolonifer*	*B. subtilis*	In vivo; AI; EC	Pusey and Wilson 1984
		R. stolonifer	*Enterobacter cloacae* (Jordon) Hormaeche and Edwards	In vivo; AI; BEF	Wilson et al. 1987
		R. stolonifer	*E. cloacae*	In vivo; AI; EC	Wisniewski et al. 1989
		R. stolonifer	*K. apiculata*	In vivo; AI; LC	McLaughlin et al. 1992
Pear (*Pyrus communis* L.)	Blue mould	*P. expansum*	*P. cepacia*	In vivo; EC	Janisiewicz and Roitman 1988
		P. expansum	*P. syringae*	Postharvest dip; AI; EC	Janisiewicz and Marchi 1992
	Grey mould	*B. cinerea*	*P. cepacia*	In vivo; EC	Janisiewicz and Roitman 1988
		B. cinerea	*Pseudomonas gladioli* Severini	In vivo; AI, EC	Mao and Cappellini 1989
		B. cinerea	*P. syringae*	Postharvest dip; AI; EC	Janisiewicz and Marchi 1992
	Mucor rot	*M. piriformis*	*C. laurentii; Cryptococcus flavus* (Saito) Phaff et Fell; *Cryptococcus albidus* (Saito) Skinner	In vivo; AI; EC	Roberts 1990b
	Fireblight – fruit	*E. amylovora*	*Erwinia herbicola* (Lohnis) Dye	In vivo; AI; EC	El-Goorani and Beer 1991
		E. amylovora	*E. amylovora*; *P. tabaci*	In vivo; AI; EC	Wrather et al. 1973
Pineapple (*Ananas comosus* (L.) Kerr)	Leathery pocket; Fruitlet core rot; Fruitlet corking	*Penicillium funiculosum* Thom	*P. funiculosum* (avirulent)	Field application; AI; EC	Lim and Rohrbach 1980
Plum (*Prunus salicina* Lindl.)	Brown rot	*M. fructicola*	*B. subtilis*; *Bacillus thuriengensis* Berliner	In vivo; AI; EC	Pusey and Wilson 1984
Strawberry (*Fragaria* spp.)	Grey mould	*B. cinerea*	*Cladosporium herbarum* (Pers.) Link ex Gray; *Pullularia pullulans*; (de Bary) Berkh.; *Penicillium* sp..	Greenhouse; AI; EC; Field Sprays EC	Bhatt and Vaughan 1962
		B. cinerea	*Trichoderma* sp.	Field sprays; NI; BEF	Tronsmo and Dennis 1977
		B. cinerea	*Trichoderma* sp.	Field sprays; IC; NC/LC	Gullino et al. 1989
	Strawberry rot	*Mucor mucedo* Mich. ex St.-Am.	*Trichoderma* sp.	Field sprays; NI; BEF	Tronsmo and Dennis 1977

[a] AI = Artificial inoculations; NI = Natural infections; IC = Integrated control included; EC = Effective biological control compared to untreated control; ECC = Biological control significantly more effective than comparative fungicide; PT = Pilot tests; NC = No control; LC = Limited control; BEF = Biological control equally effective as fungicide; in vivo = antagonist tested on fruit or leaves in the laboratory.

[b] *Pichia guilliermondii* (Wickerham) [anamorph, *Candida guilliermondii* (Castalani) Langeron and Guerra] (McLaughlin et al. 1990b), erroneously identified as *Debaryomyces hansenii* (Zopf) Lodder and Kreger Van-Rij (Mclaughlin et al. 1992).

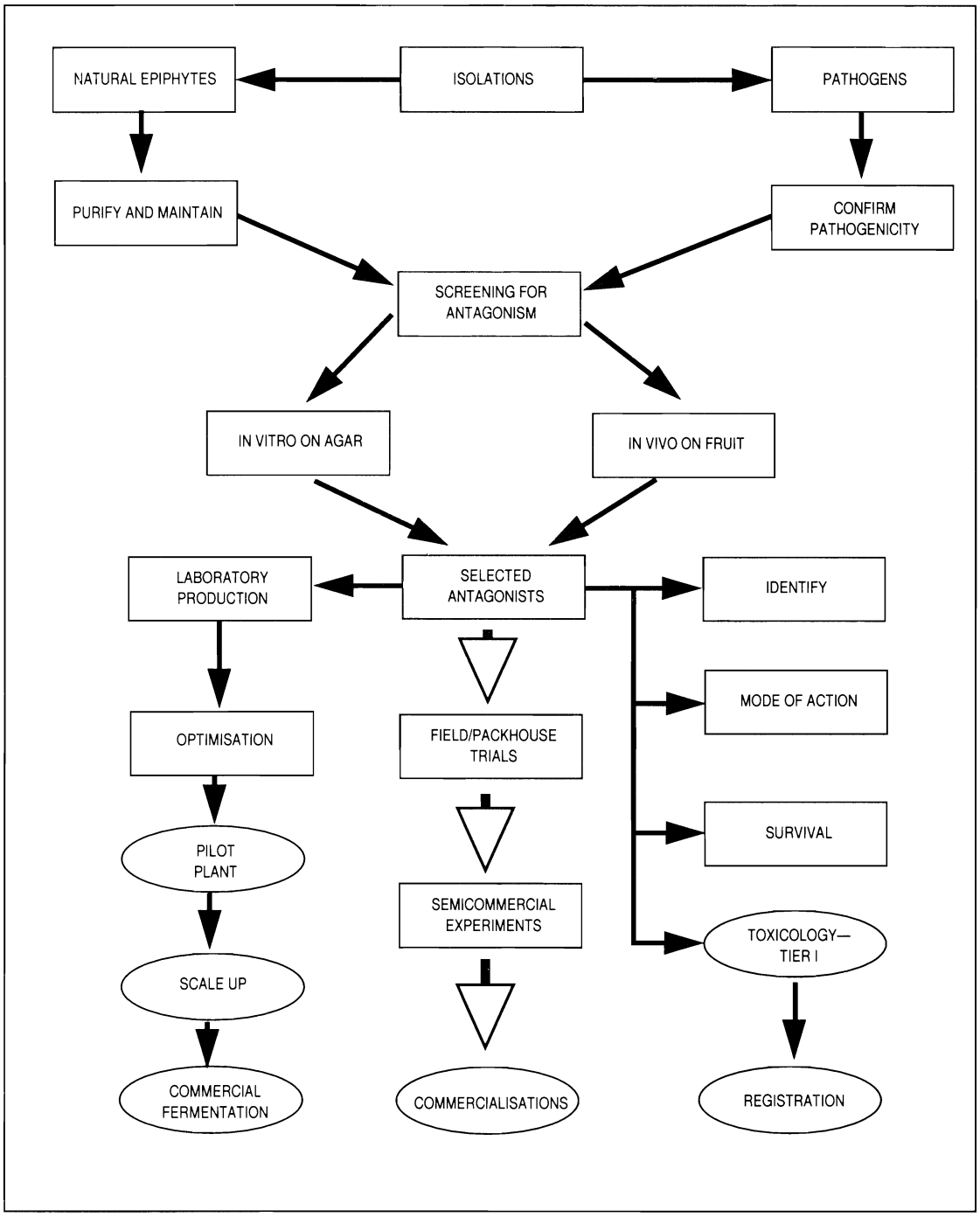

Figure 1. Flowchart of biological control research strategies showing the role of research (❑) and commerce (○)

Although both approaches proved effective, larger volumes of antagonists are required for preharvest sprays than for postharvest applications. For instance, to control postharvest decay in one tonne avocado fruit, approximately 900 L of a 10^9 cells/mL *B. subtilis* suspension is required for preharvest sprays, compared with 1 L for treating one tonne of fruit by postharvest fine spray wax application. This inevitably renders preharvest treatment considerably more expensive. However, preharvest treatment has the added advantage of potentially controlling preharvest as well as postharvest diseases. For example, the preharvest avocado fruit disease *Cercospora* spot caused by *Pseudocercospora purpurea* (Cke) Deighton was effectively controlled with preharvest *Bacillus* sprays aimed at controlling postharvest diseases (Korsten and Kotzé 1992). Furthermore, Korsten et al. (1989) and Korsten (1993) reported that antagonists effectively established a residual population on the phylloplane, which resulted in sustained protection for a prolonged period. Most reports dealing with biological control of postharvest diseases nevertheless involve postharvest antagonist applications (Table 1). These can be targeted more effectively to the site were protection is required (Wilson and Wisniewski 1989). Temperature and humidity can also be controlled more readily in packhouses. In addition, the postharvest environment is an artificial 'ecological island' separated from the buffering effect of natural microbial ecosystems (Wilson et al. 1991). The postharvest environment thus appears to present a more suitable milieu for biological control than do field conditions (Wilson et al. 1991). Only results obtained in the postharvest environment will be discussed in this review.

Latent vs Wound Infections

Knowledge of the epidemiology of the pathogen is one of the prerequisites for practical application of biocontrol agents (Droby et al. 1991a). Most postharvest infections of citrus and temperate fruit occur through wounds, whereas quiescent infections play a major role in subtropical fruit. To control wound-invading pathogens, antagonists must be able to colonise wounds and inhibit the pathogen. Yeasts mostly exert antagonism through competitive colonisation and/or nutrient competition (Droby et al. 1989), and are ideally suited to displace the pathogen in wound lesions. *Debaryomyces hansenii* (Zopf) Van Rij, for instance, exhibits its biocontrol activity most strongly against infections of injured fruit, and not against infections already established in the fruit peel (Chalutz and Wilson 1990). Antagonists which are mostly competent at wound sites cannot be expected to be effective against latent infections or against pathogens that infect tissue directly (Wilson et al. 1991). With tropical and subtropical fruit, quiescent infections and pathogens that infect through lenticels, constitute different 'battlefields' for pathogen/antagonist interactions, and may be more difficult to control biologically (Wilson and Wisniewski 1989). Antagonists used against quiescent infections would therefore require a different mode of action than antagonists used for protection of wounds. In our investigations, *Bacillus* spp. were effective in controlling quiescent infections in both pre- and postharvest application strategies (Korsten et al. 1989, 1991a, 1993a,b; Korsten and Kotzé 1992).

Antagonists

Antagonists successful in controlling postharvest diseases of subtropical crops include bacteria such as *B. subtilis*, *B. licheniformis*, *Bacillus stearothermophilus* Donk, *Bacillus megaterium* de Bary, *Bacillus amyloliquefaciens* Priest, Goodfellow, Shute and Berkeley, *Pseudomonas cepacia* Palleroni and Holmes, *Pseudomonas syringae* Van Hall, *Pseudomonas corrugata* Roberts and Scarlett, and *Pseudomonas fluorescens* Migula, yeasts such as *Pichia guilliermondii* (Wickerham), and the filamentous fungi *Aureobasidium pullulans* (De Bary) Arnaud, *Myrothecium roridum* Tode ex Steudel, *Myrothecium verrucaria* (Alb. and Schw) Ditm. ex Steudel, *Trichoderma viride* Pers. ex Gray, and *Penicillium funiculosum* Thom (Table 1). Suggested characteristics of an 'ideal antagonist' have recently been outlined (Wilson et al. 1991), and the genus *Bacillus* has most of these (Lynch 1988).

In our studies, *Bacillus* spp. were effective in controlling postharvest diseases of avocado, mango, and lychee (Table 1). These *Bacillus* spp. were all dominant naturally-occurring epiphytes of avocado, mango and lychee (Korsten et al. 1991b, 1993a,b; Korsten 1993). *B. subtilis* effectively controlled anthracnose, DCC, and SE in postharvest dip, ultralow volume (ULV) and wax spray applications (Korsten et al. 1989, 1991a; Korsten and Kotzé 1992). Pusey (1989) listed several plant diseases that could be controlled with *B. subtilis*. He was also the first to evaluate *B. subtilis* in semicommercial experiments on the packing line (Pusey et al. 1988), and the first to patent the use of *B. subtilis* as a postharvest biocontrol agent (U.S. Patent no. 4 764 371). Other *Bacillus* spp. evaluated in our studies have not previously been described as antagonists of postharvest fruit pathogens. Of these, *B. licheniformis* controlled anthracnose and SE of mango (Korsten et al. 1991b), lychee postharvest decay (Korsten et al. 1993a) and anthracnose, DCC, and SE on avocado (Korsten and Kotzé 1992). *B. megaterium* and *B. stearothermophilus* were effective against lychee postharvest decay in postharvest dip applications (Korsten et al. 1993b), whereas *B. cereus* reduced the aforementioned avocado postharvest diseases (Korsten et al. 1989; Korsten and Kotzé 1992). Koomen and Jeffries (1993) also reported effec-

tive control of mango anthracnose by using *B. cereus* in postharvest applications.

One of the earliest reported uses of *Bacillus* was the fermentation of soybeans into natto, a traditional Japanese food. The current consumption of natto fermented by *B. subtilis* var. *natto*, together with the low level of reported incidences of pathogenicity amongst strains of *B. subtilis*, and the widespread use of their products and those of their close relatives in the food and beverage industries, have resulted in the granting of GRAS (Generally regarded as safe) status to *B. subtilis* by the U.S. Food and Drug Administration (Harwood 1992).

Mode of Action

In order to optimise disease control, it is important to understand the mode of action of the antagonists so that these attributes can be utilised to improve performance (Lynch 1988). In practice, few organisms antagonise by a single mechanism (Atlas and Bartha 1987). Negative interactions most likely to occur in the plant microbial environment include site exclusion (Janisiewicz 1988), competitive colonisation (Bhatt and Vaughan 1962), nutrient competition (Lim and Rohrbach 1980; Heye and Andrews 1983; Chalutz et al. 1988; Wisniewski et al. 1989; Roberts 1990a; Chalutz and Wilson 1990; 1992; McLaughlin et al. 1990; 1992), antibiosis (Pusey and Wilson 1984; Singh and Deverall 1984; Utkhede and Sholberg 1986; Boudreau and Andrews 1987; Janisiewicz and Roitman 1987; Stretch,1989; Wilson and Chalutz 1989; El-Goorani and Beer 1991; Smilanick and Dennis-Arrue 1992), induction of host defence mechanisms (Lim and Rohrbach 1980; Janisiewicz 1987; Chalutz et al. 1988; Stretch 1989; Chalutz and Wilson 1990; 1992), and direct interaction with the pathogen (Dubos 1984). The mode of action of *Bacillus* is probably through production of antibiotics and/or nutrient and space competition (Utkhede and Rahe 1980; Pusey 1989). Gueldner et al. (1988) reported the isolation of antifungal iturin peptides from *B. subtilis* which are active against mycelial growth of *Monilinia fructicola* (Wint.) Honey. However, antibiotics are secondary metabolites produced by microorganisms under optimal growth conditions when excess substrate is available (Atlas and Bartha 1987; Sequira 1987). Such optimal nutrient conditions, according to Blakeman (1985) and Atlas and Bartha (1987), are not normally found in natural habitats like plant surfaces. Antibiotics also do not accumulate in natural habitats, but can be broken down by resident epiphytes, be inactivated by adsorption to leaf tissue, or be lost to the atmosphere (Atlas and Bartha 1987; Singh and Faull 1988). In certain microsites such as wounds on fruit surfaces, released nutrients can promote antibiotic production by antagonists (Sneh 1990), thus protecting infection sites. However, the role of antibiotics with quiescent infections must still be ascertained. In our investigation, different modes of action were evident at different stages in the life cycle of the pathogen. These included site exclusion, nutrient and space competition, and antibiotic production (L. Korsten, unpublished data).

Integrated Control

Biological products which can be used in combination with conventional crop protection procedures should readily gain acceptance (Schwarz 1992). Although integrated control has been implemented successfully against root diseases (Cook and Baker 1983), surprisingly little information is available on integrated control of above-ground plant diseases (Wilson and Wisniewski 1989; Jeffries and Jeger 1990; Andrews 1992; Wisniewski and Wilson 1992). Nonetheless, various reports on successful integrated control of fruit diseases have been published (Table 1). In our investigations, the *Bacillus* spp. used as antagonists were compatible with benomyl (Korsten et al. 1991b), prochloraz and chlorine (Korsten 1993), and were subsequently evaluated in an integrated program with these compounds. *B. subtilis* in particular showed promise when integrated with quarter strength prochloraz, and effectively controlled SE and DCC on Fuerté, SE and anthracnose on Hass, and SE on Ryan avocado fruit (Korsten et al. 1993a). Such an integrated control approach, using a considerably reduced concentration of the fungicide in combination with an antagonist, could be more acceptable from a safety standpoint than treatment with the fungicide at its recommended concentration (Droby et al. 1991a). However, combining quarter-strength fungicide concentrations with a biocontrol agent was not always more effective than when using the antagonist on its own. For instance, Korsten et al. (1991b) found that a quarter- strength benomyl combined with *B. licheniformis* and applied in a hot water dip (52°C) was less effective in controlling anthracnose on mango than a hot water *B. licheniformis* dip on its own. Similarly, dipping avocado fruit in chlorine before a *B. cereus* dip, did not improve the level of anthracnose and SE control already achieved with a *B. cereus* dip on its own (Korsten et al. 1989).

Chemical vs Biological

If biological control cannot produce results comparable with that of commercial fungicides, it will not be a viable commercial option (Swinburne 1978). Where biological agents have to compete in a market dominated by an effective and relatively inexpensive fungicide, the challenge and demands facing biocontrol agents are great (Andrews 1992). Superimposed on these demands is the reality that growers' concern is primarily with the economic aspects of control, generally risk-averse, and inclined to rely on measures which

act promptly (Andrews 1992). In our investigations, *B. steartermophilus, B. megaterium,* and *B. licheniformis* dip applications on their own or in combination, were more effective than a benomyl dip in controlling postharvest decay and preventing secondary infection of lychee (Korsten et al. 1993b). Also, in a second fine spray application experiment, *B. subtilis* was as effective as benomyl in preventing secondary infections on lychee (Korsten et al. 1993b), while *B. licheniformis* dip treatment was as effective as the commercial benomyl treatment in controlling SE, and more effective in reducing internal anthracnose severity on mango (Korsten et al. 1991b). Furthermore, a *B. cereus* dip treatment controlled avocado postharvest diseases anthracnose, DCC, and SE more effectively than did a prochloraz dip application, and was as effective as the prochloraz ULV application (Korsten and Kotzé 1992).

Antagonist Application Methods

If biocontrol can be made compatible with existing farming practices, it will add to its commercial acceptance. Pusey et al. (1988) incorporated *B. subtilis* into fruit wax used commercially on the packing line, and thereby effectively controlled postharvest diseases on stone fruit. Similarly, Korsten et al. (1991a) were able to control anthracnose, DCC, and SE on avocado with *B. subtilis* applied in Tag-wax (polyethylene) on the commercial packing line. They also found the antagonist capable of surviving for at least 32 hours in the Tag-wax without a reduction in viable cells. This would enable packhouses to mix the antagonist into the wax on a daily basis, without replenishing the antagonist-wax formulation during the day in operation. ULV antagonist applications are effective in controlling avocado postharvest diseases. However, Korsten et al. (1993b) found a *B. megaterium* fine spray application more effective in controlling postharvest decay and secondary infection of lychee than when applying the antagonist in a dip.

Antagonist Concentration

Of importance in any successful biocontrol program is the requirement that the antagonist be effective at low concentrations (Wisniewski et al. 1989). Since effectiveness of control is closely related to initial levels of the pathogen present on the fruit surface, more effective control can be achieved by increasing antagonist concentrations (Janisiewicz 1987). Lychee postharvest decay was controlled at 10^8 cells/mL, but not at lower concentrations. However, secondary infection on lychee fruit was effectively prevented by antagonist concentrations of 10^5–10^8 cells/mL (Korsten et al. 1993b). A similar range of antagonist concentrations was found effective in controlling avocado postharvest diseases (Korsten et al. 1991a).

Antagonists Applied Singly or in Combination

Janisiewicz (1988) found antagonist combinations more effective in controlling several diseases than when antagonists were applied singly. Applying mixtures of antagonists did not necessarily improve effectiveness. For instance, Korsten et al. (1989) found that *B. subtilis* combined with *B. cereus* more effectively controlled DCC than when *B. subtilis* was applied on its own. However, the antagonist mixture was less effective in controlling anthracnose than the *B. subtilis* treatment on its own. On the other hand, Korsten and Kotzé (1992) found *B. cereus* on its own or combined with *B. subtilis* equally effective in controlling all three postharvest diseases of avocado.

Cultivar Effect on Biocontrol

Biocontrol of postharvest fruit diseases is complex, and numerous interactions affect the efficacy of the treatments. Janisiewicz and Marchi (1992) highlighted the importance of cultivar effect on the outcome of biocontrol treatments. Lychee postharvest diseases could effectively be controlled on both Mauritius and Madras lychee cultivars (Korsten et al. 1993b), whereas mango postharvest diseases were effectively controlled on Sensation and Keitt (Korsten et al. 1992). Biocontrol of anthracnose, DCC, and SE of avocado was effective on Fuerté (Korsten et al. 1988, 1989, 1993a; Korsten and Kotzé 1992), and Hass cultivars (Korsten et al. 1991a, 1993a). However, only anthracnose and DCC could be reduced on Edranol (Korsten et al. 1989), and SE on Ryan (Korsten et al. 1993a). Variation in effectiveness when different pear cultivars were dipped in a suspension of *Pseudomonas syringae* Van Hall was attributed to differences in physiological processes governing antagonism (Janisiewicz and Marchi 1992). Variation in susceptibility between cultivars is a well-known phenomenon, e.g. the exceptional proneness of Fuerté avocado fruit to postharvest decay (Jacobs 1974). It is also known that variations in the incidence of avocado postharvest diseases occur throughout the season (Darvas 1982), and that they are related to rainfall (Peterson 1977).

Consistency

Consistency in disease control is an important trait for any disease control agent. Thus, for commercial acceptance, biocontrol will have to give consistently high levels of control (Korsten et al. 1991b). In addition, biocontrol must be effective throughout the season and at several localities, as was demonstrated by Korsten et al. (1993a) with avocado.

Conclusions

A variety of factors will determine the present and future situation in biological and integrated disease control, e.g. public opinion, and the role of regulatory authorities in the commercialisation of biological products (Schwarz 1992). The range of products will be determined by the possibility of obtaining patent protection for organisms intended to be used for biocontrol. Patents have been issued or are pending on a number of these antagonistic microorganisms (Wilson et al. 1991). The acceptance of biological crop protection methods by producers and consumers will also depend greatly on how long they retain their efficacy and whether the methods of application are compatible with existing systems and moreover, whether they operate at a reasonable cost (Schwarz 1992).

In this study, biocontrol has been shown to be a viable option for disease control which can effectively be implemented in any farming practice or packhouse operation. Control equal to or more effective than that achieved with fungicides is possible with optimised antagonist applications. However, certain key aspects will have to be addressed urgently. These include: 1) registration of antagonists with concurrent acquisition of toxicological data; 2) commercialisation and optimisation of fermentation and formulation technology; 3) storage and application of antagonists; 4) product consistency in achieving disease control; and 5) public acceptance of biocontrol as an alternative to fungicides.

Future commercial development of microbial antagonists as biocontrol agents will most likely depend on relatively small niche markets where different antagonists can be used to control specific fruit diseases (Janisiewicz and Marchi 1992). It is perhaps important to keep in mind that biocontrol is fundamental applied ecology (Andrews 1992). Therefore, a thorough knowledge of the mode of parasitism, infection and epidemiology of the pathogen, antagonist mode of action, and microbial interactions can aid considerably in predicting prospects for success. Long-term biocontrol strategies would more and more entail management of microbial communities to favour biocontrol agents and disfavour the pathogen (Andrews 1992). We feel that biocontrol has a lot to offer as a future alternative control strategy.

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Sulfur Dioxide Fumigation in Postharvest Handling of Fresh Longan and Lychee for Export

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Abstract

Sulfur dioxide (SO_2) applied as a fumigant effectively controlled saprophytic surface fungi and prevented skin browning, two of the major postharvest problems of harvested fresh longan and lychee. A standardised procedure using gaseous SO_2, whereby a ratio of 5:1 between the free space volume (mL or L) of the fumigation chamber and fruit weight (g or kg) was employed.

The effect of SO_2 on surface growth of fungi, SO_2 injury to the rind, and SO_2 residue levels in the treated fruit depended on the concentration of SO_2 applied, and varied with cultivar, particular crop, and the duration of fumigation. From 30–65% of applied sulfur dioxide was absorbed by the fumigated fruit. Maximum efficacy was obtained when whole fruit residues immediately after fumigation were 200–350 ppm. Residue levels decreased rapidly during the first two days after fumigation. Residues were concentrated in the skin. Levels in the fruit aril were very low. A maximum residue level (MRL) of 30 ppm for the fruit aril is proposed.

There is scope for a choice of application system for commercial fumigation facilities. The system used at present for longan employs an initial fumigation using a high concentration of SO_2 for a short duration, allowing an operator to treat more than one chamber load per night. Whatever the application system, fumigation facilities must include a scrubbing system to reduce the operator and environmental hazards associated with the use of SO_2.

During the 1991 and 1993 seasons, a range of SO_2 slow-release pads was developed at the Thailand Institute for Scientific and Technological Research (TISTR). These are suitable for the control of skin browning and disease in lychee and longan during a range of storage and transportation times. There is now the potential for a European market accessible by sea for Thai lychees and longans.

Sulfur dioxide (SO_2) is one of the most widely used food preservatives. The fumes of burning sulfur were used by the ancient Egyptians and Romans to sanitise wine vessels, an application which continues to this day in a more controlled manner. Sulfiting agents such as sulfur dioxide, sodium and potassium metabisulfite, and sodium and potassium sulfite have been used in food. The sulfites display a wide range of useful effects in food, including inhibition of non-enzymatic browning (the formation of mellanoidin pigments), as an antioxidant, and as a reducing agent by inhibition of various enzymatic catalysed reactions (notably enzymatic browning involving oxidation of phenolic compounds present in food), and inhibition and control of microorganisms. Their control of browning and antimicrobial effects maintain the quality and nutritional value of food. A partial list of sulfited food is provided in Tables 1 and 2 (Taylor and Bush 1986).

Sometimes sulfites are condemned as cosmetic additives added merely to improve the physical appearance of the finished products, particularly in their restaurant application in salad bars. It is this application that has been the most problematic, since the sulfite added to lettuce remains in free inorganic form not in a bound form as occurs with other fruit and vegetables (Martin et al. 1986). While scientific panels continue to judge sulfites as safe for the majority of consumers, considerable concern has arisen regarding the potential hazards faced by sulfite-sensitive individuals, who are almost exclusively severe asthmatics. The threshold for sulfite sensitivity varies among individuals and the type of food, ranging from about 3 mg to 120 mg SO_2 equivalent. A joint FAO/WHO Expert Committee on Food Additives applied a 100-fold safety factor, and estimated the acceptable daily intake (ADI) for humans at 0.7 mg/kg of body weight/day (cited by Taylor and Bush 1986). A selection of particular meals can result in considerably higher sulfite intakes. However, exceeding the ADI in this manner would result in no harm to normal individuals unless done on a regular basis.

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Table 1. Estimated total SO_2 levels as consumed in some sulfided foods

Food	Total SO_2 (ppm)
>100 ppm	
Dried fruit (excluding dark raisins, prunes)	1200
Lemon juice (non-frozen)	800
Salad bar lettuce	400–950
Lime juice (non-frozen)	160
Wine	150
Molasses	125
Sauerkraut juice	100
50–99.9 ppm	
Dried potatoes	35–90
Grape juice (white, white sparkling, sparkling, red sparkling	85
Wine vinegar	75
Gravies, sauces	60
Fruit topping	60
Maraschino cherries	50
10.1–49.9 ppm	
Pectin	>10–50
Shrimp (fresh)	>10–40
Corn syrup	30
Sauerkraut	30
Pickled peppers	30
Pickled cocktail onions	30
Pickles/relishes	30
Corn starch	20
Maple syrup	20
Imported jams and jellies	14
Fresh mushrooms	13
<10 ppm	
Malt vinegar	10
Dried cod	10
Canned potatoes	10
Beer	10
Dry soup mix	10
Soft drink	<10
Instant tea	<10
Pizza dough (frozen)	<10
Pie dough	<10
Sugar (esp. beet sugar)	7
Gelatin	6.6
Coconut	5
Fresh fruit salad	5
Domestic jams and jellies	5
Crackers	5
Cookies	5
Grapes	1–5
High fructose corn syrup	3

Source: The re-examination for the GRAS status of sulfiting agents. January 1985. Life Science Research Office. Federation of American Societies for Experimental Biology. Total SO_2 level based on Monier-Williams assay.

Table 2. Suggested sulfur dioxide levels in dried vegetables and fruit

Food	SO_2 (ppm)
Beans	500
Cabbages	1000–2500
Carrots	500–1000
Peas	300–500
Potato granules	250
Potato slices	200–400
Corn	2000
Apples	1000–2000
Apricots	2000–4000
Peaches	2000–4000
Pears	1000–2000
Raisins	1000–1500

In 1986, the U.S. Food and Drug Administration proposed two regulations relating specifically to sulfites (FDA 1986a,b). One requires the declaration of sulfites on the label when the residual sulfite exceeds 10 ppm as total SO_2. The second regulation rescinded the generally recognised as safe (GRAS) status for sulfites for use on fruit and vegetables in the raw state, including the direct use of sulfite in salad bars. Allowable SO_2 levels of selected food items in selected countries are given in Table 3 (Anon. 1992). Foods for which no regulatory standards exist are also allowed to contain sulfites. However, this provision excludes meat, fish, poultry, and foods recognised as a source of thiamine (Hadziyev 1988).

In summary, there is reason for concern about sulfite use in food. However, the use of good manufacturing practice and labelling may be sufficient to control existing hazards for sulfite-sensitive asthmatics.

Use of Sulfur Dioxide on Fresh Grapes

SO_2 was used in California in the 1920s to prevent decay and fermentation of wine grapes. However, it took several years, until 1931–1932, to develop a satisfactory fumigation program for table grapes (Pentzer et al. 1932). An initial gas treatment was developed which effectively controlled decay during the 8–10 days required to transport the refrigerated fruit to eastern markets (Harvey 1955). Later (1956–1959), the treatment schedule was expanded to include periodic refumigations for grapes held in storage up to 6 months (Harvey 1956; Ballinger 1985). It became a standard practise in California to apply the initial fumigation the same day that the grapes are harvested.

SO_2 fumigation of grapes is aimed primarily at controlling decay caused by fungi. The treatment sterilises the berry surface. SO_2 is also beneficial to the stems, causing them to bleach slightly and retain a light green colour (Harvey 1977). With the exception of grapes,

Table 3. Allowable SO_2 levels (ppm) in food in selected countries

Country	Food	Allowable SO_2 levels
Canada	Dried fruit and vegetables	2500
	Beverages	70 (free)
	Wines	350 (total)
	Beer	15
	Sweeteners	
	corn syrups and molasses	500
	dextrose	20
	Tomato paste and products	500
	Fresh fruit	0
Hong Kong		350
Malaysia	Dried fruit	2000
	Fruit juice (conc.)	350
	Wines	450
	Ginger (direct consumption)	140
	Ginger (dry root)	150
	Glucose syrup	300
	Glucose	40
	Fresh fruit	0
Singapore	Dried fruit and vegetables	2000–3000
	Fruit (other than fresh fruit)	350
	Fruit juice (conc.)	350
	Fruit juice (direct)	120
	Wine	300
	Ginger (dry root)	150
	Sugar or sugar syrups	70
	Tomato pulp and products	350
	Yoghurt, fruits	60
	Fresh fruit (pulp)	0
Japan	Standards of usage for foods in general	30
The Netherlands		100 (not exceeding 300 at the exporting countries)
France	Fresh lychee	30 (temporary level considering to lower to 10)
USA	Fresh grape	10

most other fresh fruits are easily injured by SO_2. When applied incorrectly, SO_2 may also cause various degrees of injury to grapes. Thus, they should be exposed to only the minimum quantity of gas needed.

A number of systems for treating fresh grapes has been developed over the years (Nelson and Gentry 1966, 1968; Nelson 1970; Harvey and Vota 1978). The systems most commonly employed are: an initial high concentration–short duration SO_2 fumigation followed by subsequent periodic fumigation at a slightly lower concentration; the use of SO_2 slow-release pads enclosed in the fruits boxes (Anon. 1981); and a continuous trickle system at a low level of SO_2 for long-term storage (Dahlenburg et al. 1979).

Postharvest Handling of Longan and Lychee and the Use of Sulfur Dioxide in Maintaining Fruit Qualities

Longan and lychee are probably two of the most perishable of tropical fruits. There are two areas in the postharvest handling chain of longan and lychee which deserve special attention. Firstly, precooling should be applied to remove field heat and provide effective tem-

perature management during transportation. This enables maintenance of fresh quality and flavour, reduces desiccation, and prevents browning of the rind. Secondly, effective postharvest fungicidal treatment is needed to prevent fruit decay.

Both longan and lychee are non-climacteric fruit which exhibit, at 25°C, a moderate rate of respiration (30–45 mL CO_2 /kg/hour), and a low rate of ethylene production (less than 0.1 µL/kg/hour) (Tongdee et al. 1982). However, both fruits deteriorate rapidly after harvest. Shelf life at room temperature (30°C) is less than 72 hours (Campbell 1959). One of the major problems at high temperatures and humidities is the growth of saprophytic fungi, mainly *Botryodiplodia* spp., on the fruit surface (Prasad and Bilgrami 1974). At a low relative humidity, deterioration by decay is reduced, but the fruit loses its freshness. The rind turns brown, dry, and brittle, and the aril wilts and shrivels. The rot problem is reduced but not entirely eliminated by cold storage. Fruit stored at 5–7°C also suffer from chilling injury, indicated by browning of the rind, and upon removal to ambient temperatures, the injured fruit are more susceptible to fungal infection (Tongdee et al. 1982).

Earlier attempts to develop postharvest treatments for longan and lychee (Morevil 1973; Akamine and Goo 1977; Swarts and Anderson 1980; Scott et al. 1982; Johnson 1989;) including an adaptation of SO_2 fumigation procedures used for fresh table grapes (Roth 1963, cited in Nip 1988; Hu and Liu 1979) were either ineffective or resulted in the development of off-flavour.

However, by 1984, reports from South Africa were saying that sulfur fumigation was effective in controlling decay and preventing browning of fresh lychee (Swarts 1985), and exporters in South Africa were able to successfully ship large volumes of lychee by sea to Europe.

Application of Sulfur Dioxide for Longan and Lychee by the Initial Fumigation System and its Commercial Application in Thailand

In the fumigation system, SO_2 gas is added to an enclosure in order to control or eliminate undesirable microorganisms. The most appropriate system for longan under the present handling system in Thailand, where the transportation period is less than 2 weeks to major longan importing countries, is the high concentration–short duration fumigation system. The development of such a fumigation system also takes into consideration the scale of operations, compatibility with the existing handling, packaging, and marketing systems, and socioeconomic circumstances in Thailand.

Gaseous SO_2 from vaporising liquid SO_2 held in pressurised cylinders was used as a source of SO_2 in all experimental work carried out at the Thailand Institute for Scientific and Technological Research (TISTR). For small- scale fumigation, plastic surgical syringes were used to withdraw SO_2. Nonabsorptive glass or plastic containers were used as fumigation chambers. For large-scale work, fumigation chambers made of either stainless steel (capacity 0.5 m^3) or formica-lined plywood (capacity 1.7 m^3) were used and a precision flowmeter used for introducing SO_2 into the chamber.

For consistency and reproducibility, a standardised fumigation procedure was used where the ratio of fruit weight and the free-space volume of the fumigation chamber was maintained at 1:5. Separate indices were established to indicate the degree of fungal growth on the fruit surface and SO_2 injury of the rind. SO_2 was assayed by a modified Monier-Williams method. For a small fumigation container, residual headspace SO_2 at the end of fumigation was determined by subjecting the container to a continuous airflow for about 30 minutes and trapping the outflow air in a 3% hydrogen peroxide solution containing an indicator. The SO_2 in the trap was titrated with alkali and quantified. For a large chamber, final headspace SO_2 concentration was determined by portable SO_2 detector tube (Drager tube). For commercial operations, SO_2 was generated by burning sulfur heated by an external electric source. Most fumigation rooms were made of formica-lined plywood.

The effect of 20 minutes fumigation with SO_2 on fungal growth and symptoms of SO_2 injury on the rind depended on the application rates, as illustrated for lychee cv. Honghuai and longan cv. Do in Figures 1 and 2. Fungal growth or rotting was effectively controlled at high application rates. Symptoms of SO_2 injury occurred at intermediate concentrations and resulted in a far more extensive fungal growth on the surface of the fruit than found on the non-fumigated control. *Botryodiplodia* spp. remained the predominant fungi on the surface of fruit fumigated at below a minimum rate. The main symptoms of SO_2 injury on lychee immediately after fumigation was an uneven bleaching of the rind which developed into irregular reddish-brown spots, circles, or lines by 24 hours. As the application rate increased, there was a uniform bleaching of the rind, its colour changing from red to creamy yellow.

On longan the symptoms of SO_2 injury, indicated by irregular brown circles or lines, became apparent on the underside of the rind 2 days after fumigation. Uniform bleaching of the rind of longan fruit, at higher application rates, resulted in an attractive pale-brown colour. However, at excessively high application rates, the aril turned from shiny and translucent to dull white in both longan and lychee and an off-flavour became apparent. The aril of fumigated fruit turned pinkish. This was especially noted on the stem end of longans after 10 days or longer in storage. Recontamination occurred during long-term storage with *Penicillium* sp. becoming the predominant flora on the fruit surface.

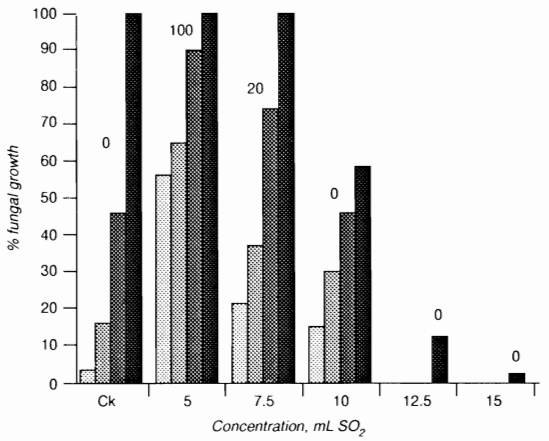

Figure 1. Effect of SO_2 fumigation concentrations on surface fungal growth on lychees. Columns within each treatment represent fungal growth assessed in sequence on days 7, 9, 10, and 11. Values above each column indicate SO_2 injury (%).

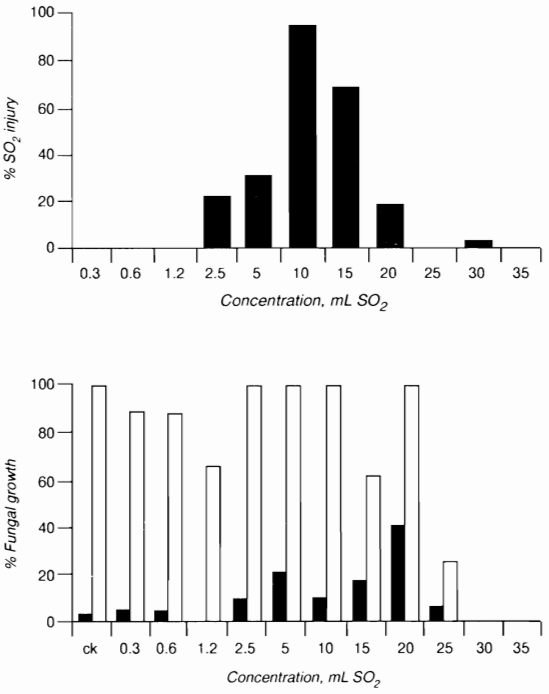

Figure 2. Effect of SO_2 fumigation concentrations on SO_2 injury and surface fungal growth on longans. Columns in treatments ck to 10 mL represent fungal growth assessed on days 4 (■) and 7 (❑), and in 15–35 mL assessed on days 6 (■) and 8 (❑).

SO_2 residues increased with length of fumigation (Fig. 3). Applied SO_2 was found mainly on the rind. Residue levels at 100 ppm showed evidence of partial inhibition of fungal growth. Due to SO_2 injury occurring at shorter fumigation duration, a minimum of 20 minutes was required. Immediately after fumigation, residue levels ranged from 150–400 and 1200–3200 ppm for the whole fruit and the rind, respectively (Figs 4 and 5), depending on the application rates. Residue levels declined with storage by approximately 50% during the first 2 days. Seven days after fumigation, fruit maintained residue levels of 35–100 and 150–800 ppm for the whole fruit and the rind, respectively, depending on the application rates. The aril had few or only trace residues. There was a slight increase in residue levels in the aril with storage. This increase was also noted in lychee (data not shown). The effects of several pre- and post-fumigation treatments on longan, including aeration or washing, had little effect on SO_2 residues assayed immediately after fumigation (Table 4).

In a series of carefully executed and analysed experiments on lychee, SO_2 levels were assayed periodically to determine the effect of various post-fumigation treatments, including the use of an acid dip for colour improvement of fumigated lychees. Residue levels on the rind showed significant differences, supporting the theory of a carryover effect: the migration of SO_2 from the rind to the aril. It is probable that the aril, affected by the carryover SO_2 on the rind, remains as though subjected to continuing fumigation by SO_2. Thorough aeration to reduce the SO_2 levels in the rind of the fruit after fumigation is thus strongly recommended.

Table 4. Effect of pre- and post-fumigation treatment on SO_2 residues (ppm) in longan

Treatment	Whole	Rind	Aril
Standard fumigation treatment	160	1280	0
Pre-fumigation treatment			
wet fruit	185	1120	3
air drying of wet fruit	190	1360	0
Post-fumigation treatment			
aeration	150	1340	2
washing with water having pH adjusted at:			
pH2	160	1300	0
pH4	170	1360	<1
pH7	145	1200	0
pH12	170	1360	0

A linear relationship exists between application rates and residue levels (whole fruit basis) of fumigated fruit (Fig. 4) and the respective final residual SO_2 concentrations in the headspace (final concentration) of the fumigation chamber (Fig. 6). For longan fumigated at a recommended rate of 200–300 mL SO_2/kg of fruit, SO_2

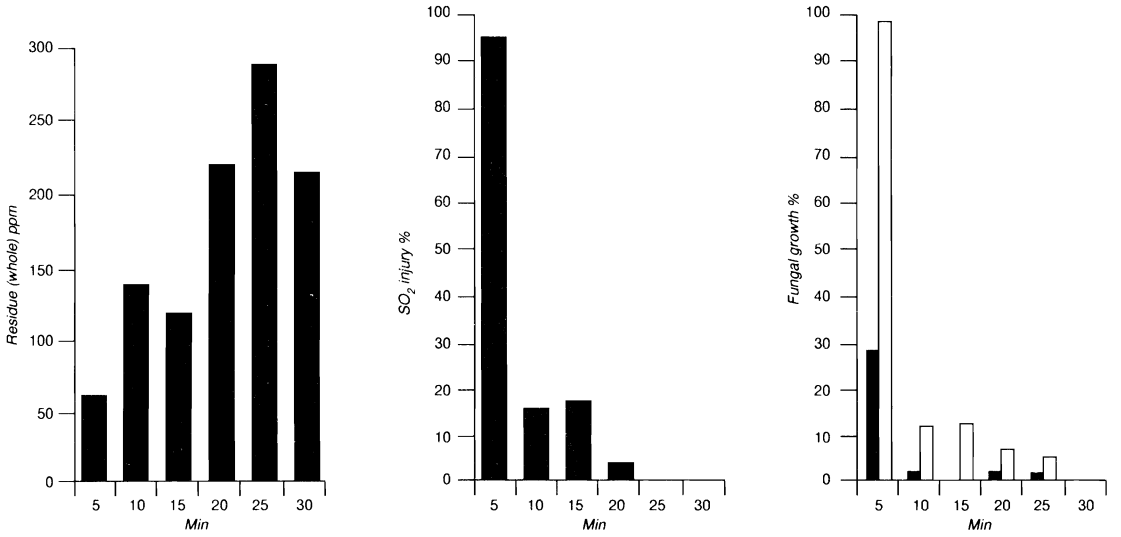

Figure 3. Effect of fumigation exposure periods on SO_2 residues (whole fruit), surface fungal growth, and SO_2 injury of longans. Residues were analysed immediately after fumigation. Columns in each treatment represent fungal growth assessed on days 4 (■) and 7 (❑).

residues ranged from 200–300 ppm and 1500–2500 ppm (data shown in Fig. 5) for the whole fruit and the rind, respectively. At such a rate, SO_2 concentration remaining in the chamber at the end of the fumigation period was about 1.5%. The recommended rate for lychee cv. Honghuai and cv. Emperor is 75–125 mL SO_2/kg and for cv. Khom, 125 mL SO_2/kg, and the residential headspace SO_2 concentrations 0.3–0.45 and 0.65%, respectively. A linear relationship between application rates and sorption of SO_2 by the fruit, calculated from the difference between the SO_2 applied and the remaining headspace SO_2 in the chamber, is illustrated in Figure 7. Figure 8 plots SO_2 residues obtained by theoretical calculation and by direct SO_2 assaying. Some 30–65% of applied SO_2 can be accounted for. Our results indicate that there are important equilibria between the amount of SO_2 applied, and sorption of the fruit, and the SO_2 residues detected on the fruit.

Correct fumigation requires the establishment of an SO_2 concentration sufficiently high to result in an effective SO_2 level on the rind, thus providing a desirable degree of control of fungal growth on the fruit surface throughout the marketing period. The concentration should be such as to avoid SO_2 injury symptoms on the rind, tainting of the aril, and unnecessarily high residue levels. A high level of SO_2 on the rind appears to sterilise the fruit surface, as indicated by the occurrence of recontamination on longan and lychee fruit with storage, where *Penicillium* sp. rather than *Botryodiplodia* spp. became the predominant fungus on the fruit surface.

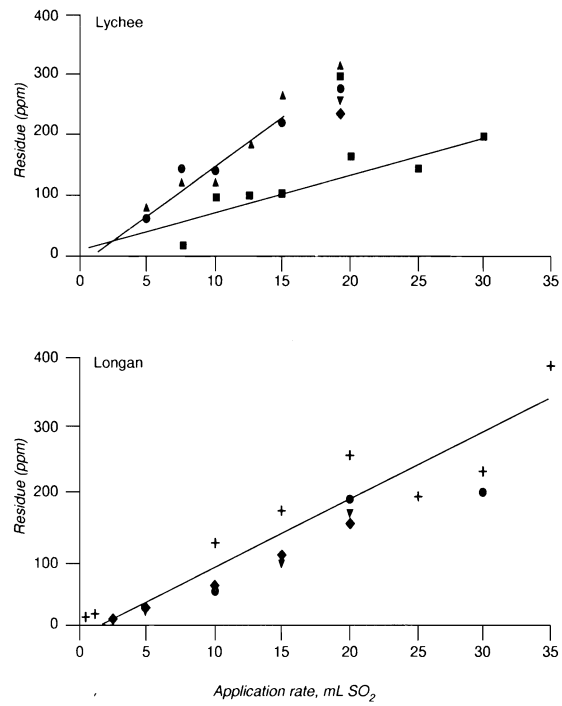

Figure 4. Relationship between SO_2 application rates and SO_2 residues (whole fruit) of fumigated lychees (cv. Honghuai and Khom) and longans (cv. Do).

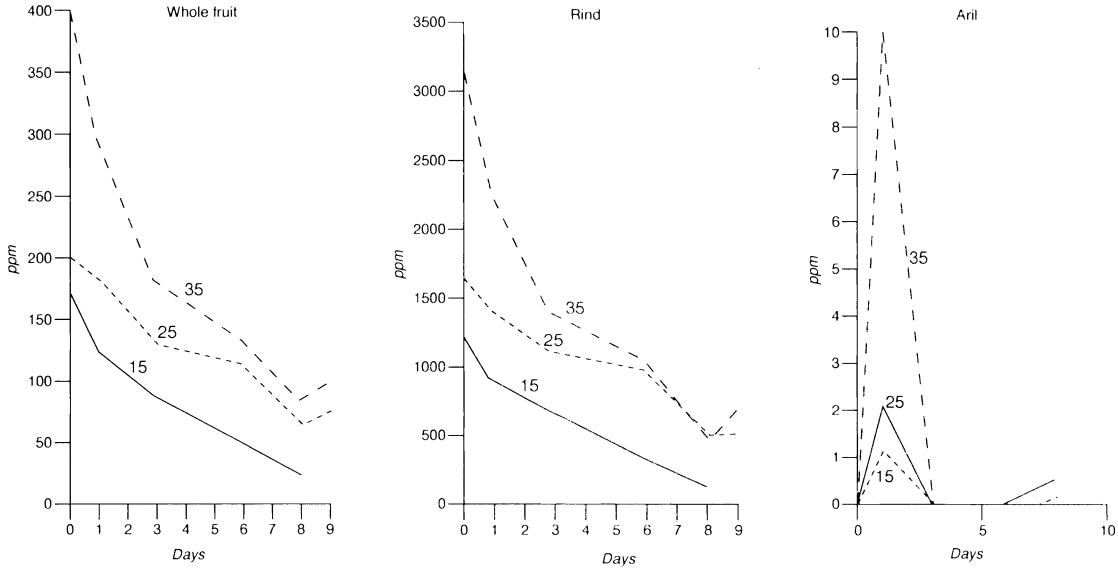

Figure 5. SO_2 residues on fumigated longan fruit stored at 22°C. SO_2 application rates (mL/kg) indicated on curves.

Variations from standard fumigation procedures are often unavoidable during commercial operations. For example, when burning sulfur is used as a source of SO_2, the SO_2 concentration increases gradually in the chamber. Splitting the SO_2 gas injection was used to simulate such a condition in our test chamber. Table 5 indicates that longan fruit receiving split SO_2 injections had residue levels similar to those having one injection, provided sufficient fumigation time after the last injection was allowed. Timing of fumigation duration (a minimum of 20 minutes) should begin only when sulfur has been completely burnt.

Table 5. Comparison of single and split application of SO_2 on residue levels (ppm) in longan

Application method	Whole fruit	Rind	Aril
30 mL for 20 min	320	1950	1
30 mL for 40 min	370	2250	8
15 mL for 10 min plus 15 mL for 10 min	210	1350	<1
15 mL for 20 min plus 15 mL for 20 min	340	2050	2
3 mL for 2 min, applied 10 times	200	1300	1

Table 6 illustrates residue levels of longan samples from subsequent scale-up experiments where fruit were fumigated at a recommended rate using a large fumigation chamber. Residues determined immediately after fumigation showed a consistent agreement with the experimental data obtained in glass jars. The dosage of SO_2 to be administered into a fumigation chamber depends upon: (1) the sorption of the fruit and the amount to be fumigated; (2) the size of the room or, more precisely, the free-space in the room; and (3) the

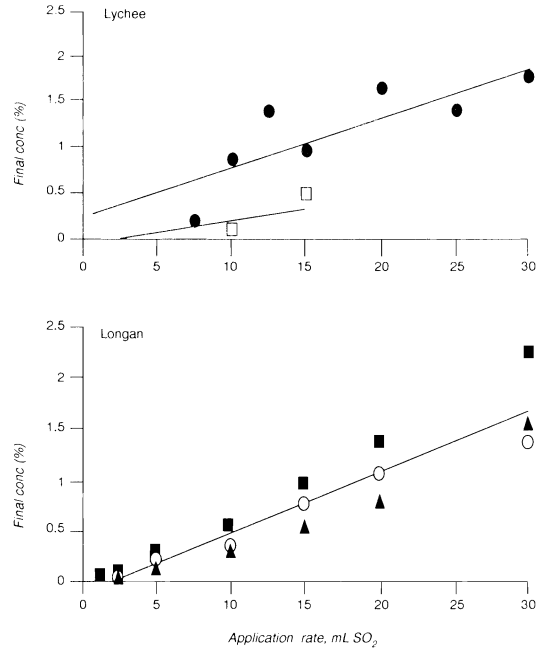

Figure 6. Relationship between SO_2 application rates and SO_2 sorption by lychees (cv. Honghuai and Khom) and longans (cv. Do).

Table 6. Maximum SO_2 residue levels (ppm) estimated from logan fruit samples in a scale-up trial

Sample no.	Day 0[a]			Day 1			Day 2		
	whole	rind	aril	whole	rind	aril	whole	rind	aril
1	280	1850	6	180	1300	14	140	920	4
2	230	1730	7	160	1320	5	130	1010	5
3	380	2650	20	240	1590	31	150	1080	7
4	290	1950	11	210	1440	8	130	880	4
5	280	1960	8	160	1210	9	150	1040	12
6	270	2050	10	200	1330	14	140	960	6
7	260	1820	8	180	1150	13	110	900	5
8	230	1690	7	190	1350	8	130	880	10
9	260	1940	4	150	1190	4	120	1100	8
10	260	1840	7	180	1290	20	–	–	–
Calculated MRL	565	3970	20	400	2740	30	300	2100	15

[a] Residues analysed immediately after fumigation at a recommended rate for longan

sorption by containers and packaging materials and the room surface, and losses through leakage. Allowances will also have to be made for the fruit stalks which were found to be more absorbent than the fruit (data not shown). The quantity of SO_2 needed is a combination of the space dosage (S) and the commodity dosage (M). The weight of SO_2 required can be calculated from the following equation:

$$\text{weight of } SO_2 \text{ (g)} = S + M$$
$$= (A \times B \times C) + (D \times E)$$

where A = the concentration of SO_2 to maintain %
B = the free space in the room, in litres
C = weight (in g) of 1 L of SO_2, at 30°C, 2.574 g/L
D = weight of fruit, in kg
E = sorption of fruit, in g/kg

and weight of sulfur to be burnt = weight of $SO_2/2$.

Thai longan exporters began to use the sulfur treatment commercially in 1989. It is now in widespread use. SO_2 residues were monitored on samples taken from many trials and commercial shipments during 1989–91. There was great variation in residue levels in samples taken from different fumigation facilities (Table 7) and at various postharvest handling stages (Table 8). In 1991, fumigated longans also began to appear on, and were well received by the domestic market. In anticipation of wider use of this technology, a code of 'good agricultural practices' was drawn up in 1992 by TISTR. It is essentially a quality assurance scheme covering:

1. inspection and certification of fumigation facilities;
2. fumigation process and post-fumigation operational control; and
3. residue monitoring, reporting, and labelling.

Through this QA scheme it is hoped to promote safe and effective SO_2 application techniques to ensure that operators take into consideration consumer and environmental concerns.

Table 7. Variations in SO_2 residue levels (ppm) of longan fruit samples from three packing houses

Sample No.	Packing House A			Packing House B			Packing House C		
	whole	rind	aril	whole	rind	aril	whole	rind	aril
1	490	2180	206	120	800	7	300	1750	40
2	460	1770	258	140	840	13	260	1420	13
3	360	1780	106	160	950	7	180	1780	19
4	560	2460	217	100	670	12	150	910	26
5	420	1870	182	40	240	6	190	1270	13
6	540	2400	230	90	640	11			
7	830	3820	176	150	980	12			
8	410	2180	72	170	1110	18			
9	380	1490	227	60	380	9			
10	360	1520	141	90	410	18			

Table 8. Variations in SO_2 residue levels (ppm) of longan fruit samples at various postharvest stages

Sample no.	Klong Toey Seaport			Packer	Hong Kong Seaport[a]		
	whole	rind	aril		whole	rind	aril
Container 1	300	1860	39	a	85	700	0
A2	380	1970	75	b	65	430	0
3	200	1200	21	b	130	690	50 (by air)
4	150	920	0	c	160	1140	3
5	300	1420	80	d	80	520	0
6	220	1350	9	e	50	290	2
7	220	1540	5	f	30	230	0
8	210	1250	18	f	80	630	1 (by air)
9	270	1280	50	g	110	850	0
10	210	1270	11				
Container 1	270	1790	22				
B2	310	1820	20				
3	390	1780	113				
4	260	2000	66				
5	370	2100	47				
6	350	2230	60				
7	470	2370	80				
8	360	2000	38				
9	310	2150	14				
10	340	2000	40				
Container 1	260	1680	17				
C2	270	1480	28				
3	215	1350	7				
4	140	970	8				
5	180	1230	1				

[a] Residues were analysed on samples brought back to TISTR after 2 days.

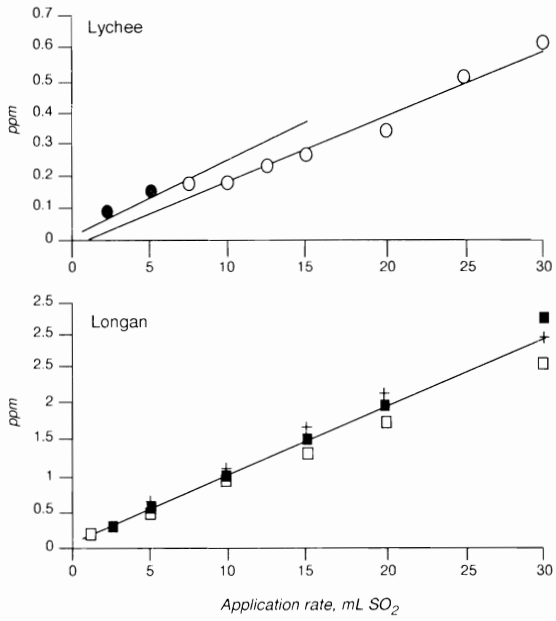

Figure 7. Relationship between SO_2 application rates and headspace concentrations of SO_2 at the end of a 20-minute fumigation of lychees (cv. Honghuai and Khom) and longans (cv. Do).

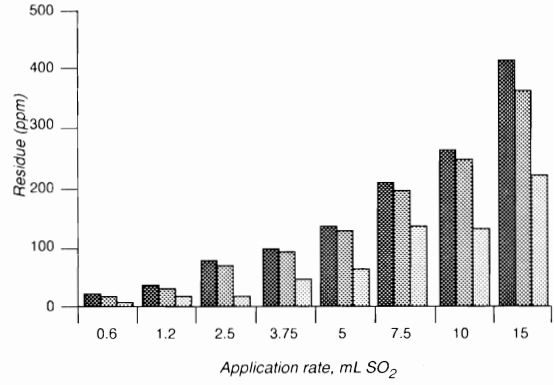

Figure 8. Relationship between SO_2 application rates and SO_2 residues (whole fruit) of lychees (cv. Honghuai).

- Theoretical calculation obtained by total SO_2 input/weight of fruit.
- Theoretical calculation obtained by (total SO_2 input – remaining SO_2 in the headspace)/weight of fruit.
- SO_2 residues assayed by modified Monier Williams method immediately after fumigation.

Design and Integration of Other Sulfur Dioxide Application Systems

The experience and understanding of basic principles gained with the standardised fumigation procedures, and the development of the high dose–short duration fumigation system, have allowed development of other SO_2 application systems at the laboratory scale. These include the use of SO_2 release pads, trickle application of SO_2 gas, and a sodium metabisulfite liquid dip. The choice of system and its integration into existing commercial practice is partly science and partly art. While scientists and some private sector operators are looking at technical options, there is no real pressure at present from the major operators to change from the high concentration–short duration fumigation system.

Acknowledgment

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Postharvest Diseases and Disorders — Session Summary

Chairman: Dr Anna Snowdon, University of Cambridge, U.K.
Rapporteur: Mr Tony Cooke, Queensland Department of Primary Industries, Australia

POSTHARVEST pathologists are few in number, in view of the magnitude of the problems awaiting investigation, particularly in the tropical environment. Current emphasis throughout the world is on integrated methods of disease control, for reasons of economy, environmental protection, and public demand for reduced chemical usage.

Conference papers, posters, and discussions illustrated the range of options available, including aspects of crop husbandry, biological control, and postharvest treatments of various kinds. But the refinement of control methods depends on a detailed knowledge of pathogen behaviour (survival, dissemination, and infection mechanisms) as well as an understanding of host resistance. Concern was expressed that some postharvest programs do not devote sufficient attention to the fundamentals of pathology. Molecular biology dominates the research scene.

There is much interest in developing simple 'test-kits' to assist in disease identification, but there is a worrying decrease in the funding and personnel devoted to classical taxonomic studies. More support is needed for herbaria and culture collections, both national and regional, to complement the international initiatives in conserving host germplasm and thereby sources of resistance genes.

Communications networks between pathologists should be strengthened, so as to minimise duplication of research and, at the same time, maximise the benefits. Collaboration is also needed with physiologists working on postharvest disorders.

Efforts should be made to educate the public towards an understanding that the complete abandonment of chemicals is neither feasible nor desirable, since the alternatives would be more harmful (e.g. mycotoxins). The burgeoning interest in tropical fruit consumption needs to be accompanied by increased resources for research into novel methods of controlling postharvest diseases and disorders.

Storage and Ripening

Tropical Fruit Physiology and Storage Potential

Robert E. Paull*

Abstract

Knowledge of tropical fruit physiology has increased dramatically over the last 15 years. This gain is due in part to the interest in these crops as export income earners. The provision by developed countries of project funds focusing on fruit postharvest physiology funded much of this research, with the work being undertaken by local scientists. The basic physiology of tropical fruit does not differ from that of the more studied subtropical and temperate fruit. The related storage potential is, however, limited by some unique aspects; chilling sensitivity of the commodities, rapid ripening, and postharvest stresses imposed on fruit by the need for insect disinfestation treatments. These constraints are limited further by long distances to markets and a lack of appreciation and application of proper handling practices at the wholesale and retail levels. There is a lack of data on the effect of preharvest factors on postharvest physiology, quality, and storage potential. Areas requiring more research effort are studies on varietal differences, preharvest nutrition, and weather influences on postharvest physiology, quality and the applied aspect of storage potential. There is a need to cooperate in projects applying molecular biology to tropical fruit crops.

WORLD production of fruit is dominated by citrus, grapes, bananas, and apples (Table 1) in order of total production (FAO 1991). The figure for bananas does not include plantains and other *Musa* spp. which would make *Musa* spp. fruit number one in world fruit production. Other tropical fruit listed by the FAO (Table 1) are avocado (though some avocado types are subtropical), papaya, mango, and pineapple. Estimates of postharvest losses of these fruit vary widely both in developed countries and in developing countries (Table 1). In many cases it is unclear what these figures mean, especially with ranges of 20–95% for citrus lost postharvest in developing countries. These are guesses and, in many cases, coloured by isolated incidents. The losses given in published reports do highlight the fact that postharvest losses may involve total loss of product, the incidence being more common in some crops than others. The reduction of the losses in a systematic way requires a knowledge of postharvest physiology and its applied technical aspect, handling, and an appreciation of its biological limitation, represented as storage potential.

Tropical fruit physiology does not differ from the basic knowledge gained from studies of temperate and subtropical fruit. There are differences in the major substrates involved in ripening, the rate of ripening, and senescence and, in some cases, variation in the order various components of ripening occur. The aspects of tropical fruit physiology that make most of these fruit unique are their chilling sensitivity (Wardlaw 1948; Paull 1990a), the generally more rapid ripening of climacteric tropical fruit when compared with temperate fruit ex. apples, and the frequent need in postharvest handling of tropical fruit to expose the commodity to

Table 1. World production and postharvest losses of fruit in less developed countries.

	World production (1991)[a] ('000 t)	Estimated losses[b] (% of total crop)
Banana (*Musa* spp.)	47 660	20–80
Citrus (*Citrus* spp.)	77 322	20–95
Grapes (*Vitis vinifera* L.)	57 188	27
Apples (*Malus sylvestris* Mill.)	39 404	14
Avocado (*Persea americana* Mill.)	2 036	43
Papaya (*Carica papaya* L.)	4 265	40–100
Mango (*Mangifera indica* L.)	16 127	
Pineapple [*Ananas comosus* (L.) Merril.]	10 076	
Plantain (*Musa* spp.)	26 847	

[a] FAO (1991).

[b] National Academy of Sciences (1978).

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high temperatures or other stresses during quarantine insect disinfestation (Paull 1990b).

Storage potential is crucial to enable tropical fruit to be shipped from production areas to consumers. In more involved developed, though not necessarily advanced, marketing channels, this can take up to 4–6 weeks. A case in point is papaya shipped from Hawaii by sea; fruit can be harvested, heated for insect control, packed, and be in the shipping container in 2 days. The sea journey to California with loading and unloading takes 9 days to the wholesaler. All our research has indicated that fruit cannot be stored for longer than 21 days before postharvest disease becomes a problem, so that the wholesaler has 10 days to put the fruit in the consumers' hands. A recent inspection of wholesalers found that some fruit was being held in cold storage for 14 days or more. A further 5–7 days is needed to place the fruit on supermarket shelves. The reasons given, in part, go back to a lack of understanding of fruit physiology together with poor facilities to handle the fruit. The important point for this paper is that storage potential needs to encompass all the time spent in the various marketing steps. We should, as postharvest physiologists and individuals interested in optimum fruit handling, develop data that does not just look at how long we can hold a fruit at a particular temperature before injury or decay turns the fruit into an unsaleable item. We need to use simulated handling schemes that approximate what will happen in a commercial marketing system. This necessitates an understanding of the current handling system and the constraints that limit changes.

In the first part of this paper I wish to briefly summarise a few aspects of tropical fruit physiology, look at the question of storage potential and what storage potential figures mean, and last to indicate areas where research data are needed. In making this selection of topics, I will not address in detail the application of molecular biology, the use of coatings and wraps, and the application of modified atmospheres to tropical fruit. These topics are covered by other invited authors in these proceedings.

Tropical Fruit Physiology

Climacteric and non-climacteric

Like temperate fruit, tropical fruit can be divided, rather arbitrarily, into climacteric and non-climacteric (Table 2). This division, based on respiratory pattern and generally a dramatic and rapid change during ripening of climacteric fruit, does run into grey areas such as carambola. Some authors have suggested it is climacteric (Mitcham and McDonald 1991) while others think it is non-climacteric. The difference is a matter of degree and of some importance in commercial handling, in that ethylene can lead to earlier ripening of pre-climacteric fruit.

Respiration and ethylene

Tropical fruit vary widely in their respiration rate and ethylene production (Table 3). There is some difficulty in developing data of this type, as they are very dependent on stage of ripening and senescence as well as variety, preharvest environment, and culture. However, rates of respiration are essential to determining heat loads in refrigerated cold rooms and containers. The ethylene production rate is also needed as it relates to mixed loads and the effect of one commodity on another. The response of tropical fruits to exogenous ethylene is the same as that of other fruits that have been studied.

In passing, one is struck by the lack of relationship between the two production rates though non-climacteric fruit tend to be lower than climacteric fruit. The difference in temporal patterns between respiration and ethylene production in various climacteric fruit

Table 2. Classification of tropical fleshy fruits according to their respiratory pattern. Modified from Kays (1991).

Climacteric	Non-climacteric
Avocado (*Persea americana*, Mill.)	Cacao (*Theobroma cacao*, L.)
Banana/Plantain (*Musa* spp.)	Carambola (*Averrhoa carambola*, L.)
Biriba (*Rollinia deliciosa*, Sofford)	Cashew (*Anacardium occidentales*, L.)
Breadfruit (*Artocarpus altilis*, Parkins Fosb.)	Java Plum [*Syzygium cumini*, (L.) Skeels]
Cherimoya (*Annona cherimola*, Mill.)	Lychee (*Litchi chinensis*, Sonn.)
Durian (*Durio zibethinus*, J. Murr.)	Mangosteen (*Garcinia mangostana*, L.)
Guava (*Psidium guajava*, L.)	Mountain apple [*Syzygium malaconse*, (L.) Merril & Perry]
Mammee-apple (*Mammea americana*, L.)	Orange [*Citrus sinensis*, (L.) Osbeck]
Mango (*Mangifera indica*, L.)	Pineapple [*Ananas comosus*, (L.) Merrill]
Papaya (*Carica papaya*, L.)	Rambutan (*Nephelium lappaceum*, L.)
Passionfruit (*Passiflora edulis*, Sims)	Rose apple [*Syzygium jambos*, (L.) Alston]
Sapote (*Casimiroa edulis*, Llave.)	Star apple (*Chrysophyllum cainito*, L.)
Soursop (*Annona muricata*, L.)	Surinam cherry (*Eugenia uniflora*, L.)
Chiku (*Achras sapota*, L.)	

Table 3. Respiration and ethylene production rate of various tropical fruit at 20°C. Modified from Kader et al. (1985) with additions from Lam and Kosiyachinda (1987), Tongdee et al. (1988) and Arjona et al. (1992).

Class	Respiration		Ethylene	
	Range (mg/kg/hr)	Commodity	Range (μL/kg/hr)	Commodity
Very low	<35	Grapefruit, orange, pineapple, carambola	<0.1	
Low	35–70	Banana (green), lychee, papaya, star apple, jackfruit, passionfruit, mangosteen	0.1–1.0	Pineapple, tamarillo, coconut, carambola
Moderate	70–150	Mango, rambutan, chiku, guava, durian, mammee apple, lanzone	1.0–10.0	Banana, guava, mango, plantain, mangosteen, lychee, breadfruit, sugar apple, durian, rambutan
High	150–300	Avocado, banana (ripe), sugar apple, atemoya	10–100	Avocado, papaya, atemoya, chiku, star apple
Very high	>300	Soursop	>100	Cherimoya, mammee apple, passionfruit, sapote, soursop

Note: Vital heat BTU/ton/hr = mg CO_2/kg/hr × 10.4
kJ/ton/hr = mg CO_2/kg/hr × 11

suggests different underlying physiology (Fig. 1). In banana, the ethylene production rises before respiration rise; in papaya they occur at the same time; in many *Annona* fruit, ethylene rise occurs after the respiration rise. The difference in physiology may be in relative sensitivity of different fruit tissue to ethylene. For example, *Annona* fruit may be inherently more sensitive to ethylene than banana and the low basal levels of ethylene may be sufficient in *Annona* to trigger ripening as sensitivity to ethylene increases at the start of ripening. Banana takes the other approach of increasing ethylene concentration in order to accelerate and coordinate ripening.

There is a rough relationship between respiration rate and storage life (Fig. 2). Fruit with high respiration rates have shorter postharvest lives. The data do reinforce the need to reduce respiration and thereby increase postharvest life. Temperature management is the major method of controlling respiration rate, though is limited in most tropical fruit by their chilling sensitivity.

Chilling injury

The symptoms of chilling injury are similar for most commodities: pitting, skin darkening, failure to ripen completely, and increased susceptibility to decay. Carambola and the subtropical fruits; longan and lychee, are crops that are somewhat resistant to chilling injury (Paull 1990a), requiring a considerable time (>14 days) at 1°C before injury occurs. Frequently, injury induced by water loss is displayed and is sometimes confused with chilling injury.

In any discussion of chilling, two aspects must be considered, the temperature and the time at that temperature (Paull 1990a). Though there is not an exact fruit-specific reciprocal relationship between temperature and time, it takes a longer time at a higher temperature to develop injury than at a lower temperature. This relationship is illustrated by papaya (Fig. 3). As the storage temperature is lowered from 30°C, duration of storage life is increased, the limitation being fruit ripening and senescence. Storage life reaches a maximum of 25 days at 10–12°C. Lowering the temperature further, leads to a shorter storage life but the limitation changes from ripening to the development of chilling injury, ripening being completely inhibited. Most recommendations for optimum storage of tropical fruit are just inside the chilling range 8–12°C (Anon. 1986, 1991), as this allows ripening to be controlled and if removed before the chilling stress threshold is exceeded, the fruit still has a number of days of useful marketing life as the fruit ripens. Unfortunately, similar data are not available or are fragmentary for many tropical fruit (Paull 1990a). The actual relationship between storage temperature and duration can vary with variety, preharvest conditions, stage of ripeness, and postharvest treatments.

The application of heat treatments to ameliorate chilling injury symptom development has been researched for a number of years. These treatments have normally involved intermittent warming during chilling exposure. Recently, however, it has been shown that a prestorage heat treatment of 24 hours or so at 38°C can reduce chilling injury in tomato (Lurie and Klein 1991) and mango (McCollum et al. 1993). We have not found

a similar response in papaya. Improvement of fruit quality has also been found with similar treatments (Klein and Lurie 1992). Similar treatments may have application to tropical fruit.

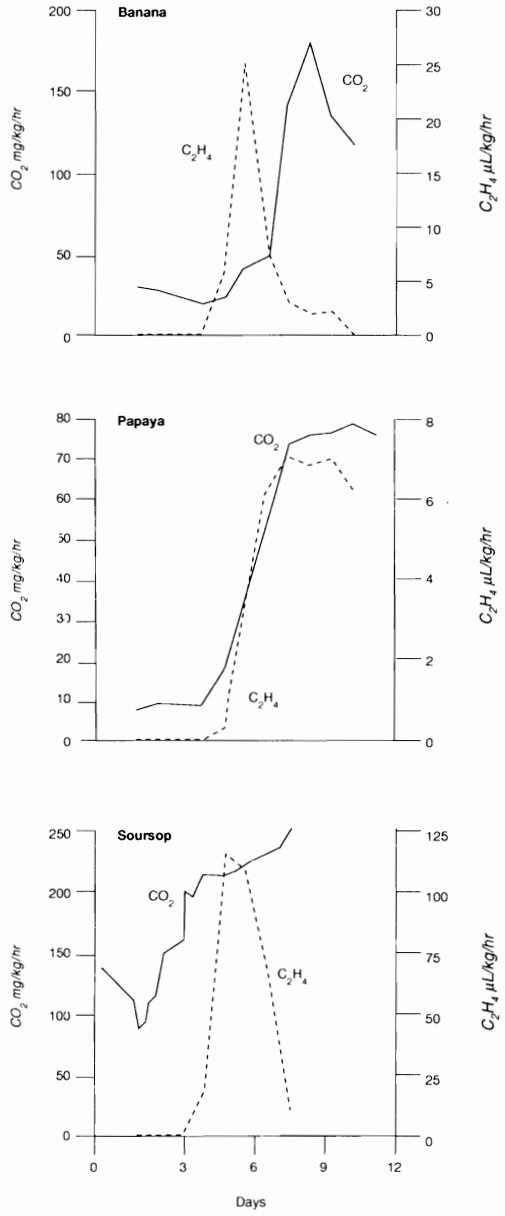

Figure 1. Climacteric pattern of respiration and ethylene production during fruit ripening of three tropical fruit with different temporal patterns: banana (redrawn from Hassan and Pantastico 1990); papaya (redrawn from Paull and Chen 1990); and soursop (redrawn from Paull 1982).

Moisture loss

Loss of weight of tropical fruit postharvest, mainly a loss of water, is dependent upon the commodity, variety, preharvest conditions, vapour pressure deficit, wounds, postharvest heat treatments, and the presence of coatings or wraps. Tropical fruit can be grouped from low moisture loss rate, such as from a coconut; to medium, avocado, bananas, pummelo; to high, guava, lychee, mango, papaya, and pineapple. Fruit having lost 6–8% of their fully turgid initial weight begin to show signs of weight loss (Robinson et al. 1975; Paull and Chen 1989b). The initial signs are skin wrinkling, though skin discoloration is the first symptom in some fruit. This loss of weight, besides reducing overall appearance, is also an economic loss if fruit is sold by weight.

On a per unit area basis the stem scar is frequently the site of highest water loss though most is lost through lenticels, stomata, and the cuticle of the skin in fruits with a larger surface area. Water loss requires some uniformity in presenting data (Burton 1982; Woods 1990). The most common method is percent of initial weight loss per day (Sastry et al. 1978), but, to allow comparison with other fruit and tests done under different conditions, percent initial weight loss per day per unit of water vapour pressure deficit is preferred (Table 4). Tropical fruit have water loss rates between about 0.1–0.3 % loss/day/mbarWVPD. Insect quarantine heat treatments pose an additional problem, in that additional water is lost early in the postharvest handling of the fruit. This early loss can be in the order of 1–2% in the case of papaya and is not regained during cooling following treatment. The fruit soon reaches the threshold when visible shrivelling occurs (Paull and Chen 1989a).

An even less–studied aspect is the effect of water loss on rate of fruit ripening. Loss of 0.5% per day in plantain (George et al. 1982) can reduce the preclimacteric period 65% (Table 4). The reduction in preclimacteric life is dependent upon variety, as the papaya variety Bentong held under dry conditions had no reduction in preclimacteric life while the variety Taiping held under the same dry condition had a 50% reduction compared with fruit held under moist conditions (Nazeeb and Broughton 1978).

Storage Potential

Storage potential is normally given as the postharvest life of a commodity held at its optimum storage temperature (Anon. 1986, 1991). This potential is dependent upon variety, preharvest environment, and culture (Arpaia 1993), maturity at harvest (Tongdee et al. 1988), and storage conditions (Anon 1986; 1991). Postharvest life is terminated because of physiological, mechanical, and pathological factors (Kader et al. 1985), with symptoms such as excessive water loss, bruising, skin scald,

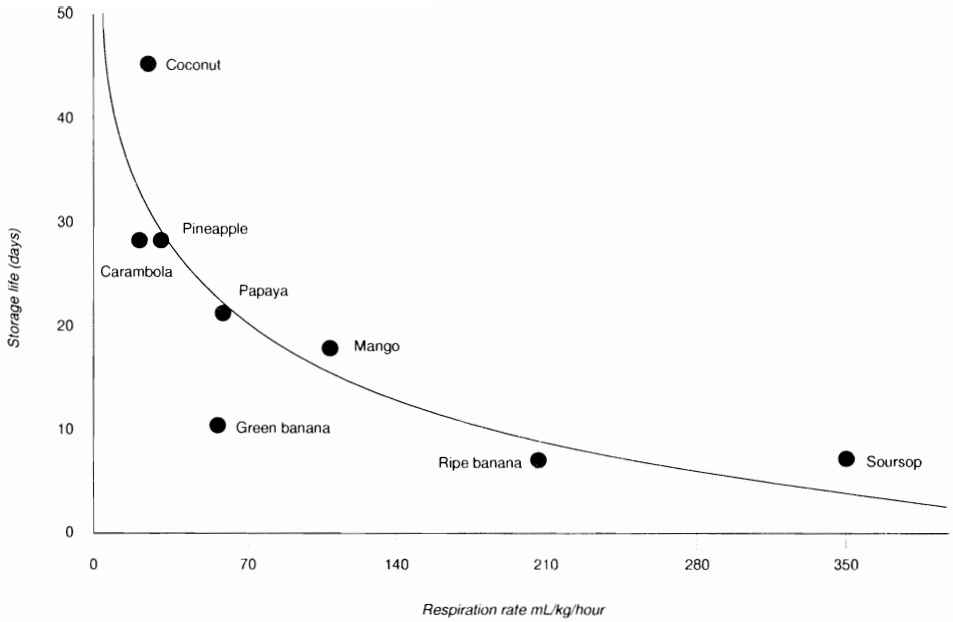

Figure 2. Relationship between respiration rate and postharvest life of tropical fruit held at their optimum storage conditions

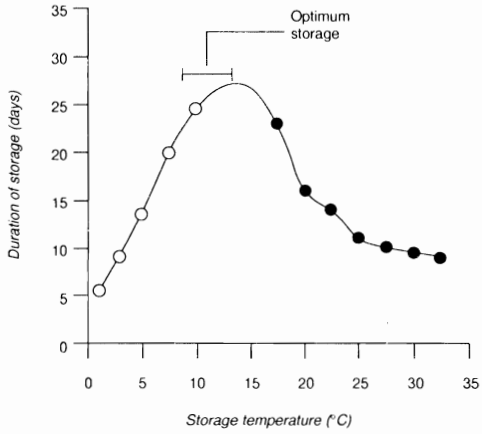

Figure 3. The time and temperature relationship of incipient chilling injury for papaya fruit (○) and fruit ripening (●) at various temperatures. Redrawn from Chen and Paull (1986) and Paull (unpublished data, 1987).

failure to ripen, and decay. The limitation imposed by chilling injury on tropical fruit puts a different constraint on storage potential as storage temperatures higher than 8–12°C lead to ripening and senescence, with lower temperature leading to chilling injury as discussed earlier.

Commercial publications (Anon. 1986, 1991) present storage potential of many fruits, vegetables, and flowers, including many tropical fruit (Table 5). The postharvest life, or storage potential, is given along with optimum storage temperature. The values for postharvest life should be taken as a maximum. The range of storage life given also indicates variability in the infor-

Table 4. Comparison of water loss from different tropical fruit and percentage reduction in preclimacteric period of fruit showing weight loss.

Tropical fruit	Water loss		% reduction
	% loss/day	% loss/day/ mbar WVPD	
Avocado	0.5		47
	1.0		30
Banana	0.4	0.3	9
	1.0		20
Custard apple	Dry/wet		30
Guava		0.3	
Mango		0.1	
Papaya Sunset		0.08	
Bentong	Dry/wet		0
Taiping	Dry/wet		50
Plantain	0.5		65
Rambutan		0.32	
Sapodilla		0.30	

Sources: Littmann 1972; Robinson et al. 1975; Nazeeb and Broughton 1978; Broughton and Tan 1979; Burton 1982; George et al. 1982; Paull and Chen 1989b; Hassan and Pantastico 1990; Cutting and Wolstenholme 1992.

mation available. These values have been extracted from published and unpublished data where many criteria were applied to the determination of the end of storage potential. These criteria are frequently the appearance of disease and/or loss of appearance due to scald and wrinkling. There is, however, a need to incorporate other more subjective eating quality criteria such as flavour, taste, and texture. It is also unclear whether the data incorporated a period for retailing and consumer handling. They are mostly based upon laboratory studies that do not allow for the vagaries of commercial handling.

Table 5. Storage potential, indicated as postharvest life of tropical fruit and the recommended optimum storage temperature. Data extracted from commercial publications (Anon. 1986; 1991).

Fruit	Postharvest life at optimum temperature (days)	Optimum storage temperature (°C)
Acerola	50–58	0
Atemoya	28–42	13
Avocado – Mexican	14–28	5
– West Indian	14–28	10
Banana	7–28	14
Breadfruit	14–40	13
Carambola	21–28	1
Cherimoya	14–28	13
Coconut	30–60	0
Durian	42–56	4
Granadilla	21–28	10
Guava	14–21	10
Jackfruit	14–45	13
Langsat	10–15	11
Longan	21–35	2
Lychee	21–35	1
Mammee	14–21	13
Mango	14–25	10–12
Mangosteen	14–25	13
Papaya	7–21	8–12
Passionfruit	14–21	12
Pineapple	14–36	10
Pummelo	84	7
Rambutan	7–21	12
Sapote	14–21	12
Star fruit	21–28	9
Sugar apple	28	7
White sapote	14–21	19

Future Research Needs

The types and amount of tropical fruit appearing in international markets are expected to increase. The range of fruit that will also be seen will go beyond the current banana, pineapple, mango, papaya, and to a lesser extent carambola, cherimoya, rambutan, and lychee. This requires data on physiology and responses of these and other potential tropical fruit to the stress experienced following harvest. This work should lead to the development of handling protocols that can be utilised by the commercial sector. In developing these data, there is a need to understand and appreciate the constraints in the current marketing system. Areas in which additional research is needed include the following:

1. The effects of preharvest factors on postharvest life of commodity is an area with little developed definitive research results. The data available indicate a very significant influence. These factors can alter the sensitivity of fruit to heat treatments and cold storage.
2. Chilling injury, time–temperature response, and methods to ameliorate damage should be addressed.
3. Heat treatments to control postharvest disease and insects, with a focus on physiological responses and factors that affect injury occurrence.
4. Water loss, especially its loss and control during postharvest handling and marketing. This requires an understanding of the factors involved and role of different treatments in altering the rate of loss.
5. Market system analysis and the use of simulated handling and storage regimes that allow easier transfer of data to the commercial sector. This should provide more realistic estimates of storage potential.

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Biochemical and Molecular Approaches to Fruit Ripening and Senescence

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Abstract

Advances in our understanding of the induction of ripening and the senescence that follows ripening have depended upon a battery of chemical, biochemical and, more recently, molecular techniques. New methods have been used as they have become available and each has made a contribution to the understanding of fruit metabolism; some have provided useful measures of fruit quality or maturity. In hindsight, some methods, or the way in which methods have been used, have been more valuable than others. The tropical fruits have, in general, been studied less intensively than the major temperate fruits. The likely value of employing particular methods to increase knowledge of the ripening behaviour of tropical fruits can be assessed by comparison with earlier experience on temperate crops. A case is made that enzyme studies in vitro, and studies with substrates and/or inhibitors added to tissue slices, have contributed little to knowledge beyond that given by precise chemistry. Molecular genetics allows very discrete analysis of hypotheses and will advance knowledge of those fruits for which transformation systems are available. Proper use of the techniques depends upon good methodology in nucleic acid and protein fractionation, and on intelligent definition and selection of the questions for review.

THIS title was chosen for me and I have accepted it as given. It is an interesting title for it carries a challenge to evaluate the various biochemical and molecular approaches that may be used to study fruit ripening. This is a useful thing to do at this time when new methods are available, when interest in the subject is expanding in response to the opportunities that new methods present and, in the context of this conference, where there is consideration of how to advance the commercial use of a range of tropical and subtropical species on which there has been relatively little biochemical research.

The title is intriguing also in that it distinguishes fruit ripening from senescence. There has been a debate among physiologists for some time as to whether ripening is synonymous with senescence. I take a position that allows a distinction between the two, a position in which I will be joined by all those whose business is selling 'ripe' but not senescent fruit. Undoubtedly ripening advances senescence but non-ripening mutants eventually senesce. Ripening and senescence share some mechanisms and biochemical pathways, but it does not seem to be necessary to complete what is known in commerce as ripening in order to senesce.

The main biochemical aspects of ripening are well known to those associated with the industry, even if they are unacquainted with the terminology. Ripening generally involves sugar accumulation, either directly or via starch, acid loss, softening, colour change, and flavour development. It is generally known that ripe fruit bruise easily and become susceptible to disease. It is also widely known that the gas ethylene promotes ripening and senescence, and that tropical fruits, especially if they are yet to ripen, should not be stored at very low temperatures. Finally, it is recognised that cultivars differ in the changes they undergo with ripening and in their postharvest behaviour. If we add to these a concern for the responses of the fruit to atmospheres other than air, we have the substance of the biochemistry that concerns the industry.

Defining biochemistry broadly, the available research approaches can be listed as follows:

1. Visual or observational analysis
2. Gas exchange
3. Chemical evaluation using destructive analysis
4. Other non-destructive chemical analysis
5. Enzymology
6. Pathway analysis using additives and/or inhibitors
7. The use of mutants in conjunction with other methods
8. Molecular biology
9. Molecular genetics

In terms of advancing our control of the quality of fruit marketed in the tropics what contribution can be expected from each of these methods?

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Visual Observation

Most of us use the superb analytical features of the human eye, together with olfactory and tactile senses, to gauge fruit quality on a daily basis. We can sense colour, texture, and volatile content with a high degree of discretion, and we can see microbial or physiological disease symptoms. If we choose to use a taste panel, we can add non-volatile flavour discrimination and statistical treatment. Possibly the majority of breeding, disease control, and storage experiments depend upon this type of biochemistry. When the experiments are well designed and executed, the analyses are satisfactory. They have the advantage that the analytical techniques employed are identical to those used in the market place. They have the disadvantage that they convey only a relative message to the outside observer; they can describe, for example, a relative lack of flavour but they cannot convey the extent of the deficiency.

Gas Exchange

Fundamental to any understanding of fruit physiology is information on the pattern of respiration change and of ethylene production. Modern automated instrumentation allows a rapid assessment of a fruit's response to harvest maturity, temperature, and atmosphere. The respiratory quotient gives information on substrate use or progression towards fermentation. Combined with systems for providing and maintaining gas atmospheres around a fruit there is no more efficient way of gaining information on how fruits will respond to storage variables.

It is of interest that despite the vast study that has been made of ethylene in fruit on the one hand, and the ripening of major temperate fruit on the other, it has only recently been recognised that there is a very wide range in ethylene production rates among cultivars (El-Agamy at al. 1981; Watkins et al. 1989). This is because detailed studies have tended to be limited to a few cultivars and notably in apples to Golden Delicious. With modern equipment, selection for a desired pattern of ethylene production and for a low base level of dark respiration is possible and should lead to the selection of cultivars with a good storage potential.

Invasive Chemical Analysis

Observational analysis can describe ripening as a sweetening, a loss of astringency, a softening in texture, and a development of aroma. If the aim is to manipulate the process either in terms of objective standards or by physiological or genetically modifying the process, a more precise description in quantitative terms of the process may be needed. It will, for example, be necessary to know whether the sweetening is due to starch breakdown, acid conversion to sugar, rapid sugar accumulation in the fruit, or some combination of these. Consider the ripening of the grape or of papaya in each of which the sugar content increases dramatically prior to harvest maturity (Lavee and Nir 1986; Chan et al. 1979), but is also associated with a loss of organic acids or of astringency. Organoleptic analysis will discern the increase in sweetness but will not provide the evidence that allows the conclusion that the increase in sweetness is mostly due to an increase in the rate of assimilation — a matter that cannot be accomplished after harvest.

Modern methods of chemical analysis can provide strong evidence of the pathways involved in many reactions. The pathway of ethylene biosynthesis is well known to most fruit physiologists. There are few cases where an evaluation of the level of the enzymes 1-aminocyclopropane-1-carboxylate (ACC) synthase and ACC oxidase (EFE) is more informative than a measure of the ethylene production rate coupled with a measure of ACC and malonyl ACC. For sure, the interpretation of the chemical evidence is dependent on a knowledge of the pathway, but that knowledge is now available and the pathway does not need to be rediscovered in every cultivar of every species.

Detailed chemical analysis can make a particularly useful contribution when complex catabolic events are under review. Two of the most complex are the macromolecular structures involved in cell membranes and cell walls.

Sensitivity to chilling temperatures is a major event confronting those who seek to prolong postharvest life in tropical crops. There is an extended and unfinished debate on the prime cause or causes of chilling sensitivity and the debate will not be resolved here. However, one well presented theory is that the relative sensitivity to low temperature depends upon the fatty acid composition of the membrane phospholipids (Murata 1983; Raison and Wright 1983). The theory, in one refined form, proposes that the responses of the membranes — and ultimately the plant — to low temperature depends on the fatty acids that occupy the 2-acyl position of the phospholipid phosphatidylglycerol (Murata 1983; Roughan 1985; Orr and Raison 1990). This theory depends upon a wealth of detailed analysis of crops, including horticultural crops. The difference is genetically controlled and the genetic difference was detected by detailed chemical discrimination. We will return to this matter.

An example of interest to fruit physiologists and all interested in plant senescence is the deterioration in cell membrane function that appears to accompany ripening and senescence and leads in some cases to fermentation and in others to tissue browning. There are proposals that membrane-associated oxidative events precede the ethylene-induced ripening events and contribute to the

increase in ethylene sensitivity in avocado (Meir et al. 1991). This is in line with much evidence that oxidative damage contributes to the senescence syndrome. While I do not mean to endorse claims that oxidative damage is the prime cause of senescent deterioration in plants, this is a serious proposal supported by some chemical evidence and it is pertinent to our use of controlled atmospheres for fruit storage. There is every prospect that the enhanced chemical evidence will lead to the development of hypotheses that can be tested experimentally. It is of the very nature of this type of evidence that it identifies a lesion but does not expose whether the lesion results from a decline in repair or an acceleration in damage.

A third example of complex catabolism concerns texture changes and cell wall structure. Increases in cell wall plasticity are implicated in the softening of many ripening fruit, including tropical fruit. In no case, however, is the mechanism underlying the changes in plasticity well understood. It is important that there is an understanding of fruit texture, because maintaining a texture that is consistent with satisfactory handling through storage and marketing is a key aspect of developing a profitable export industry. Moreover, a number of storage disorders including low temperature injury and heat damage involve a disturbance of the softening mechanisms.

For many years, based on the changes in pectin solubility that accompany ripening and limited observations on enzymes, it was assumed that fruit softening involved hydrolytic catabolism of pectins. There was, however, no direct chemical evidence for this. Such evidence was gathered in tomato by Huber (1983a) but the initial evidence of extensive hydrolysis of the pectins has not been confirmed. More recent evidence using methods that control enzyme activity in extracts and appropriate methods for measuring molecular mass show that pectin hydrolysis occurs but is limited (Seymour and Harding 1987; Seymour et al. 1987). Non-cellulosic neutral sugar polymers undergo similar changes in size distribution as pectins (Huber 1983a,b). Loss of galactans from the cell walls was shown early and the galactan loss appeared to be from the pectin fractions (Gross 1990). The chemical evidence shows that a complex of changes is involved in modifying tomato fruit texture through ripening and that enzymes acting on pectins, galactans, and hemicelluloses may be included in this complex. The evidence does not lead to enthusiasm for any hypothesis that texture change results solely from the hydrolytic cleavage of the polygalacturonic chain. The chemistry does suggest a concern for the mechanism by which galactose and arabinose is removed from the cell wall complex. Again, we will return to this matter later, but the point can be made that intensive work on the mechanisms of change in the cell walls of tomato and some other fruits have led to the development of methods of analysis of cell wall components that can give very useful leads on softening mechanisms, or, in the case of aberrant softening, on the site of the lesion. (Gross 1990; Selvendran and O'Neill 1987; Seymour et al. 1987; Wade et al. 1992; York et al. 1986).

There are matters on which chemical analysis gives little guidance. Consider the important question of respiration. Chemistry will tell of the total potential substrate in the tissue, and analysis against time will tell of the use of the potential substrates for respiration or other purpose. Chemistry will also tell of changes in ATP or of any of the intermediates of the respiratory pathways. But tissue analysis will give no information on turnover of an intermediate, nor will it distinguish metabolic compartments. There has been hope that cell fractionation techniques will allow meaningful comparisons of, for example, vacuoles versus protoplasts, but time plus leakage tends to discount the value of such comparisons. The increasing sensitivity of analytical procedures does allow information to be gained on very small tissue or fluid samples. Thus, analysis of a few microlitres of apoplast fluid of tomato gave us some insight to the composition of the fluid interacting with fruit cell walls (Table 1). One matter that may eventually be resolved by X-ray analysis is the distribution of calcium in fruit cells. Most fruit physiologists would agree that there is some relationship between fruit calcium and fruit quality in terms of texture and storage potential. Defining the calcium pool that regulates this response has proven difficult and consequently there is no reliable means of assessing which samples will benefit from calcium additions.

Table 1. Solutes in tomato fruit apoplast

Solute	Concentration (mM)	
	Cultivar 1	Cultivar 2
Sucrose	4.3 ± 1.2	4.3 ± 0.7
Fructose	18.0 ± 2.4	25.0 ± 1.7
Glucose	13.9 ± 1.9	22.4 ± 1.8
Potassium	18.8 ± 2.9	20.6 ± 4.7
Calcium	1.3 ± 0.4	1.2 ± 0.4
Magnesium	1.0 ± 0.2	1.0 ± 0.4
Phosphorus	1.7 ± 0.3	1.6 ± 0.4
Sodium	1.3 ± 0.5	1.1 ± 0.2
Citrate	2.2 ± 0.2	3.3 ± 0.4
Malate	6.4 ± 1.1	6.5 ± 1.2
Glutamine	2.0 ± 0.4	2.1 ± 1.0
Arginine	2.3 ± 0.6	2.3 ± 0.4
Nitrate	0.0 ± 0.0	0.0 ± 0.0
Hexose-phosphates	0.0 ± 0.0	0.0 ± 0.0

Note: Apoplast fluid was displaced from green fruit 30 days post-anthesis using a pressure dehydration technique, displacing the fluid via a continuity established through the pedicel vascular system. Data of Patrick, Mott, and Brady.

It is difficult to escape the conclusion that modern chemistry has important contributions to make to our understanding of fruit ripening. Methodologies have been developed and assessed on a number of fruits, and their usefulness and limits exposed. There would seem to be a strong case for stimulating interest of well-equipped chemistry departments in the tropics in the changes involved in ripening and stored tropical fruits.

Non-invasive Chemical Analysis

The disadvantage of detailed chemical analysis is that the extraction and/or analytical techniques destroy the sample. A study of changes with time requires multiple samples with the associated statistical problems. The benefit of increasing sensitivity of analytical methods may not be redeemed because of the overriding need for replication.

Non-destructive measurements of fruit properties are of particular value. They allow successive measurements on samples, increasing the feasibility of making detailed time-course studies. Reflectance measurements for pigment content are among the most widely used methods, and the use of chlorophyll fluorescence to measure chloroplast function is extremely useful in organs that retain some chlorophyll (Smillie and Hetherington 1983). Such fluorescence measurements can detect environmental damage and repair in a sensitive way using procedures that take only a few seconds.

Other methods are becoming available that allow some analysis of tissue composition without damage to the tissue. While these are commonly called non-invasive methods this is not strictly so since they mostly involve the use of radiation or of strong magnetic fields. Near infrared analysis can be used to measure the sugar content of some tissues and it also can be used to detect the type of superficial browning that commonly results from bruising. Of more interest to the biochemist is nuclear magnetic resonance which has, for example, been used for measuring ATP levels through ripening, the content of the respiratory intermediate, fructose-2,6-bisphosphate, or the pH of intracellular compartments. Besides the prospect for doing time-series observations (Saltveit 1991), a major advantage of NMR analysis is that it avoids the prospect of metabolite decay through extraction and it can give information on compartments within cells. The demonstration of ATP concentration through the climacteric of avocado fruit (Bennett et al. 1987) was an important event in fruit biochemistry because it established that useful chemical energy was accumulated by the cells from the climacteric respiration, confirming the viewpoint of Young and Biale (1967) and eliminating lingering suggestions that the ethylene-provoked respiratory response involved uncoupling or extensive use of the alternative electron transport pathway.

The biochemistry of fruit cells, as with other storage tissues, tends to be dominated by the large vacuole that occupies ninety or more percent of the total volume. Slight shifts in the distribution of metabolites between the large vacuole and relatively small cytoplasmic compartments can have a profound effect on cell function. Most biochemical approaches to fruit cell metabolism are confounded by the problems associated with the cell compartments but NMR offers a means of measuring changes with time in the pH of vacuole and cytoplasm and probably also of the apoplast (Roberts et al. 1992). In vitro measurements suggest that the passive diffusivity properties of the tonoplast and perhaps the plasmalemma change with ripening (Brady et al. 1970). Such an increase in 'leakage' is sometimes supposed to lead to the increase in disease incidence in ripe fruits. In fact it is not known what effect the increase in diffusivity has in the intact tissue. It may be that it results in significant changes in both the cytoplasm and the apoplast, providing respiration substrates to the cytoplasm and an environment that mobilises calcium and allows cell wall expansion in the extracellular compartment. On the contrary, it may be that the metabolite pumps on the membranes are able to maintain the metabolic compartments in the face of the increase in diffusive flux. NMR studies of ripening fruit have the potential to answer this important question.

Other examples of non-destructive analyses are the use of electron spin resonance to measure lipid phase changes in relation to chilling injury (Raison and Orr 1986), and the direct calorimetric measure of heat output by tissues (Criddle et al. 1990). When coupled with sensitive gas-exchange analysis, the calorimetric technique can determine the efficiency of respiration, the use of the alternative pathway, and the refrigeration needs for temperature maintenance.

While some of these methods, for example reflectance and fluorometric methods, are available and affordable, others are either undergoing development or beyond the budget stretch of most who are concerned with fruit metabolism. They do, however, offer a means of probing the living tissue without unduly diverting it from its ontogenetic course, and their expanded use should be encouraged.

Enzyme Studies

For some the very substance of biochemistry is the study of enzymes in isolation and enzymes coupled into pathways. The biochemist's response to an observation of a shift in respiration rate or to a chemical shift as in a malate/citrate change or a browning reaction is to postulate which enzyme or enzymes are involved and why the change in equilibrium has occurred.

In fruit, such an approach has seldom been successful or useful. This can be illustrated by a consideration of

respiratory metabolism, a matter central to the questions of ethylene responses, of fruit ripening and fruit storage, of storage in controlled or modified atmospheres, and of refrigeration. Since the climacteric was observed in 1924 (Kidd and West 1924), biochemists have sought an explanation in terms of the modified regulation of the glycolytic enzymes (Solomos 1983) or from a study of mitochondria in isolation (Moreau and Romani 1982). Despite a half-century of endeavour we are unable to explain the ethylene effect on respiration in terms of metabolic control of key enzymes, of substrate release, of gene transcription, or of phosphate acceptor control. Attempts at explanation are confounded by an inability to analyse the separated cell compartments, and therefore by an ignorance of the environment of the enzyme or organelle in question. When I surveyed the papers on mango enzymes recently, 5 of 14 dealt with glycolytic enzymes and were attempts to explain respiratory changes in terms of metabolite control. This is an exercise in classical biochemistry but it will not add to an understanding of fruit ripening. There is no likelihood that the enzymes are not present and there can be no proof that the enzyme in isolation is behaving as the enzyme in the cytoplasmic milieu.

The other enzyme papers I found on mango dealt with hydrolytic or oxidative enzymes (Table 2). Such studies are occasionally instructive but the chances are not high. Most of the enzymes are rather universally distributed and a failure to demonstrate an activity does not establish that it is absent from the tissue. Neither does the presence of an enzyme establish its potential for change in situ. Particularly is this the case with hydrolytic enzymes. For these the equilibrium is always towards hydrolysis but in situ the equilibrium is seldom realised. For example, all cells contain proteases, but their potential activity is seldom exhibited, probably because they are limited by susceptible substrate. Likewise most fruit cells seem to contain pectinmethylesterase, and tomato and citrus contain large amounts. In aqueous solution the equilibrium for these enzymes is towards de-esterification but in situ the pectin substrates remain highly esterified. Consequently, there is no unambiguous finding from a measure of the changes with time in the content of an enzyme that appears always to be in excess. The exercise is particularly uninformative if isoforms of the enzyme are not distinguished.

Table 2. Recent enzyme studies on ripening mango fruit.

Enzyme class	Number of publications
Glycolysis	5
Starch or sucrose	2
Cell wall modifying	4
Lipid modifying	1
Peroxidase/PPO	4

Texture is a most important property of fruits that are traded internationally. Consequently, there is a need to select for handling methods and/or genotypes that maintain an acceptable texture during shipping and marketing. Disorders that include a failure to soften satisfactorily seem common in tropical fruit and there is a tendency to seek an explanation for the disorder in terms of a difference in the level of one or other enzyme. In no case is the role of these enzymes in the texture change defined, and without an appreciation of the normal an explanation of the abnormal is unlikely. The presence of an enzyme gives no measure of its activity in the tissue, and adequate chemical analysis is, in most cases, a more direct measure of critical change.

There are, of course, examples where enzyme studies have been useful. The enzyme work that established the pathway of ethylene biosynthesis was a major contribution to our understanding of fruit function (Yang and Hoffman 1984), and our understanding of ripening processes depends critically on a knowledge of the other major metabolic pathways. Environmental or developmental responses can often be accurately plotted by measuring a change in enzyme distribution as in using ACC oxidase as an index of maturity in pome fruit (Ye and Dilley 1991) and alcohol dehydrogenase as a measure of anoxia (Longhurst et al. 1990). Recently, the level of total soluble solids (TSS) in *Lycopersicon* species and hybrids was related to the presence or absence of vacuolar invertase (Yelle et al., 1991) — an interesting and useful finding. The phenotype associated with the lack of the invertase had a high ratio of sucrose to reducing sugars with the resultant effects on turgor apparently allowing a higher accumulation of soluble solids. The phenotype could have been detected by analysis, but undoubtedly the clarity of explanation given by the enzyme analysis aided the use made of the observation.

Pathway Analysis

When biochemists have attempted to check the progress of a metabolic pathway, or to check in vivo control points postulated from in vitro studies, they have mostly used radiolabelled intermediates or inhibitors of specific reactions. In specific circumstances the methods have had outstanding success. In storage tissues, success has been more limited. To gain entry of metabolic intermediates to storage tissues, the tissue must be disturbed by slicing and/or vacuum or pressure infiltration (Palmer and McGlasson 1969). Such treatments change the tissue so that in quantitative terms the study has departed from its original aim. Because fruit cells have large storage pools, reaction precursors have sometimes to be added in rather high concentrations in an attempt to maintain analytical sensitivity and negate the effects of endogenous dilution. Such additions again change

the equilibrium and may alter the reaction rates or even the balance between pathways. The experiments eventually depend upon some judgment of the influence of metabolic compartments on the observations and an unambiguous interpretation is seldom possible.

The fruit slice has been widely used in vegetable and fruit biochemistry (Laties 1964; Hulme et al. 1968; McGlasson et al. 1971a,b), but its use has declined with recognition of the rapidity and size of the responses to slicing (Schuster and Davies 1983). Recently, its use has been reexamined with a view to its potential for the study of the turnover of cell wall polymers in tomato fruit (Campbell et al. 1990), but its value for this purpose has yet to be fully established.

Metabolic inhibitors have value in isolating an effect if they are specific, if they can be introduced without undue physical disturbance of the tissue, and if the inhibition of one pathway does not unduly influence another so that the observed consequence is a downstream effect not directly due to the inhibited reaction. The use of the volatile inhibitor of ethylene synthesis, norbornadiene, can be very useful and, commercially, silver thiocyanate is extremely valuable although few would claim that its effects are limited to blocking ethylene receptors. Some of the difficulties of using inhibitors in biochemical studies have been discussed elsewhere (Brady 1988).

While there may be specific biochemical questions that can be approached by the use of labelled metabolites and/or inhibitors, these methods do not appeal as ones that will be generally useful in the study of the heavily vacuolated, rapidly differentiating tropical fruits.

The Use of Mutant Lines

Comparative biochemistry has been useful in the study of complex tissues and responses as is well illustrated in the matter of chilling injury (Patterson and Graham 1987). The comparisons become more valuable when the genetic differences are minimised, and comparisons involving ripening mutants have been particularly useful in defining physiological and biochemical questions. The *rin* (ripening inhibited), *nor* (non ripening), *alcobaca*, and *never ripe* mutants of tomato have been used extensively (Grierson et al. 1987), but two other examples of mutations that have not been so extensively exploited are worthy of consideration.

In tomato, the *dg* or dark green mutant is an aid to breeders who aim to intensify fruit colour but it has another aspect that has been studied by Kock and Nevins (1990). The fruit are firm and do not soften appreciably. Chemical studies show little degradation of the cell wall pectins despite the presence of large amounts of the pectin-degrading enzymes pectin methylesterase and polygalacturonase. Analysis of the mutant clearly leads to the conclusion that the presence of the pectin-hydrolysing enzymes are not of themselves sufficient to ensure pectin degradation and fruit softening. A similar conclusion was demanded by observations on the mutants generated by specific gene transfer experiments (Fischer and Bennett 1991).

In peaches the *stony hard* mutant bears fruit that, in normal circumstances, do not soften or soften very slowly. However, when exposed to ethylene, the mutant fruit ripen well, including the expression of the softening pattern that is characteristic of the background genotype (Yoshida 1976). The mutation has eliminated the ethylene production that is part of the ripening syndrome but has left the maturing fruit sensitive to ethylene. In this respect, the *stony hard* mutation differs from the tomato 'ripening mutants'. This mutation offers the opportunity of distinguishing events that are maturity-related from those that are ethylene-regulated. In peaches — and other temperate stone fruit — sugar accumulation continues through the ripening stage so that tree-ripened fruit have higher total soluble solids readings than fruit harvested before full ripeness at commercial maturity. The delayed ripening apparent in ethylene-sheltered *stony hard* fruit will allow the limits to sugar accumulation in these lines to be explored. There is also the opportunity to examine cell wall and pigment changes that are, or are not, dependent on a response to ethylene.

Mutants are available in some tropical fruits, as in papaya (Zhang and Paull 1990) and, intelligently used in conjunction with the other biochemical methodologies, these will help to unravel biochemical control points in ripening.

Molecular Biology

The advent of molecular biology has given studies of fruit ripening a considerable momentum. Molecular biology, in combination with molecular genetics, has given researchers, for the first time, the potential to study the impact of the expression of a single gene on a complex reaction, and biochemical theories can be tested with relative precision (Fischer and Bennett 1991). While the experiments are undoubtedly very expensive in comparison to those using the earlier methodologies, they may lead to unambiguous answers and to commercially valuable products.

In their first use, the molecular techniques established that fruit ripening involved the expression of a set of 'ripening specific' or 'ripening related' genes, and in tomato the expression of some of these could be provoked by adding ethylene to a competent tissue. The second important contribution of the technique was the definition of the products of the genes that were activated through ripening (Table 3). From the accumulating knowledge in this field the conservation of sequence between species is being defined (Table 4), and each

addition of knowledge on any species will aid the study of those species not yet evaluated. The third area in which molecular biology will make a contribution, and here the main game is yet to be played, is in the definition of the sequences that control gene action and the factors to which the control sequences directly respond. There is not yet sufficient knowledge to judge the cross species usefulness of the control sequences, but heat and light sensitive regulatory sequences have been shown to operate in alternative hosts.

Heterologous probes — sequences for an enzyme in one species used to evaluate the presence for a template for a similar enzyme in a second species — will be a useful but not sufficient tool to pursue the situation in plants not yet studied in any detail. It is poor use of the technology to limit studies of gene expression to experiments that involve the use of heterologous probes. On the other hand, the information on conserved sequences and use of polymerase chain reaction (PCR) techniques vastly simplifies the recovery of gene sequences. The cloning and sequencing of genes detected by heterologous probes will define the relationship of the detected gene product to the probe and will add to the knowledge base. The homology may allow the decision that the gene product has the same function as the product of the gene used as a probe, but this will not invariably be the case. Sometimes, perhaps often, it will be prudent to have the new gene expressed and establish the function of its product.

Table 3. Genes activated through ripening

Gene product	Fruit	Reference
1. Endopolygalacturonase	tomato	DellaPenna et al. 1986
	peach	Lester, unpublished
	avocado	Dopico et al. 1993
2. ACC oxidase	tomato	Smith et al. 1986
	apple	Ross et al. 1992
	avocado	McGarvey et al. 1990
	peach	Callahan et al. 1992
3. ACC synthase	tomato	van der Straeten et al. 1990
	apple	Dong et al. 1991
	zucchini	Sato and Theologis 1989
4. β-1,4-Glucanase	avocado	Christoffersen et al. 1984
5. Cytochrome P450 oxidase	avocado	Bozak et al. 1990
6 Phytoene synthase	tomato	Ray et al. 1992
7. Proteinase inhibitor	tomato	Margossian et al. 1988
8. Alcohol dehydrogenase	tomato	van der Straeten et al.1991

One reason for caution is that the sequences that are known to be conserved between families of genes may be for regions of the sequence that are involved in the active centre or substrate-recognition parts of the protein gene product. Thus, all or many enzymes that act on or interact with β-1,4-glucan chains may have common or related sequences; however, they may not all carry out the same reaction or have identical substrate affinities: some may act on mixed 1,3-1,4 sequences, some on celluloses, some on non-cellulose glucans, and some exclusively on xyloglucans (Maclachlan and Brady 1992). Similarly, it cannot be assumed that all sequences showing some homology to the ACC oxidase sequence have ACC as substrate and are involved in ethylene synthesis. After all, the well-known ptom13 gene product was identified by analogy to another dioxygenase (Hamilton et al. 1991), a recognition that has greatly clarified the role of the enzyme in ripening fruit (Ververidis and John 1991).

Just as heterologous gene probes are useful in pursuing gene use in other fruits, immunorecognition is useful in protein studies. Antibodies that recognise particular proteins in one species may well detect a closely related protein in another species. Such use of comparative biochemistry is very profitable, especially if it offers an affinity purification system. Again there is need for caution, not accepting that a positive detection on a western blot is anything more that the presence of a related sequence. When the protein is known or suspected of being a glycoprotein, there is an additional reason for caution for some glycan sequences are quite common and powerfully antigenic (Lauriere et al. 1989).

The limits to the conclusions that can be drawn from enzyme activity measurement were noted in an earlier section. It does not follow from this that protein studies are not important to the elucidation of the biochemistry of ripening and senescence. Activity measurements seldom distinguish isozymes, but when isozymes are distinguished a pattern of potential activity that may be important to the differentiation (ripening) sequence may well emerge. Protein studies are inevitable in defining the potential enzyme action of the protein encoded by a gene detected with a heterologous probe. Finally, the amino acid sequence of a purified protein may be the information that is necessary to allow the generation of gene probes, or to confirm that an isolated cDNA has the sequence of an enzyme that is present in the tissue. As knowledge increases, it will become evident that genes are often present in gene families and that there is not always a simple relationship between the relative con-

Table 4. Sequence conservation in endopolygalacturonase genes.

AVOCADO[a]					
..WW (83)	IGTGDDCIS	(13)	TCGPGHGISIGSLG	(22)	NGLRIKTW..
TOMATO[b]					
..WW (83)	IGTGDDCIS	(13)	TCGPGHGISIGSLG	(22)	NGVRIKTW..
PEACH[c]					
..WW (83)	IGTGDDCIS	(13)	TCGPGHGISIGSLG	(22)	NGVRIKTW..
OENOTHERA[d]					
..AW (82)	IKTGDDCIS	(13)	TCGPGHGISVGSLG	(22)	NGVRIKTW..
COCHLIOBOLUS CARBONUM[e]					
..WW (83)	IKNQDDCVA	(13)	QCSGGHGVSIGSVG	(21)	NGVRIKTI..
PSEUDOMONAS SOLANACEARUM[f]					
..WW (111)	INTGDDHVA	(16)	HFYYGHGLSIGSET	(22)	NGLRIKSD..
ERWINIA CAROTOVORA[g]					
..WW (82)	IATGDDNVA	(18)	DFGTGHGMSIGSET	(17)	NGLRIKSD..
..WW (83)	IATGDDNVA	(18)	DFGTGHGMSIGSET	(17)	NGLRIKSD..
..WW (83)	ISTGDDNVA	(18)	EFGTGHGMSIGSET	(17)	NGLRIKSD..

Note: Numbers in parenthesis are the residues separating conserved sequences.

[a] Dopico et al. 1993; [b] Sheehy et al. 1987; [c] Lee et al. 1990; [d] Brown and Crouch 1990; [e] Scott-Craig et al. 1990; [f] Huang and Schell 1990; [g] Saarilahti et al. 1990, Hinton et al. 1990.

centrations of the transcript copy number and the accumulated product of the transcript. That is, if there is a gene family involved, and a cDNA is recovered from a library made from the RNA from ripening fruit, it cannot be assumed that this cDNA bears the sequence for the most prominent protein product of the gene family. It is prudent to isolate and sequence the protein.

Studies of softening in tomato fruit have been useful in defining the relative value of enzyme/protein/gene studies. Hobson demonstrated in the 1960s that there was some apparent relationship between changes in fruit pectin, the presence of endopolygalacturonase activity, and the process of softening in tomato fruit (Hobson 1964). In the next twenty years, the correlation between the presence and apparent action of this enzyme and the progression of softening was reexamined a number of times (Huber 1983a) without serious challenge to the proposition that softening was a function of polygalacturonase action. Other important information accumulated in this interval. Isozymes of the enzyme were described (Ali and Brady 1982), and the distinctive chemical features of the three isoforms established. Eventually this knowledge allowed the gene for the active subunit to be recognised among those genes that increase in ripening wild type tomatoes (Table 3, Grierson et al. 1986; DellaPenna et al. 1986; Sheehy et al. 1987) but not in ethylene-treated non-ripening mutant lines (Knapp et al. 1989). There followed the recovery and chemical description of a second subunit present in one isoform (Pogson et al. 1991) and the sequence of its gene (Zheng et al. 1992).

Molecular Genetics

There are two aspects to molecular genetics that will be treated. There is the capacity to generate transgenic plants that may be single gene mutants or have multiple copies of a single engineered gene, and the capacity to recognise genomic differences that are important to the control of ripening and/or senescence.

Returning to the case study of the softening tomato, we can recognise these key events:

1. the development of the hypothesis that softening is a function of endopolygalacturonase action;
2. the isolation and sequencing of the endopolygalacturonase protein and then its gene; and
3. the recognition that the endopolygalacturonase gene is expressed through ripening.

These add up to an hypothesis that softening in tomato fruit depends on the transcription of the endopolygalacturonase gene during ripening.

Molecular genetics provided the opportunity to test the hypothesis by repressing the effects of gene transcription using antisense technology (Smith et al. 1988; Sheehy et al. 1988) or by expressing the gene in a non-ripening mutant (Giovannoni et al. 1989). The use of molecular genetics led to the rejection of the hypothesis that softening depended only on the expression of the

endopolygalacturonase gene or even only on the presence of the potentially active endopolygalacturonase protein. It also led to a realisation that endopolygalacturonase action limited shelf-life and favoured disease in ripened tomato fruit. The experiments taught us a good deal about the ripening process because the technique allowed one genetic variable to be isolated.

The role of ethylene in fruit ripening is well recognised. It is not surprising then that a reduction of ethylene production by antisense technology aimed at the ACC synthase or ACC oxidase genes (Hamilton et al. 1990; Oeller et al. 1991), or by the removal of ACC following the expression of the bacterial ACC deaminase gene (Klee et al. 1991) delays fruit ripening and gives an extended shelf life. When ACC synthase gene expression is strongly repressed by multiple copies of the reverse orientation (antisense) gene, fruit do not ripen unless ethylene is added.

There is no more important topic for those who would store and ship tropical fruit than chilling sensitivity. The temperature responses of plants are in part a function of the acyl groups attached to the membrane lipids. When the level of unsaturation of the fatty acids is changed the temperature responses of the cells change (Wada et al. 1990). Murata and his colleagues have taken the gene for glycerol-3-phosphate acyl transferase from squash and from *Arabidopsis* and placed it, under a constitutive promoter, in tobacco (Murata et al. 1992). The acyl transferase enzyme from *Arabidopsis* forms phosphatidyl glycerol product with more unsaturated fatty acids than does that from squash. The transgenic tobacco expressing the *Arabidopsis* gene was more chilling tolerant, and the tobacco with the squash gene less chilling tolerant than control plants. Thus a start has been made in controlling the chilling tolerance of plants.

In the three examples quoted, constitutive promoters have been attached to the introduced sense or antisense genes. That is, there has been no deliberate attempt to confine the expression of the introduced gene to some tissues or some period. If chilling sensitivity is to be usefully manipulated in tropical crops, then tissues and perhaps time will need to be targeted. A change in membrane lipids through the whole plant will almost certainly modify the growth performance of the plant and profoundly influence crop yield. There will be little benefit in overcoming fruit chilling sensitivity if the fruit is on an 'arctic mango'. Tissue-specific promoters are therefore a critical element in using molecular genetics for crop improvement.

These examples show the power of molecular genetics in investigating the fruit-ripening process. In each case there was available evidence from natural mutants or between species that pointed to the conclusions that arose from the molecular experiments. In tomato, there were the *dg* mutants that had lots of endopolygalacturonase but did not soften. In peaches there was the *stony hard* mutant that produced no ethylene and did not ripen until exposed to exogenous ethylene. The molecular experiments were superior because we knew what the gene differences were.

This brings us to the second aspect of molecular genetics, the use of molecular probes to define genotype differences. We stated earlier that the real value in the use of transgenic plants was that we knew how they differed from the standard genotype. If we could define how natural mutants were different, there would be the same advantage. For example if we knew where the pathway of ethylene synthesis was blocked in the *stony hard* peach mutant we would have more confidence in its use when examining precise hypotheses of ripening control. There are now available the probes that permit an examination of natural mutants to see if there are mutations in the structural genes that are expected to participate in particular pathways. This is a limited approach because mutations may be in non-coding regulatory parts of genes, and there are often multiple genes coding for each protein species.

In peach fruit the difference between melting and nonmelting texture appears to the plant breeders to lie in a single gene (Sherman et al. 1990). To biochemists, there is a difference between melting flesh and nonmelting flesh lines — but also between freestone and clingstone lines — in that melting flesh, freestone fruit can be shown to have the endopolygalacturonase enzyme and nonmelting, clingstone fruit do not (Pressey and Avants 1978). In terms of other cell wall catabolising enzymes — cellulase, pectin methylesterase, exopolygalacturonase — the two groups are not distinguished. From this there arises the hypothesis that the single gene difference between the two groups is in the endopolygalacturonase gene, but in view of experience with tomato fruit the hypothesis cannot be accepted without further evidence. There is more than one endopolygalacturonase gene in peach so the gene expressed in the melting flesh fruit needs to be identified and a means of distinguishing the genes established. The hypothesis can then be evaluated in terms of analysis of the DNA sequences released by endonucleases that contain the relevant gene or parts of it. There is a reasonable chance that such an examination will reveal any significant change in gene structure between the melting and nonmelting lines.

While it may sometimes be possible to map mutations in detail and occasionally to find a mutation in a known structural gene or its adjacent promoter sequence, there will be cases when the gene causing a phenotype change cannot be defined. Since, in many or most cases we have no complete understanding of the biochemistry of the processes involved in ripening or senescence, these mutations or gene arrangements can be a source of new knowledge. Gene probes that mark the phenotype may be derived using randomly amplified or specifically

chosen gene sequences (Tanksley et al. 1989; Williams et al. 1990). These will not immediately lead to the regulatory genes controlling phenotype, but they will be useful to plant breeders and in defining the complexity of the genetic controls involved. With improving techniques for chromosome walking, new controls and new information on the regulation of ripening will be revealed.

Towards Long-life Tropical Products

There are some staightforward matters of good practice that need to be followed to maximise the shelf life of horticultural products. Harvest before the product is fully ripe, keep at a low temperature while avoiding chilling damage, and avoid ethylene exposures, moisture loss, and surface damage. Beyond these matters of general good practice, specific product knowledge that includes some understanding of the ripening and senescence processes can help to define handling conditions that will aid the delivery to consumers of quality product.

What approaches will most efficiently describe ripening in a new cultivar or a product not previously studied? The first approaches should be to describe gas exchange (CO_2, O_2, C_2H_4) and major chemical shifts, and the influence of storage temperature and atmosphere on these. There is no basis for assuming that cultivars within a species will be identical in these matters and the variances between cultivars are valuable information.

Further advances in the development of products and handling systems that will aid trade development will depend on identifying and using key control elements within the plant. It is here that a better understanding of the biochemistry and molecular biology of the products will be useful. There are many areas of ignorance but the extent and consequences of membrane changes, and the control points for respiration are matters of critical importance. They both reflect a generally poor appreciation of the dynamic nature of plant cells and the difficulty of probing individual compartments and the fluxes between them. The use of non-destructive physical probes on well-defined natural or engineered mutants will be important approaches.

Regular breeding and selection, assisted by molecular probes for desired phenotypes, will generate lines better suited to modern commerce. Genetic engineering can be expected to contribute in terms of regulating ethylene production, softening, colour, and perhaps flavour. There is scope too for using the natural flexibility of the plant, developing handling regimes that allow tissues to adapt to the temperatures and/or atmospheres that are most useful. Molecular probes will aid the selection of the most efficient conditioning treatments. Finally, there is the promise of bigger advances modifying temperature responses or basic respiration in more dramatic ways. These changes will follow and be dependent on the use of tissue and/or development time gene promoters. Plant tissues are remarkably flexible in their metabolism. The inbuilt flexibility probably reflects a need to respond to a variable environment — light/dark, temperature, flood/drought, invasion, wind, and so on. We can use the flexibility to give maximum storage, as when a heat stress is applied prior to cold storage (Lurie and Klein 1991). It follows from this that when the need for metabolic flexibility is removed, as when harvested tissue is placed in an unchanging environment and sheltered from disease stress, the tissues can tolerate a reduction in their metabolic rates. This is achieved most directly by reducing respiration rate. A product, down-regulated in respiration rate in the harvested tissue, will have superior postharvest handling characteristics at low, non-chill temperatures.

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Calcium and Fruit Storage Potential

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Abstract

Calcium is an essential plant nutrient that profoundly influences the physiology of plants and plant products during growth and development. Numerous senescence and physiological disorders in horticultural crops are related to calcium deficiency. Considerable research effort has been invested to harness the beneficial effects of calcium for quality maintenance and shelf life extension of fruit and vegetables. However, except for apples, no satisfactory commercially-applicable methods of postharvest calcium treatment of fruit and vegetables are currently available. Systematic study of the effect of calcium and calcium application techniques is required to develop treatment methods with commercial potential.

CALCIUM (Ca) (A.Wt. 40.08) is a naturally-occurring alkaline-earth metal commonly found in plant and animal tissues. The basic structural and regulatory roles of Ca in animals are well documented. Ca is essential in animals for the normal formation of bones and teeth, contraction of muscles, clotting of blood, and normal functioning of nerves. Adequate dietary Ca is considered by the medical profession to be indispensable in the prevention of osteoporosis, high blood pressure, and colon cancer.

On the other hand, even though many senescence and physiological disorders of horticultural crops prior to harvest have long been known to be related to Ca deficiency, and the various roles of Ca at the cellular and applied level have been studied extensively in recent years, relatively little is known about the primary functions, and the basic mechanisms by which Ca influences the integrity of horticultural plants and plant products. Available knowledge tends to suggest that Ca ions are important intercellular messengers in plants, and that Ca is intimately involved in many vital physiological plant processes involving cell walls, cell membranes, chromosomes, and enzyme activation (Jones and Lunt 1967; Sharples and Johnson 1977). A number of researchers have postulated that Ca exerts its influence on senescence and ripening through its action in modifying cell membrane and cell wall integrity, structures, and functions (Rousseau et al. 1972; van Goor 1973; Cooper and Bangerth 1976; Paliyath et al. 1984). The fundamental actions of Ca in plants and plant products has been reviewed by Ferguson (1984).

What is better known however, is that many horticultural crops are highly prone to the development of physiological disorders, and that Ca plays a key role in their development. Over thirty physiological and accelerated senescence disorders which develop in various horticultural commodities before harvest are reported to be related to the deficiency of tissue Ca, and enhancing the Ca content has been known to reduce the occurrence of the respective disorders (Shear 1975; Wills et al. 1976; Simon 1978; Bangerth 1979; Bramlage et al. 1985; Perring 1985).

Further to its influence on physiological disorder development, there is increasing evidence to suggest that Ca also plays a vital role after harvest. Numerous investigators have demonstrated that the postharvest quality and shelf life of fruit, vegetables, flowers, and leaves are closely related to the Ca status in their respective tissues (Tingwah and Young 1974; Shear 1975; Bangerth 1979; Hopfinger and Poovaiah 1979; Arteca et al. 1980; Collier and Tibbitts 1982; Huber 1983; Ferguson 1984; Goszczynska et al. 1989; Pearson-Mims and Lohr 1990). Ca applied to various commodities after harvest was found to be effective in delaying their general senescence through reducing their basic metabolic activities such as respiration and ethylene production (Bangerth et al. 1972; Faust and Shear 1972; Bramlage, et al. 1974; Ferguson 1984; Eaks 1985; Davenport and Peryea 1989), inhibiting specific ripening changes such as softening and chlorophyll degradation (Bangerth et al. 1972; Poovaiah and Leopold 1973; Tingwah and Young 1974; Bramlage et al. 1974;

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Suwwan and Poovaiah 1978; Poovaiah 1979; Wills and Tirmazi 1982; Buescher and Hobson 1982), retarding physiological disorder development (Jackson 1962; Fidler et al. 1973; Lamiani-Magnani et al. 1983; Perring and Pearson 1987; Ferguson and Watkins 1989; Hewett and Watkins 1991), and increasing resistance to both chilling injury (Perring 1968; Chaplin and Scott 1980; Moline 1980) and invasion by decay microorganisms (Sams and Conway 1984).

Unfortunately, despite considerable research efforts over a number of years by many investigators, commercially viable techniques for the postharvest application of Ca to control the storage life of fresh horticultural crops other than apples have so far proven to be elusive. Some of the potential benefits and risks associated with postharvest Ca treatments were discussed by Bramlage and Weis (1986). The purpose of this review is to provide the reader with a clearer picture of the present state of knowledge of postharvest research of Ca on fruit and vegetables. Attempts will be made to draw attention to the major difficulties hindering the realisation of Ca as a commercially applicable postharvest antisenescence treatment.

History of the Use of Calcium on Horticultural Crops

Much of the early research on the role of Ca in modifying the behaviour of horticultural commodities was focused on the relationship between tissue Ca content and the occurrence of physiological disorders in temperate fruits (De Long 1936). The most intensively researched and documented studies were carried out on bitter pit, a physiological disorder of apples which can occur to the fruit before and/or after harvest. The incidence of bitter pit disorder in apples was found to be closely related to low tissue Ca levels. The incidence of the disorder can be minimised by raising the Ca concentration in the fruit. Various studies in the late 1950s and early 1960s have shown that Ca, applied as sprays before harvest, was effective in reducing the disorder. However, the results obtained were highly variable (Garman and Mathis 1956; Baxter 1960; Martin et al. 1960). It was not until the 1970s, with the advancement of postharvest Ca application techniques, such as dipping and positive or negative pressure infiltration, that complete control of bitter pit in apples was achieved (Jackson 1962; Shear 1975; Bangerth 1979; Ferguson and Reid 1979; Mason 1979; Scott and Wills 1979). Although the physiological reasons for the disorder are still not fully understood, the work of Scott and Wills in particular, was instrumental in the commercial adoption of Ca as a postharvest treatment of apples to control bitter pit in Australia and New Zealand.

In the course of seeking a solution to the bitter pit dilemma, it became obvious that Ca also has an impact on the development of other physiological disorders in apples and pears. While it cannot provide complete control, Ca was found to reduce physiological disorders such as internal breakdown (Bangerth et al. 1972; Blank 1974; Porritt et al. 1975; Sharples 1976; Lidster et al. 1978; Meheriuk and Moyls 1989), senescence breakdown (Fidler et al. 1973; Sharples and Johnson 1976; Hardenburg and Anderson 1979; Johnson 1980; Betts and Bramlage 1977), low temperature breakdown (Scott and Wills 1975), water-core (Amezquita-Garcia 1973; Hardenburg and Anderson 1979), cork spot (Faust and Shear 1968) and, to a lesser extent, scald (Porritt et al. 1975) of apples during storage. However, greater research effort is needed to evaluate whether the application of Ca to control these disorders is technically and economically possible.

The successful application of Ca as a postharvest treatment to control bitter pit in apples, coupled with mounting evidence that postharvest application of Ca also has an arresting effect on the loss of quality and senescence of a range of fruit and vegetables other than apples, provided the impetus for further study into the use of the compound in subsequent years.

Development of Ca Application Techniques

Preharvest

Regular application of Ca to plants, including apple trees, via the soil has long been a commercial practice. Unfortunately, though Ca is one of the most abundant elements in the soil, very little of what is available enters apple roots owing to poor absorption. To compound the problem, once Ca enters the roots, it moves very slowly through the tree due to the relative immobility of Ca in the phloem and in non-vascular tissues (Bangerth 1979). It can take up to 3–4 years for Ca to move from the roots to an apple on a mature tree. Moreover, Ca distribution within the tree is often uneven, resulting in individual fruit on the same tree having different Ca levels, and therefore different respiration rates at harvest and hence onset of climacteric. Even within the same fruit, Ca distribution is not uniform. Chaplin and Scott (1980) observed that chilling injury in avocados was more serious at the distal end of the fruit where there is less Ca than the proximal end.

To improve Ca uptake from the soil and movement in the tree, various cultural techniques such as maintenance of soil moisture, prudent fertilisation, avoidance of over-pruning, maintenance of uniform cropping to control vegetative growth, and avoidance of excessive fruit size (Bramlage 1989) were proven to be helpful but inadequate in eliminating bitter pit and associated disorders. Subsequently, field spraying of Ca salts directly onto the fruit as a means of improving Ca uptake was

adopted from the 1950s. However, while multiple field spraying was found to improve Ca uptake by the fruit, excessive applications and high Ca spray concentrations were found to be injurious to the foliage. Furthermore, the practice of field spraying of Ca was expensive and time-consuming, and did not guarantee fruit free from bitter pit. The disorder remained a serious problem in many important apple cultivars in a number of countries including Australia, New Zealand, and the USA for a number of years until the development of postharvest Ca application techniques in the early 1970s.

Postharvest

Treatment techniques which have been investigated for the postharvest application of Ca are:

- dipping fruit in Ca salt solutions under ambient pressure;
- dipping fruit in Ca salt solutions under vacuum; and
- dipping fruit in Ca salt solutions under positive air or hydrostatic pressure.

Ambient dipping. Research on the immersion of fruit in Ca solution under ambient pressure to facilitate Ca uptake was first conducted on apples. Scott and Wills (1979) tested a number of Ca compounds on apples and found calcium chloride ($CaCl_2$) to be the most effective, and caused the least injury on the fruit. Ca compounds such as Ca lactate, Ca hydroxide, Ca carbonate, superphosphate, Ca gluconate, and Ca hydrogen phosphate were considered either not effective, or less effective than $CaCl_2$. The phytotoxic effect of Ca on apples was found to vary widely from cultivar to cultivar. Jonathan was found to be particularly prone to Ca injury while Granny Smith was relative resistant (Scott and Wills 1979). Lau et al. (1983) found that Ca injury on Golden Delicious apples can be reduced by rapid controlled atmosphere (CA).

The technique of dipping apples in $CaCl_2$ solutions at ambient pressure was relatively inexpensive to set up, easily incorporated into existing packing and grading systems, and often gave good control of bitter pit, provided the fruit were not rinsed after dipping. However, postharvest dips in solutions of Ca at ambient pressure often yielded variable results, and caused skin injuries to the fruit because surface Ca has to be left on the fruit surface for considerable time to facilitate adequate Ca uptake (Scott and Wills 1979). Earlier studies by Reid and Padfield (1975) and Sharples and Johnson (1976) found that the concentration of Ca required to give worthwhile control of bitter pit in apples invariably resulted in fruit injury. The problem of slow Ca absorption, poor fruit coverage, and skin injury was eventually resolved with the introduction of pressure and vacuum infiltration techniques or the use of skin coatings in the form of surfactants and/or food thickeners in the Ca dipping solution.

Since skin is the major barrier to absorption and Ca penetrates apples primarily through lenticels and other small discontinuities, the amount of Ca taken up, and hence bitter-pit control, varies with the number and nature of the penetration sites in the skin. Uniform coverage of fruit surface is therefore important for uniform and enhanced Ca uptake. A number of researchers have shown that mixing surfactants such as Agral or detergent (Scott et al. 1985; Rowe 1987), L-77 (Lee 1980), or Tween 20 (Choi and Lee 1989) into Ca dipping solutions increased the number of penetration sites covered on the fruit and therefore effected a more rapid initial uptake. However, Mason (1979) also revealed that while the use of surfactants gave an improved coverage of the dip solution on the fruit, the surfactants reduced the amount of Ca available at any given site of entry, resulting in less than half of that obtained without the surfactants. Subsequently, improved Ca retention and sustained Ca uptake during storage were obtained by the inclusion of food thickeners or emulsifiers such as corn flour, wheat flour, xanthan gum, guar gum, arrowroot, and lecithin (Mason et al. 1974, 1975; Reid and Padfield 1975; Lidster and Porritt 1978; Johnson 1979; Mason 1979; Hardenburg and Anderson 1981; Mika et al. 1983; Choi and Lee 1989; Meheriuk and Moyls 1989). Wieneke (1980) observed that the localisation of native Ca and that from the postharvest dip were the same.

Mika et al. (1983) found that, in addition to improving the absorption of Ca into the fruit, thickeners such as wheat flour and corn starch also improved the appearance of the fruit by imparting a glossy sheen without increasing fungal diseases. However, not all surfactants and thickeners were effective in assisting greater Ca uptake, or were beneficial to the fruit. Surfactants such as Citowett (Blank 1974), and food thickeners such as pectin and albumin, which bind chemically with Ca, did not increase the penetration of Ca (Johnson 1979; Mika et al. 1983). Greater Ca uptake was also found to be stimulated by loosening the wax barrier on the skin by dipping warm apples in warm Ca solutions or dipping warm fruit in cold Ca solutions (Lee 1980; Lee and Dewey 1981; Mika et al. 1983), or by storage in moderate RH (80–94%) (Lidster et al. 1977).

The use of $CaCl_2$ combined with a surfactant is now a recommended commercial practice for the control of bitter pit in apples in a number of countries including Australia, New Zealand, the U.S.A., and Britain. The use of 3% $CaCl_2$ and 0.6% Agral is now a mandatory practice in Western Australia for the control of bitter pit on Granny Smith, Golden Delicious, Delicious, and Cleopatra apples intended for long term storage or export. The practice has proven to be adequate provided sufficient surfactant was added to the Ca solution to permit rapid absorption, and treatment commences as soon as possible after harvest. Ca can also be mixed with scald inhibitors to provide a single treatment for bitter

pit and scald, and improve the level of scald control (Little et al. 1980). While the addition of food thickeners can provide greater Ca retention and total absorption, the compounds were not used commercially because of additional cost and inconsistency, unsightly sticky deposit, increased phytotoxic effect of Ca on the lenticels (Hardenburg and Anderson 1979), and enhanced incidence of core flush, brown heart, and alcohol formation caused by excessive modification of the fruit's internal atmosphere (Knee 1976; Johnson 1979).

Despite the technique's success on apples, ambient dipping was found to be ineffective as a postharvest treatment for facilitating Ca absorption into most other produce (Wills and Yuen, unpublished data). Unlike apples which readily absorbed Ca from Ca solutions under ambient pressure, most fruit and vegetables were found to be relatively impermeable to penetration by Ca under ambient conditions. The problem of Ca penetration was eventually solved with the development of the positive and negative infiltration techniques in the late 1970s by Scott and Wills.

Vacuum infiltration. Although more expensive to set up, vacuum infiltration provided a more rapid influx of Ca into produce and resulted in a higher total Ca uptake when compared to ambient dipping. The technique facilitated a more rapid and greater uptake of Ca into fruit and vegetables submerged in Ca solution, firstly by drawing out the intercellular gases from produce under vacuum, and secondly by replacing it with the solution containing Ca upon release of the vacuum. The vacuum infiltration technique had a distinct advantage over ambient dipping in that the produce could be rinsed of surface Ca immediately after treatment to reduce the risk of skin injury, and no corrosive Ca deposit was left on packing and grading equipment (Scott and Wills 1977; Scott and Wills 1979; Mason 1979; Meheriuk and Moyls 1989).

While vacuum infiltration with Ca resulted in apples that were greener, firmer, free of bitter pit, and having little skin injury, internal injury was found to be particularly severe on apple cultivars such as Golden Delicious, Jonathan, and Twenty Ounce which have an open calyx (Scott and Wills 1979). Furthermore, skin injury as a result of vacuum infiltration of Ca was still a major problem for other fruit and vegetables. Unfortunately, at the negative pressures and Ca concentrations that were necessary to elicit a significant delay in ripening, the vacuum application process invariably compounded the phytotoxic effect of Ca on most produce, resulting in unacceptable levels of skin injury (Yuen, unpublished data). It was not clear whether the injury to the skin was caused by the drawing of a vacuum which might have caused cell damage, or compounded the phytotoxic effects of Ca on the cells. Ca injury susceptibility was found to vary widely with cultivar, sources of fruit, and seasonal differences.

Pressure infiltration. Scott and Wills (1979), Conway and Sams (1987), and Yuen et al. (1993b) demonstrated that air or hydrostatic pressure infiltration was also highly effective in facilitating Ca uptake into produce when compared with other infiltration methods. Unlike the vacuum technique, in which intercellular gases of tissues were more gently exchanged with the solution containing Ca, pressure infiltration forced the Ca solution directly into the fruit tissues, hence resulting in greater skin damage. As with the vacuum infiltration technique, skin injury remained a significant stumbling block in realising the commercial application of this technique for most produce except apples.

Effect of Ca on Individual Commodities

Fruits

Pome fruits. The ability of applied Ca to influence the postharvest quality of fruits and vegetables other than physiological disorders was first demonstrated on apples. Apples treated with Ca and stored in air were found to have increased tissue strength and firmness (Scott and Wills 1979; Hardenburg and Anderson 1979, 1981; Conway and Sams 1987; Abbott et al. 1989; Glenn and Poovaiah 1990), and increased decay resistance to invasion by pathogens (Conway and Sams 1987; Conway et al. 1987b). The observation that Ca treatment had no additional effect on the firmness retention of apples stored under CA, or high CO_2 and Rapid CA, led Lau et al. (1983) to postulate that Ca delayed ripening in apples by reducing the respiration and ethylene production rates. Stow (1989) further suggested that applied Ca delayed softening, and hence ripening, by replacing the loss of Ca at the Ca attachment sites caused by the movement of Ca from the middle lamella during softening associated with ripening.

The effect of Ca on pears has been less extensively studied. Available evidence suggests that Ca has a similar, but lesser effect on pears than on apples. The incidence of pear physiological disorders such as internal breakdown and cork spot, a disorder like bitter pit, were known to be significantly retarded by the application of Ca (Al-Ani-Am 1978; Zerbini and Sozzi 1980; Vaz and Richardson 1985). As with apples, Ca applied after harvest was also found to inhibit pear respiration and ethylene production (Vaz and Richardson 1985), firmness loss (Richardson and Al-Ani-Am 1982), and ripening (Wills et al. 1982). The rate of pear respiration was found to be inversely correlated with fruit Ca concentration (Richardson and Al-Ani-Am 1982). However, despite the absence of serious skin injury (Wills et al. 1982) and the many beneficial effects of Ca on pears, the technology was not widely adopted due to the lack of industry interest. The pear industry did not perceive

physiological disorders to be a problem serious enough to warrant the commercialisation of Ca as a postharvest treatment for pears.

Ca applied either pre- or postharvest was found to have little effect on the incidence of bitter pit in quinces (Holevas and Biris 1980)

Stonefruits. Studies by Yuen (unpublished data) suggested that postharvest Ca application could be a viable postharvest treatment for the shelf life extension of plums. Yuen found that Ca applied under vacuum not only delayed the ripening of Santa Rosa, Laroda, and Blood plums by up to 1 week at 20°C, but also that, unlike other stonefruits such as peaches, nectarines, and apricots, skin injury symptoms sustained on plums tended to fade as the fruit ripened. The cause of injury symptom disappearance was not entirely clear. Yuen postulated that, as the fruit ripened, the fruit partially repaired its injury sites and that, combined with the gradual attainment of red skin colour, this helped to reduce the visual injury symptoms. Yuen (unpublished data) also showed that Ca injury to the fruit could be further avoided if the plums were more mature at harvest.

There appears to be limited potential for Ca as a postharvest life-extension treatment for peaches. Postharvest application of Ca retarded fruit firmness loss and increased resistance to decay, but caused severe skin injury (Conway et al. 1987a; Wills and Mahendra 1989). On the other hand, while peaches treated with preharvest Ca spray had no effect on decay development of the harvested fruit when inoculated with *Monilinia fructicola* (Conway et al. 1987a), the treatment resulted in improved postharvest quality and shelf life (Robson 1989).

Postharvest application of Ca was found to have an adverse effect on other stonefruits such as nectarines and apricots. While postharvest infiltration of Ca did retard the firmness loss of both fruits, nectarines developed unacceptable skin injury and undesirable flesh reddening and woolliness, and apricots sustained severe skin injury (Yuen, unpublished data). Limited studies with cherries also showed that firmness loss (Traversi and Massignan 1987) and cracking caused by water injury (Glenn and Poovaiah 1989) were reduced by postharvest Ca dipping. However, as with many other fruits, the benefits obtained as a result of Ca application did not economically justify further development of the treatment to the commercial stage.

Berries. A few studies demonstrated that Ca applied as a preharvest spray (Cheour et al. 1990), or as a postharvest dip on whole or sliced fruit (Morris et al. 1980; Rosen and Kader 1989), delayed ripening and gray mould development, and firmness loss in strawberries. While Ca applied to blackberries prior to harvest had no effect on berry firmness, acidity, or colour upon harvest, it reduced the rate of ripening of the fruit during storage (Morris et al. 1980).

Tropical fruits. Available studies on tropical fruits suggest that Ca may have commercial potential as a postharvest treatment for the shelf life extension of avocados, particularly at ambient temperatures. Hass and Fuerté avocado softening, respiration, and ethylene production rates (Tingwah and Young 1974; Wills and Tirmazi 1982; Eaks 1985; Wills et al. 1986, 1987), chilling injury susceptibility (Chaplin and Scott 1980), and response to applied ethylene (Tingwah and Young 1974) were shown to be markedly reduced after postharvest treatment with Ca. Yuen et al. (1993a) showed that Hass and Fuerte avocado ripening can be delayed by up to 16 days at 20°C with Ca. However, the magnitude of delay was found to vary widely from study to study.

Wills and Sirivatanapa (1988) attributed the variation in ripening response to applied Ca to differences, caused by varying cultural practices, in the Ca status of the different fruit. Yuen et al. (1993a) further suggested that the variation in ripening response of the different fruit to applied Ca could also be due to the maturity differences of the fruit from different growers and districts, the extent of response being proportional to the amount of Ca taken up to the threshold level. Yuen et al. (1993a) also demonstrated that while fruit maturity did not have a significant effect on the amount of Ca taken up by the fruit when vacuum infiltrated with Ca, postharvest application of Ca to Hass or Fuerte avocados harvested before prime harvest elicited a greater delay in ripening and caused less skin injury than those fruit harvested at prime harvest or after prime harvest. Unlike many of the fruit treated with Ca, Ca-treated avocados, especially the Hass variety, have shown the capacity to ripen to satisfactory eating quality. However, further studies are needed to improve the effectiveness of Ca infiltration and increase the reliability of the treatments to ensure consistent quality upon ripening.

Ca applied pre- (Sive and Resnizky 1985) and/or postharvest (Tirmazi and Wills 1981; Timarzi 1982; Wills et al. 1988; Mootoo 1991; Yuen et al. 1993b) markedly delayed the ripening of a range of mango varieties such as Cengkir, Arumanis, Gedong, Tommy Akins, Maya, Julie, Haden, and Kensington Pride, by up to 12 days. However, skin injury, uneven flesh ripening, and incomplete degreening of the peel of the treated fruit were major problems. Yuen et al. (1993b) modified a number of Ca treatment parameters and found the level of skin injury can be significantly reduced by varying the temperature of the fruit or the Ca solution at application, or packaging the fruit in polymeric films. Johnson et al. (1990) examined the effect of Ca on the development of stem-end rot in Kensington Pride mangoes and found Ca had no effect.

Limited studies found that jackfruit treated with Ca 15 days prior to harvest had a longer postharvest life and reduced rate of weight loss (Gupta and Singh 1987),

while postharvest application of Ca accelerated banana ripening (Wills et al. 1982).

Vegetables

Owing to their high susceptibility to the phytotoxic effects of Ca, postharvest treatment with Ca appears to have little application for vegetables. However, preharvest addition of Ca to irrigation water was found to be effective in promoting the quality and shelf life of harvested *Agaricus bisporus* mushrooms, mainly by retarding the rate of bacterial growth and surface browning (Barden et al. 1990; Bartley et al. 1991; Solomon et al. 1991). Tirmazi (1982) studied the effect of postharvest Ca application on tomatoes and found Ca prevented the produce from ripening.

Extensive screening studies by Wills and Yuen (unpublished data) showed that genetic variance, cultural practices, preharvest climatic conditions, and harvest maturity played key roles in determining the response of produce to applied Ca. There is increasing evidence to suggest that climacteric fruit respond more positively to the shelf life extension effects of Ca than nonclimacteric produce. It is now also generally accepted that $CaCl_2$ is the most suitable Ca compound for postharvest Ca application, and that a Ca concentration of 4% in the solution gives the greatest delay in ripening and the least skin injury for most produce, irrespective of the application technique used.

The majority of the research in this field seems to indicate that the greatest obstacles to realisation of the commercial potential of Ca as a postharvest treatment are skin injury, uneven ripening and development of colour, and rot development, all of which reduce produce sensory quality and consumer acceptability.

Ca and Resistance to Pathogens

Fruit and vegetables with enhanced levels of Ca due to pre- or postharvest treatment with Ca were found to have a greater resistance to the development of decay. Ca-treated apples and pears were more resistant to infection by *Penicillium expansum* (Conway and Sams 1984, 1985, 1987; Conway et al. 1987b, 1988, 1991) and *Phialophora malorum* (Sugar et al. 1991), respectively, while *Monilinia fructicola* growth was suppressed in peaches treated with Ca (Conway et al. 1987a). The severity of *Erwinia* soft rot in potatoes was also found to be lowered when the Ca content of the tuber was enhanced (McGuire and Kelman 1984). The mechanism by which Ca enhances tissue resistance to pathogen invasion is not clear. Conway and Sams (1984) proposed that the Ca effect on decay could be due to the formation of cell wall components resistant to degradation by pathogens. A number of researchers substantiated Conway and co-workers' observations on fruit by producing mushrooms (Barden et al. 1990; Solomon et al. 1991) and strawberries (Cheour et al. 1990) which were less prone to microbial decay. McLaughlin et al. (1990) further showed that the presence of Ca enhanced the biological control efficiency of yeasts such as the *Candida* sp. on pathogens such as *Penicillium expansum* and *Botrytis cinerea* in fruit.

Ca and Chilling Injury

The Ca status of fruit and vegetables has long been implicated as a major factor influencing their susceptibility to chilling injury (CI). Produce containing relatively high concentrations of Ca are known to be less sensitive to CI than those with low Ca. This is not surprising given that Ca is known to play an important role in the ordering of specific membrane phospholipids (Haverstick and Glasser 1987) and in the hardening of plants exposed to reduced temperatures (Ramesha and Thompson 1984). Early indication that Ca affects CI in fruit and vegetables was observed by Perring (1968), Bangerth et al. (1972) and Scott and Wills (1975) who showed that apples treated with Ca had a lower incidence of low temperature breakdown. This observation was strengthened by later studies by Chaplin and Scott (1980) who demonstrated that avocados treated with Ca had an increased resistance to CI. CI in vegetables such as okra was also found to be abated to some extent by treatment with Ca (Ilker and Morris, 1975). The results obtained supported the hypothesis of Simon (1978) that symptoms of CI occur in Ca-deficient tissues because they cannot withstand the elevated turgor pressure from increased osmotic uptake of water so cells rupture causing necrotic lesions (Lyons and Breidenbach 1987). However, the effect of Ca on CI is not conclusive. A number of studies have shown that Ca dipping could result in increased CI in papaya fruit (Kader and Morris 1975; Chen and Paull 1986) and failed to ameliorate CI symptoms in tomato (Moline 1980).

Conclusion

Available evidence thus far appears to suggest that Ca has a significant potential as a postharvest treatment for the quality maintenance and shelf-life extension of a number of horticultural commodities other than apples. Greater screening of fruit and vegetables, particularly those of tropical origin which have not been extensively studied, may uncover a range of produce which possess a favourable response to the shelf life extending effects of applied Ca.

It is conceivable that major obstacles such as skin injury, uneven ripening and development of colour, and enhanced rot development can be reduced to a commercially acceptable level with improvement in the Ca application techniques and a better understanding of the

diversity of interdependent factors which affect Ca uptake and fruit response. A greater insight into the following factors is crucial to devising Ca treatment techniques and treatment parameters most appropriate for extending postharvest life, reducing decay, minimising fruit injury, and maximising fruit quality on ripening:

- type and variety of produce;
- produce Ca status and maturity at harvest;
- produce and Ca solution temperature during treatment; dipping solution pH;
- Ca concentration in the dip;
- dipping time and the range of pressures;
- the addition of surfactants, thickeners, and fungicides to dipping solution;
- storage atmosphere composition, temperature, humidity, and time that may affect Ca uptake, distribution, and function in the produce; and
- produce resistance to injury and decay.

The economic incentives for greater research to capture the commercial benefits of the postharvest application of Ca are enticing. Postharvest losses of fresh fruit and vegetables resulting from the lack of suitable, adoptable, and/or affordable postharvest treatments and technologies are a major worldwide concern. Ca is natural, cheap, and edible. It offers the opportunity for the development of a unique, simple to apply, safe, and cost-effective postharvest life extension treatment suitable for application on selected horticultural crops at the farm level in developing countries, as well as for integration into modern produce handling operations in developed countries. Furthermore, the potential of Ca to confer chilling injury resistance in produce, as well as to delay ripening and subsequent deterioration under ambient conditions, provides scope for the development of an alternative method for the shelf life maximisation of chilling sensitive produce such as tropical and subtropical fruit and vegetables. Finally, the indication that Ca has the capability to induce resistance in produce against invasion by decay microorganisms may well open a new avenue in the area of biological control of pathogens.

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Postharvest Water Relations in Horticultural Crops: Principles and Problems

Daryl Joyce* and Brian Patterson†

Abstract

A fresh appearance in horticultural products is dependent on water retention. On the other hand, surface water favours microbial spoilage. Good practice in postharvest horticulture includes the control of water transfer between commodity, packaging and refrigeration cooling coils. Temperature differences between package and produce cause water to condense and temperature gradients are particularly difficult to avoid when coolrooms or shipping containers are being stowed, and when transport is from a warm humid environment to markets in cool or cold regions. High humidity storage rooms help keep water within the produce, and condensation is generally not a problem within them. However, they involve extra costs and some packages lose strength as they absorb water from the humid air. Strategies to segregate condensate from the product should be adopted when products are packaged within a water barrier. The principles involved in the control and retention of water in horticultural produce in sealed packages or in coolrooms are discussed with particular attention to the avoidance of microbial spoilage.

Fruits contain more water than any other chemical. Because it influences the quality we call 'freshness', the importance of retaining as much of it as possible in the fruit is recognised in markets around the world. Skilled buyers relate the price of cherries and table grapes to the condition of their fruit stems, which show symptoms of water loss before they are easily detected on the fruits. In a similar way, in those countries where citrus fruits are marketed with a few leaves attached to the stem, the leaves are a visual indicator of fruit quality. For several vegetables, postharvest life under refrigeration is extended when water loss is prevented by storage at high humidity (van den Berg and Lentz 1978). At higher temperatures, wound healing is promoted by high humidity, so delaying pathogen invasion (Morris et al. 1989).

Water in fruits exchanges with water elsewhere in the postharvest environment. *Temperature*, *relative humidity* adjacent to the fruit surface, and *air movement* all influence whether the commodity tends to gain or lose water relative to other reservoirs of water. In addition, the *barrier properties* of the fruit or vegetable surface limit the rate at which the exchange takes place. Water loss can be controlled by manipulating these factors.

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It is not necessarily possible or economic to control all the factors in the environment which influence water loss. For instance, high humidity may compromise the strength of paper-based boxes. Most horticultural produce from the tropics is chilling sensitive so that storage below 10°C is not advisable. Free water is likely to be a significantly greater problem in the wet tropics. For instance, in the lowlands of Thailand the mean daily maximum temperature is about 30°C with around 85% relative humidity (RH) during the monsoon (Sternstein 1976). Under these conditions the concentration of water in the air is nearly three times the value for saturated air at 10°C. In addition the dew point is only 3°C below the ambient temperature. As a result, condensation is likely to be a problem during cooling to storage temperatures. This will worsen the tendency for decay which is already present because of the higher storage temperatures that are necessary for most tropical crops. This paper highlights ways in which these variables can be manipulated so that the benefits of keeping as much water as possible in the commodity can be realised in a way that minimises possible problems.

Water Relations of the Commodity

Osmotic potential. Figure 1 illustrates the meaning of osmotic potential. If a solution is separated from pure water by a membrane that is permeable to water but not to the solute, there is net flow of water through the

membrane into the solution. That is, the solution exerts a negative pressure with respect to the water because the solute (e.g. sugars, salts) interact with the water. This can be balanced by the piston pressure, as shown in Figure 1. The piston pressure is equal in magnitude and opposite in sign to the osmotic potential of the solution. Thus, the ability of a solution to attract water is expressed in pressure units as its potential relative to that of pure water. For free solutions of water this osmotic component wholly determines the water potential.

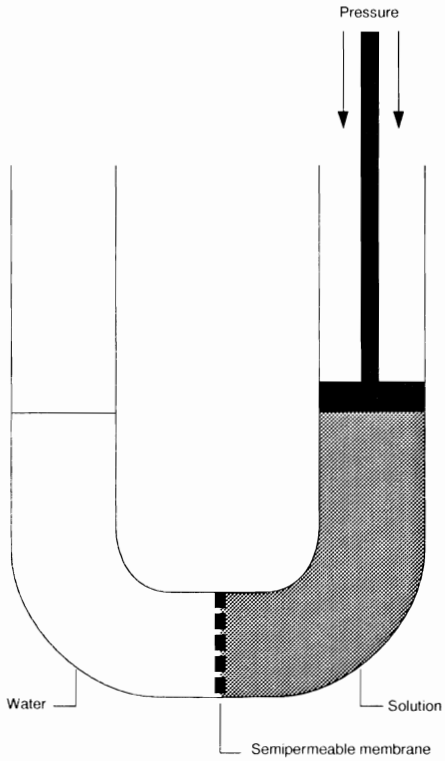

Figure 1. Diagrammatic representation of osmotic potential. The pressure on the piston is just sufficient to prevent net water movement from the left hand to the right hand arm of the U-tube. At this point the pressure on the piston is equal in magnitude and opposite in sign to the osmotic potential.

Turgor potential. The water of harvested commodities is confined within cell walls. Under well watered conditions at harvest, the cell walls and outside skin are likely to be under tension rather like the skin of an inflated balloon is under tension. This tension is the result of a turgor pressure which is positive and therefore counteracts to some extent the osmotic potential of the cell solution. The effect of turgor is most obvious when the tension of the outer skin becomes so great that the skin splits. Turgor pressure can split mature cherries and grapes on the plant when there is a prolonged spell of wet weather. It can also split packaged grapes in storage under some conditions.

Freshly harvested fruit may have a significant turgor pressure (Hatfield and Knee 1988) and turgor pressure will be significant for leafy vegetables as long as they remain unwilted. The turgor pressure of 1.5 MPa (osmotic pressure –3.0 MPa) reported for cherries at harvest (Cook and Papendick 1978) would be sufficient to increase the equilibrium RH from 98% by about 1% (Fig. 2) compared with the same fruit at zero turgor. However, only a small fraction of the tissue water needs to be withdrawn from a plant part to relieve turgor pressure and these cherries lost their turgor within 6 days.

Water potential. The sum of the positive turgor and the negative osmotic potential is the total water potential, which is almost always negative in plants (Salisbury and Ross 1986). In the above example the initial water potential of the cherries is –1.5 MPa.

Water Relations in Packages

Water barriers

A water barrier within a package impedes the passage of water vapour. Natural water barriers of the fruit skin are particularly effective in the tomato (Cameron and Reid 1982), where most of the water is lost through the stem scar. In some fruit, and especially with citrus, it is advantageous to increase the barrier properties by waxing. The most effective water barriers are those made from extruded polymer films (Beh-Yehoshua and Cameron 1989). Although usable thicknesses of the common extrudable polymers (polyethylene, polypropylene, polyvinyl chloride, polystyrene) are somewhat permeable to water vapour, the amount that escapes in this way is negligible compared with the unimpeded transpiration rate of horticultural commodities. As a consequence they can virtually prevent water loss. In contrast to these polymer films, unmodified paper and fibreboard are poor barriers to water vapour, and can also desiccate produce by absorbing water.

Relative humidity in packages

The relative humidity in a package depends on the efficiency with which the package acts as a water barrier. Within an efficient barrier, water is transpired from a solution until the vapour pressure at the surface of the solution equals the vapour pressure in the air space. Under isothermal conditions, this results in the RH equilibrating with the water potential of the commodity. If the solution is free water without contained solutes, the equilibrium RH is 100% (water potential = 0 pressure

units relative to water under the same conditions). The equilibrium RH over a free solution is related to its water potential, as shown in Figure 2 for a temperature of 0°C.

The equilibrium RH in a package containing plant tissues will be a function of the osmotic potential of the solutes in the plant material caused by the presence of solutes, offset by the turgor pressure of the tissue. In most fruits, sugar content has the largest effect on osmotic potential. Monosaccharides exert a larger effect than disaccharides (Fig. 2). It can be seen that a solution containing 15% glucose has an equilibrium RH of about 97.2%. Sucrose, because it has a smaller molecular concentration for the same Brix value, gives a higher equilibrium RH of about 98.6%. The osmotic potential is a colligative property (dependent on the number of molecules) and it can be calculated (Money and Born 1951) from published analyses. For instance Red Delicious apples (Wills and El-Ghetany 1986) whose juice contained about 15% (w/v) sugar contained 13.2 g/100 mL monosaccharide and 1.8 g/100 mL disaccharide. Figure 2 shows that together these will give an osmotic potential of –3.1 MPa, corresponding at this temperature to an equilibrium RH of 97.7%, if there is no turgor pressure. The ions and organic acids (Anon. 1990) would be sufficient to lower the equilibrium RH by a further 0.2% to 97.5% RH. However, apples are likely to be under some degree of turgor pressure (Hatfield and Knee 1988) which would increase this minimum value of equilibrium RH for this content of sugar and other solutes. Rooke and van den Berg (1985) reported an equilibrium RH for apples of about 99%, which also suggests that significant turgor pressure is likely to be present.

Turgor may increase by absorption of water in storage if sugary fruit come into contact with liquid water or with RH values above their equilibrium RH. This may occur when water is redistributed as condensation in packages.

Condensation

The dew point is the temperature at which liquid water will condense from the vapour phase. Figure 2 shows the value of the dew point depression for different values of RH, that is, the value by which the temperature must be lowered for water to condense. At all values of equilibrium relative humidity likely for postharvest commodities, the temperature has to fall by only a fraction of a degree for condensation to appear.

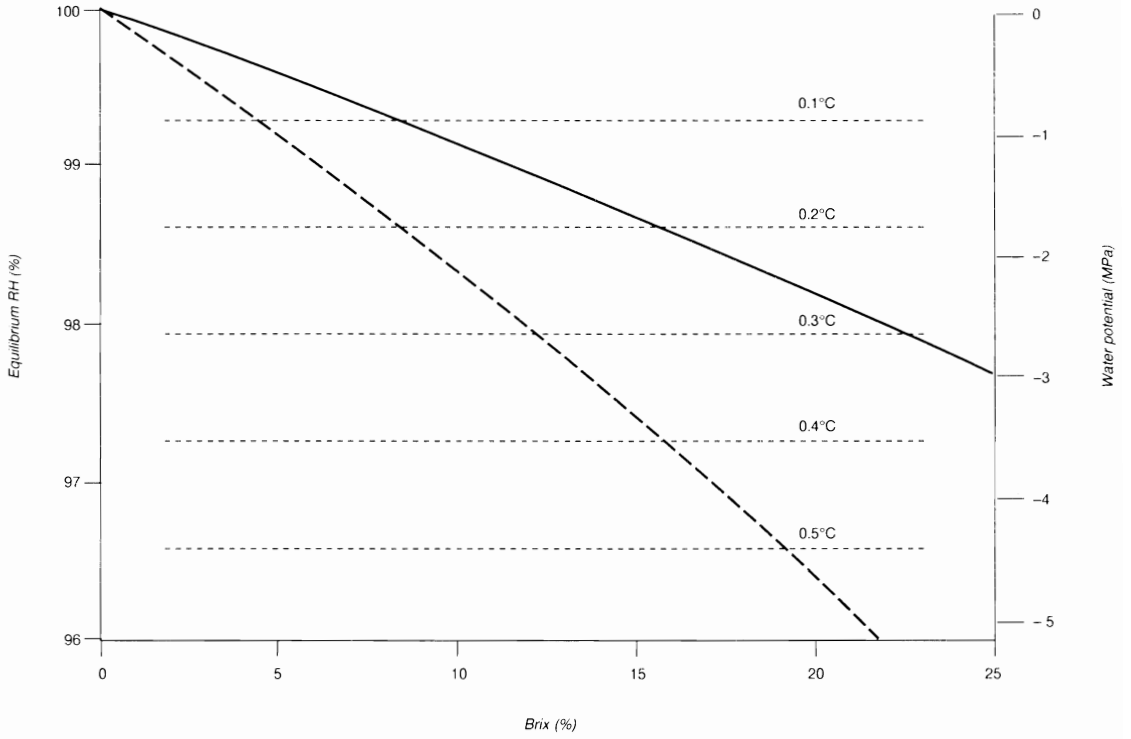

Figure 2. Relation of equilibrium RH, water potential and dew point depression of solutions of glucose (broken line) and sucrose (continuous line) at 0°C. The curves were plotted using the equations of Money and Born (1951) using concentrative data on glucose and sucrose and dew point tables (Weast et al. 1990). Water potential at 0°C was related to RH using the equation WP = (RT/V)ln(RH) (Cook and Papendick 1978).

Condensation is the result of temperature differences. Therefore, good practice in removing field heat, precooling the produce before packaging and maintaining the cold chain will necessarily minimise it. However, it is not possible to provide perfectly isothermal conditions and fluctuating temperatures may result in some parts of a package being below the dew point.

Fate of condensation

Condensation is initially deposited on the vapour barrier of the package. The source of nearly all the water is the commodity itself. During a cooling cycle, the temperature of vapour barrier will fall more quickly than that of the commodity because of its small thermal mass and its position.

The materials of the most common vapour barriers such as polyethylene are hydrophobic and this influences the behaviour of the condensed water. This results in the water accumulating on a polyethylene surface as droplets rather than as a continuous film. On such a hydrophobic surface the surface tension of the water overcomes the weaker interaction with the polyethylene and contracts the water into discrete droplets. The smallest droplets have the greatest degree of curvature and this increases their vapour pressure (Kell 1972). As a consequence, larger droplets tend to grow at the expense of smaller ones. Droplets also grow by accretion and on a vertical surface eventually run to make a puddle in the base of the package. These processes tend to increase the likelihood that free water will contact the fruit and damage it.

Condensation control in packaging

The ideal for condensation control is that it should prevent water loss without the risk of condensation. However, as shown above, water loss can be prevented only if the commodity is kept at equilibrium RH values. Under such conditions condensation is usually likely unless near perfect temperature control can be maintained. For this reason, most effort at reducing condensation has been directed at reducing the RH around the commodity to a moderate extent.

Solute control of RH. The RH in a package can be buffered with salts and polyols at values near 80% (Shirazi and Cameron 1992). These salts and other solutes work by providing a given value of water potential in some position in the package. Between the solute and the commodity a gradient of water potential is set up, with the local value depending on the relative position of the source of water (the commodity) and the solute. To an extent which depends on the position in this gradient, the dew point depression is increased and the likelihood of condensation reduced. The solute attracts water and may form a solution. Therefore, sachets of porous but hydrophobic material have to be used to contain the solute. For instance, sachets of spun polyethylene are effective in retaining dissolved solute while being highly permeable to water vapour.

Perforated films. Another approach to condensation control is to perforate the water barrier. A variety of perforated films of polyethylene and polypropylene are available commercially. The degree of perforation can be adjusted to match the degree of control desired. However, they are not usually suitable for use with paper based cartons, at least over extended periods, as the moisture which leaks out will be absorbed by the paper and weaken it.

Hydrophilic surfaces. Condensation tends to collect as droplets and accumulate as puddles in the base of the package. Droplet formation can be reduced by incorporating surface active agents into the polymers which are used to make the water barrier. Surface active agents tend to migrate to the surface of the film after extrusion and here they can lower the surface tension of the condensed water. The water then can form a continuous film. However, the effect may be largely cosmetic. Although condensation is less obvious when it is spread evenly rather than being present as droplets, a lower surface tension allows water to drain more easily. A more effective treatment has been suggested (Noda 1991). This is to provide a surface alloy of hydrophilic polymer on the bulk hydrophobic phase. This offers the possibility of the surface retaining the condensation more efficiently without changing surface tension.

Water-permeable films. The bulk hydrophilic plastics such as regenerated cellulose and polyvinyl alcohol are poor barriers to water vapour. As a consequence of their high permeability, commodities wrapped in them are unlikely to produce any condensation, even with large temperature fluctuations. This benefit is of course associated with increased water loss. There may also be a problem if packages using these films are kept at RH values higher than about 90%. Plasticiser chemicals (often glycerol) are hygroscopic and exude from these films as a water solution The plasticiser can be washed out with water but, at least in the case of cellulose, this results in a film which is unacceptably brittle.

Shrink wrapping. The technique which most satisfies the criterion of maintaining water content without increasing condensation is shrink wrapping (Ben-Yehoshua et al. 1983; Ben-Yehoshua 1985). A number of different kinds of polymer film can be stretched in two dimensions (bilaterally oriented) after extrusion. When such films are heated above a temperature of about 40–50°C they shrink to approach their original dimensions. To make a shrink wrap, a bag of such a film is made around a commodity and then given a blast of hot air that is sufficiently long to heat the film but not the commodity. This shrinks down the polymer film so that it closely contacts the skin of the fruit. As long as the

water barrier is in contact with the fruit surface, it takes on the fruit temperature by conduction. Therefore, even under grossly fluctuating temperatures, the difference in temperature between commodity and water barrier is too small for the dew point to be reached. Unfortunately, there are practical problems associated with the use of shrink wrapping. The commodity needs to be spherical or cylindrical, such as citrus or cucumber, because any parts of the film that do not press against the commodity accumulate moisture. The second problem is that it is difficult to integrate shrink wrapping into many packaging operations. For these reasons it has not been taken up by the horticultural industry to the extent that its effectiveness would suggest. However, it provides a standard for the control of water relations in packaging against which new techniques can be judged.

Conclusions on condensation

There is scope for improving condensation control in horticultural packaging, taking into account the considerations already outlined. There is active research in this laboratory to devise condensation control methods that are as effective as shrink wrapping, but which can be applied much more generally.

Water in Refrigerated Stores

In the absence of water barriers, the tendency for water to be lost from harvested produce depends in part on the vapour pressure deficit. This is the amount by which the vapour pressure of the storage atmosphere is lower than the equilibrium vapour pressure of the produce. The vapour pressure deficit at a given temperature is related to the magnitude of the difference between the storage RH and the equilibrium RH of the produce, as shown in Figure 3. The vapour pressure deficit at the evaporating surface of the produce is therefore strongly affected by the airflow, because this will influence the extent to which the bulk RH of the storage atmosphere extends to the surface of the produce.

Evaporator temperature. The temperature of the refrigerator coil (evaporator) is an important determinant of the RH of the storage space atmosphere (Dossat 1961). As the temperature differential across the coil is progressively decreased below the dew point, so the coolroom return air is dehydrated to a greater extent. Measures which reduce system running time (duty cycle) reduce this effect.

An option for increasing RH is to increase the area of the coil available for heat exchange and increase its

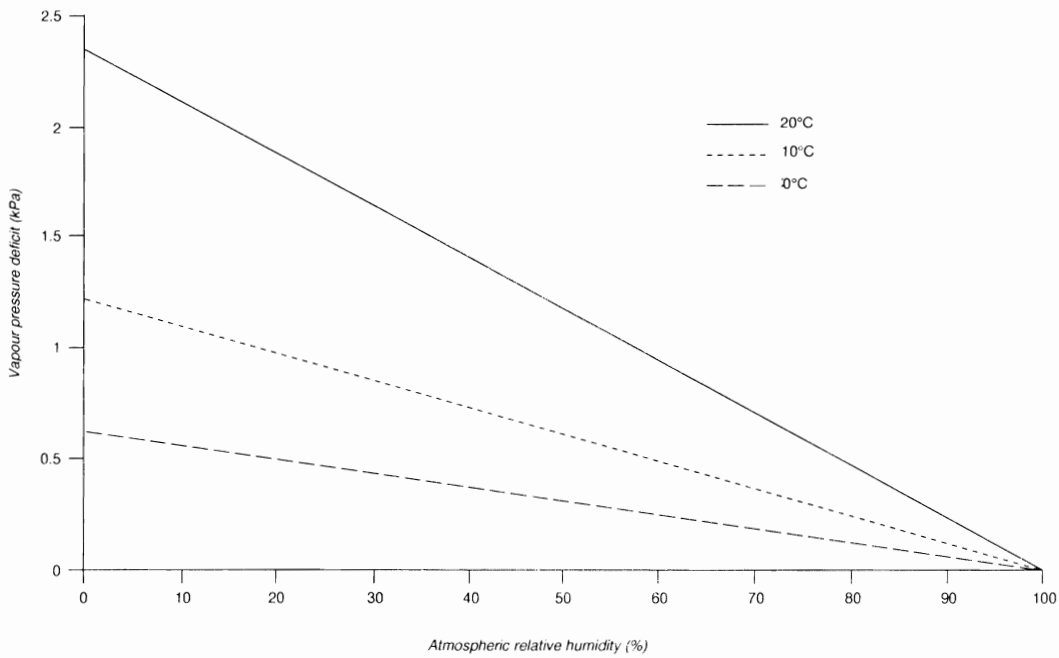

Figure 3. Vapour pressure deficit between produce (assuming an intracellular equilibrium relative humidity of 100%) and surrounding air (0–100% RH) at three temperatures (0, 10, and 20°C). Vapour pressures were calculated based on published saturation vapour pressures of water at 0, 10, and 20°C (Nobel 1974).

temperature. With a smaller coil-to-air temperature difference, less water is removed from the air. However, large coils are bulky and relatively expensive and in systems where humidity control is not crucial or space is limited (e.g. refrigerated shipping containers) small coils must be used.

Where coil size is restricted it may be possible to reduce the coil temperature during cooling of warm produce by appropriate adjustment of the evaporator pressure-regulating valve. Following cooling, when the heat load is less, the temperature difference can be reduced to give higher RH during long term storage.

When the coils ice up, cooling efficiency falls since air flow is restricted and the ice acts as an insulating blanket. Thus it is necessary to defrost the coils. During defrosting, the coils are heated and the melt water is drained outside the coolroom. In this way the refrigeration system is a water pump which removes water from within the coolroom; that is, from the produce.

The water load in a coolroom is the rate at which water is transferred to the refrigeration coils, usually from the produce. It is influenced by the nature of the produce and its packaging. Unwrapped produce with a high surface area relative to its water content (e.g. cut flowers, leafy vegetables) is likely to lose water most readily. If, however, such produce is wrapped in a moisture barrier (e.g. polyethylene film), water loss is greatly reduced.

Insulation. The external temperature can also affect the water balance in a coolroom. In hot weather, the increased heat load will mean that the refrigeration will be running for longer and more water will condense on the coils to be removed in the defrost. Thick panels with good insulating properties, such as 100 mm expanded polystyrene, minimise heat transfer. Additional strategies include a roof over the coolroom structure and insulation in the floor, especially where ground conditions are wet.

Air exchange. When coolrooms are opened or ventilated to avoid the build up of ethylene or carbon dioxide, warmer air may be introduced. Since warmer air holds more moisture, this can add to the water load. This effect may be seen as fog at the interface of coolroom and ambient air. Thus, air exchange should be minimised.

High humidity systems

The cost effectiveness of high humidity in coolrooms varies with the application. High humidity can give commodities a longer storage life (van den Berg and Lentz 1978). Whether this is better achieved by suitable packaging or by a high humidity store should be assessed in the light of the specific storage demands. Packaged products, ones with high volume relative to their surface area, or ones with relatively impermeable skins which limit water loss will benefit less from humidities above 80%. On the other hand, the additional cost of high humidity may be justified if the product is one which transpires rapidly, such as cut flowers. In this case, a design incorporating high humidity can minimise water loss and reduce the frequency of defrosts.

Air-wash systems. To obtain humidities of >90% in otherwise conventional coolrooms, the return air is passed through a high surface area matrix wetted with solution which has been cooled by flowing over the refrigeration coils (Debney et al. 1980). Such air-wash systems are claimed to achieve humidities of ca. 98%. Solutes added to the water lower its freezing point and allow cooling to 0°C or below.

Jacketed systems. Jacketed storage systems also achieve these very high relative humidities. Here refrigerated air is not circulated within the storage void, but through the ceiling, walls, and floor around the storage space (Jorgensen 1974). The shell of the storage space can be rigid or flexible. Uniform circulation of cold air over the outside of the shell is of paramount importance and effectively intercepts incoming heat. Some air circulation within the jacket is also desirable to facilitate movement of the respiratory heat load from within the stow to the inner surface of the shell. Jacketed storage systems are not widely used because of comparatively high construction costs, difficulty in achieving rapid cooling of the stow, and the large amount of condensate that accumulates on the inner surface of the shell (Hardenburg et al. 1986).

High humidity systems tend to be bulky and can be costly to install and maintain. They have a practical disadvantage in that fibreboard boxes gradually lose their strength if they are kept at high humidity because they absorb water from the atmosphere. Under such conditions, specially strengthened, waxed, or expanded polystyrene boxes may be used.

Rapid cooling

Quick cooling of produce is the first stage in reducing loss of water. Cooling reduces the vapour pressure of liquid water in produce and, therefore, the propensity for water loss. For example, at 100% RH the vapour pressure at 20°C is 2.3 kPa, whereas at 0°C it is 0.6 kPa. Thus, the vapour pressure deficit between the product and the surrounding air is markedly reduced when both are at the same low temperature.

However, during cooling, produce is very susceptible to water loss. Table 1 shows that produce at 20°C in a coolroom at 0°C and 90% RH has the potential to lose water about 30 times as fast as produce precooled to 0°C. Thus rapid means of cooling, such as pressure cooling, hydrocooling, and vacuum cooling are highly desirable.

Pressure cooling. Air-wash systems are often recommended for pressure cooling, where air is passed at high

Table 1. Relative rates of water loss (RRWL) for cooling produce[a]

Situation	Temperature (°C)	Relative humidity (%)	Vapour pressure (kPa)	Vapour pressure deficit (kPa)	RRWL
Warm produce	20	100	2.33		
Warm air	20	90	2.10	0.23	4
Warm produce	20	100	2.33		
Cold air	0	90	0.55	1.78	30
Cooling produce	10	100	1.23		
Cold air	0	90	0.55	0.68	11
Cold produce	0	100	0.61		
Cold air	0	90	0.55	0.06	1

[a] Assuming that the air in the produce is at 100% RH.

velocity, via vents in the cartons, through packaged produce. However, even produce which is susceptible to water loss, such as leafy vegetables, cool rapidly under these conditions. Thus, water loss may not be a significant problem if conventional forced-draught coolers operating at comparatively low RH are used.

Compared with room cooling, forced-air cooling minimises the risk of condensation (Watkins 1985). This is because cold air always passes over the coldest produce first, warming as it goes. In contrast, when produce is cooled in a room, the package walls and outer produce cool first. Convection currents take warm air from around the produce to these cool surfaces, where water condenses.

Hydrocooling. Cooling produce with cold water, or variations such as hydro-ice (ice slurry) or hydro-air (cold water mist/spray), results in very rapid removal of field heat because of the intimate contact of the produce with large volumes of cooling medium and the excellent heat conduction of liquid water. Hydrocooling is useful for those products which tolerate being wet (e.g. broccoli). It is important to ensure complete contact between the cold water and the produce, and to take precautions (e.g. chlorination) to avoid encouraging and spreading decay organisms. Packages for hydrocooled produce need high wet strength (e.g. heavily waxed fibreboard).

Vacuum cooling. The principle of vacuum cooling is accelerated evaporative cooling under reduced pressure. This technique is limited to those products with a high surface-to-volume ratio (e.g. lettuce). Water loss from the produce can be minimised by wetting the produce before cooling.

Vacuum cooling and hydrocooling require, as compared with most applications of pressure cooling, specialised and bulky equipment which incurs additional establishment and maintenance costs.

Conclusions on refrigerated storage

Water loss during storage is a problem that might be addressed by either novel packaging systems or modification of basic coolrooms based on forced-draught evaporators.

The problem may be most easily and flexibly dealt with through improved package design. Wax or plastic film linings offer efficient moisture barriers. However, the problem of how to obtain rapid cooling while minimising post-cooling water loss through the pressure cooling vents arises. Here there exists the potential for simple innovations in package design such as plastic film laminated onto fibreboard with an inbuilt 'plastic slide with a lever' system allowing quick and convenient closure of carton vents after cooling.

With regard to the coolroom, there is the need to return water removed from the produce to the coolroom air, thereby minimising further water loss from the product. Defrost water can, for example, be drained onto the floor of refrigerated shipping containers (Sharp 1986). However, this approach is of limited benefit as only a proportion of the water will evaporate, decay organisms may be favoured and structural damage may result. A more promising strategy would be to use the defrost cycle not only to melt but to vaporise and return the water to the coldroom atmosphere (S. Morris, pers. comm.).

Water in and around Harvested Produce

Not only does water loss diminish the firmness (turgidity) and associated fresh appearance of harvested commodities, it is a stress that reduces postharvest life (van den Berg and Lentz 1978). Water loss can also exacerbate the symptoms of other disorders [e.g. bruising of bananas (Akkaravessapong et al. 1992); mesocarp

browning of avocados (Cutting and Wolstenholme 1992)] and can accelerate loss of nutritional quality [e.g. vitamin C from leafy vegetables (Lazan et al. 1987)].

Water as a structural element

This is most evident with cut flowers and leafy vegetables. In rose flowers, as in many other plant parts, turgor pressure is structurally important. If the pedicel or flower stem loses too much water, it can no longer support the weight of the flower, which then flops over. This happens once the positive turgor pressure of the tissue is lost and at this stage of water loss the water potential equals the osmotic potential. Damage is not permanent (unless cells are physically crushed under the weight of the flower bud) and turgor can be restored by allowing the stems to take up water. Further water loss is more damaging because it concentrates the cell solutes, possibly to toxic levels. The protoplasm may shrink to the point where the intercellular connections (via plasmodesmata) are torn, possibly irreversibly. If the cell walls are sufficiently elastic to be able to tighten around the shrinking protoplasm, water loss may be less injurious (Joyce and Jones 1992).

Excess water can also destroy structure, as when fruit split with excess turgor pressure (see above). In this case turgor is a stress.

Xylem cavitation. The xylem vessels of cut flowers have a continuous column of water. If water is lost during transport and storage the resulting tension may break the continuity of the water column. This reduces the ability of the flowers to take up water via the xylem (Dixon et al. 1988).

Physiological consequences of water stress

Water loss from harvested preclimacteric fruit (avocado, banana, pear) can advance the onset of ripening (Littmann 1972; Adato and Gazit 1974). Similarly, film wrapping delays the deterioration of non-climacteric fruit such as capsicums and lemons (Ben-Yehoshua et al. 1983) and the ripening of climacteric fruit such as avocado (Joyce and Shorter 1992). For cold-stored avocados (30 days, 5.5°C), humidification of the storage environment resulted in decreases in internal physiological disorders, disease (anthracnose and stem-end rot), and browning potential (PPO activity) (Bower et al. 1989).

Why water loss causes earlier ripening and senescence of harvested produce is not well defined. Membranes (e.g. the plasma membrane) are possible sites of transduction, being at the interface of the intra- and extracellular environment, potential turgor sensors and intimately involved in cellular metabolism (e.g. transport processes, turnover of membrane components). Ben-Yehoshua et al. (1983) reported increased membrane leakiness in unwrapped fruit (compared with film wrapped). Drory et al. (1992) measured changes in phospholipid turnover in membranes from petals of carnation flowers exposed to transient water stress, and argued that activation of phospholipid degradation and/or the phosphoinositide cycle may be involved in stress transduction and reduced longevity of the flowers. Extreme water stress can lead to elevated ethylene production, and Ben-Yehoshua et al. (1983) suggest an association between ethylene and membranes in sensing water stress. For floral organs of cut and water stressed (-3.6 MPa) Geraldton waxflower var. 'Elegance', ethylene production was 1.4 μL/kg/hour as compared to 0.05 uL/kg/hour for control (–0.12 MPa) tissue (Joyce, in press). In orchids, emasculation (removal of the anther cap and pollinia) leads to desiccation of the rostellum beneath (Woltering and Harren 1989). This desiccation leads to elevated ethylene production, coloration and wilting.

Pathogens and water

Pathogenic fungi and bacteria generally are able to infect and grow better at humidities above 90% (Snowdon 1990). For example, bacterial soft rot (*Erwinia* spp.) is facilitated at >90% RH (Barnes 1979). This effect becomes most marked when free moisture such as condensation wets the produce. Contributing factors here are leakage of solutes into the water and decreased gas exchange to the plant tissue (Burton and Wiggington 1970; Lund and Nicholls 1970; Lund and Wyatt 1972). High humidity enhances the germination of spores of *Botrytis cinerea*, although the effect on *Fusarium* is much less marked (Fig. 4). Free moisture may have an additional effect, especially on the germination of *Botrytis cinerea*, which is one of the most widespread storage pathogens (Jarvis 1977; Maloy 1985).

While high humidity may favour spore germination, it does not always provide an advantage to the pathogen, especially at temperatures that allow the healing of wounds. Wound healing is favoured by humidities that approach equilibrium RH values so that invasion by *Botrytis* (Sommer 1989; Snowdon 1990) and other pathogens (Morris et al. 1989) is reduced or prevented.

In order to minimise the development of fungi (e.g. *B. cinerea*) and bacteria (e.g. *Erwinia* spp.) free moisture on produce inside packages needs to be eliminated. While this might be achieved under low humidity conditions, water loss from produce will be increased. A compromise is to maintain high relative humidity while preventing condensation, a difficult task where temperature gradients exist. One solution is continuous stirring of air to avoid temperature gradients, with the air being circulated through a high surface area (to ensure rapid exchange) humidity buffer (e.g. saturated salt solution matrix).

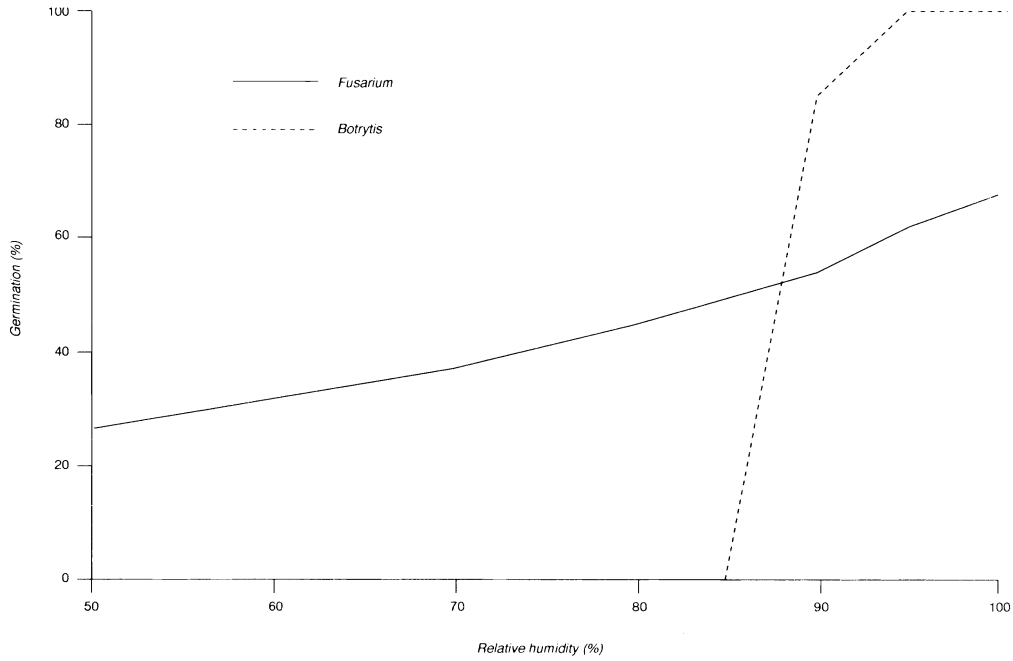

Figure 4. Effect of RH on the spore germination of *Fusarium* spp. at 30°C (Mishra and Rath 1986) and *Botrytis cinerea* at 20°C (Rippel, cited by Jarvis 1977).

Conclusion

The control of water relations of harvested horticulture produce is complicated by the diversity of interacting biotic and abiotic factors.

Crops such mushrooms and chrysanthemums are extremely susceptible to water loss compared with crops such as onions and pumpkins. Water loss results in loss of turgidity, exacerbation of other disorders (e.g. bruising), and accelerated ripening and senescence. Harvested plant organs interact with decay organisms, such that minimising water loss may be important in building or maintaining host resistance but, alternatively, high humidity or free moisture (condensation) may facilitate invasion and worsen the disease.

Harvested produce is handled in a variety of ways. It may be marketed locally, in other districts, or exported. Transport may involve road, rail, sea, and/or air. The produce may or may not be stored after harvest, and storage periods may be short, medium, or long term (Debney et al. 1980).

Given the complexity of the interacting variables the precise way that package water relations is controlled must reflect the specific demands of situation. Although the implications of water in refrigerated stores have been considered, control of water relations through coolroom equipment is perhaps of secondary importance. While temperature itself is of paramount importance in determining the rate of deterioration of produce, refrigerated storage is not applied to all produce, optimum temperatures vary between crops (e.g. tropical versus temperate crops), and it is often a commercial necessity that mixed transport and storage be practised.

It is, therefore, product packaging that offers the greatest opportunity and flexibility for regulation of the water status of individual products. An ideal package will maintain optimum in-package water relations throughout storage, handling, and marketing. The challenge is to determine the optimum in-package water relations conditions for various products and to devise packages that will maintain this condition throughout the postharvest chain. Package design should also consider the wet strength of the container. All too often produce is damaged during storage or transport because fibreboard cartons absorb water and lose their ability to protect the product. These arguments lead to the concept of active packaging, where the packaging materials interact with their contents and the environment to preserve the condition of the produce. This is especially relevant to horticultural crops from the tropics. Efficient moisture barriers are essential to prevent dehydration. At the same time, the accumulation of free water must be controlled to counter the difficulties associated with high temperatures at and after harvest.

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Modified and Controlled Atmosphere Storage of Tropical Fruits

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Abstract

Modified and controlled atmospheres (MA/CA) can be used to supplement the maintenance of optimum temperature and relative humidity for preserving quality and reducing postharvest losses of tropical fruits during transport and storage. MA/CA reduce respiration rate, ethylene production and action, compositional changes associated with ripening, and incidence of some physiological disorders. Using MA/CA to delay fruit ripening at temperatures above the chilling range, exposure of tropical fruits to chilling injury-inducing temperatures can be avoided. Carbon dioxide at 15–20% is an effective fungistat that can be used to retard decay incidence on fruits which tolerate such CO_2 concentrations. MA/CA conditions including up to 60% CO_2 and/or less than 1% O_2 are insecticidal against some insects of quarantine importance on certain fruits. Such treatments alone or in combination with cold or heat treatments will likely become part of postharvest integrated pest management programs for tropical fruits. Exclusion and removal of ethylene from transport and storage environments contribute to delaying fruit ripening and reducing growth of decay-causing pathogens. Recent advances in MA/CA technology are facilitating expanded use on intact and lightly processed fruits and this trend is expected to continue in the future.

MA/CA can supplement proper temperature and relative humidity management in maintaining quality and reducing losses of tropical fruits. The beneficial effects of MA/CA include reduction of respiration rate, inhibition of ethylene production and action, retardation of ripening, and maintenance of nutritional quality. The delay of ripening by MA/CA can facilitate transporting and storing tropical fruits at temperatures above those that cause chilling injury.

Short-term exposure of tropical fruits to O_2 levels below 1% and/or CO_2 levels above 12% can reduce incidence and severity of physiological disorders (such as chilling injury), pathogens, and insects. The tolerance limits of tropical fruits to insecticidal CAs depend upon storage temperature, O_2 and CO_2 concentrations, fruit resistance to gas diffusion, ethanol accumulation rate, and soluble solids content. Some tropical fruits tolerate insecticidal CAs for 2–5 days at 20°C though further research is needed to find out whether these durations are adequate for killing insects of quarantine importance such as tropical fruit flies.

Effective control of anthracnose and other pathogens is essential to successful use of MA/CA during transport and storage of tropical fruits. Fungistatic levels of CO_2 (15% or higher) should be tested for their efficacy in controlling postharvest diseases without detrimental effects on the quality of tropical fruits. The cost/benefit (in terms of reducing decay incidence and severity) ratio of removing ethylene from the environment surrounding tropical fruits during postharvest handling merits investigation.

Research on responses of tropical fruits to MA/CA has largely been limited to avocado, banana, mango, papaya, and pineapple. The current CA recommendations for these commodities and for five others with which limited studies have been done (cherimoya, sweetsop, durian, lychee, and rambutan) are summarised in the following tables. It should be noted that specific CA combination depends on cultivar, temperature, and duration of storage. These recommendations are for transport and/or storage beyond 2 weeks. Exposure to lower O_2 and/or higher CO_2 concentrations for shorter durations may be used for control of some physiological disorders, pathogens, and/or insects. In general, postharvest life (based on maintenance of textural and flavour quality) of these fruits is extended by 50–100% when kept in CA relative to air at optimum temperature and relative humidity.

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Avocado (*Persae americana* Mill.)

Optimum temperature: 10°C, expected range: 5–13°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	2–5 %	3–10%
Benefits:	Delayed ripening, reduced rates of CO_2 and C_2H_4 production	Delayed softening, reduced chilling injury symptoms
Potential for benefits:	Good	Good
Injurious level:	< 1%	> 15%
Injury symptoms:	Off-flavour, internal flesh browning	Skin browning, off-flavours
Potential for injury:	Moderate	Moderate

Commercial use or potential: Use during long-distance transport is expanding.

Remarks: CO at 5–10% added to CA may be useful in reducing decay problems. Exposure to 25–30% CO_2 for 2–3 days can delay decay incidence during subsequent storage in air or CA. Exclusion and/or removal of ethylene (<1 ppm) from air or CA storage are recommended.

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Banana (*Musa* spp.)

Optimum temperature: 14°C, expected range: 12–16°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	2–5 %	2–5%
Benefits:	Delayed ripening	Delayed ripening
Potential for benefits:	Very good	Very good
Injurious level:	< 1%	> 7%
Injury symptoms:	Dull yellow or brown skin discoloration, failure to ripen, off-flavours	Green fruit softening undesirable texture & flavour
Potential for injury:	High	Moderate to high
Commercial use or potential:	Use during long-distance transport is expanding. Modified atmospheres (1–5% O_2 and 4–6% CO_2) and/or ethylene-absorbers are also used commercially during transport and distribution.	

Remarks: Cooking bananas and plantains have similar CA requirements

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Mango (*Mangifera indica* L.)

Optimum temperature: 13°C, expected range: 10–15°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	3–5% (5–7% SE Asia-grown varieties)	5–10%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Moderate	Slight to moderate
Injurious level:	< 2% (< 5%)	> 10%
Injury symptoms:	Skin discoloration, off-flavours greyish flesh colour	Off-flavours, softening,
Potential for injury:	Moderate	Moderate
Commercial use or potential:	Limited use of 5% O_2 + 5% CO_2 + 5–10% CO during marine transport.	

Remarks: Avoiding chilling injury is important when CA is used. Use of heat treatments to reduce anthracnose is highly recommended.

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Papaya (*Carcia papaya* L.)

Optimum temperature: 12°C, expected range: 10–15°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	2–5%	5–8%
Benefits:	Delayed ripening (degreening and softening)	Firmness retention
Potential for benefits:	Slight to moderate	Slight to moderate
Injurious level:	< 2%	> 8%
Injury symptoms:	Off-flavours, failure to ripen	Off-flavours, may aggravate chilling injury at < 12°C
Potential for injury:	Moderate	Moderate

Commercial use or potential: None at this time; waxing may be used to modify internal O_2 and CO_2 concentrations.

Remarks: Chilling injury should be avoided when CA is used. Prestorage treatments to minimise decay during storage are essential to successful storage.

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Pineapple (*Ananas comosus* (L.) Merril.)

Optimum temperature: 10°C, expected range: 8–13°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	2–5%	5–10%
Benefits:	Delayed senescence, reduced respiration	Delayed degreening, reduced chilling injury
Potential for benefits:	Slight to moderate	Moderate
Injurious level:	< 2%	> 10%
Injury symptoms:	Off-flavours	Off-flavours
Potential for injury:	Moderate	Moderate

Commercial use or potential: Very limited

Remarks: Waxing may be used to modify O_2 and CO_2 concentration within the fruit enough to reduce incidence and severity of endogenous brown spot.

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Cherimoya (*Annona cherimola* Mill.)

Optimum temperature: 10°C, expected range: 8–15°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	5%	5–10%
Benefits:	Lower respiration and ethylene production rates, retarded ripening, firmness retention	Delayed ripening
Potential for benefits:	Good	Moderate
Injurious level:	< 1%	?
Injury symptoms:	Off-flavours	?
Potential for injury:	High	?
Commercial use or potential:	Cherimoyas can be kept for up to 6 weeks at 10 °C in 5% O_2, then ripened with good flavour at 20°C.	

Remarks: Ethylene removal can be helpful in retarding ripening.

Selected References

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Sweetsop (custard apple) (*Annona squamosa* L.)

Optimum temperature: 15°C, expected range: 12–20°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	3–5%	5–10%
Benefits:	Reduced ethylene production and respiration, delayed ripening	Delayed ripening
Potential for benefits:	Good	Moderate
Injurious level:	< 1%	15% and higher
Injury symptoms:	Failure to ripen	Flat taste and uneven ripening
Potential for injury:	High	Moderate

Commercial use or potential: None at this time (July 1993)

Remarks: Ethylene removal can be helpful in retarding ripening.

Selected References

Broughton, W.J. and Tan, G. 1979. Storage conditions and ripening of the custard apple *Annona squamosa* L. Scientia Horticulturae, 10, 73–82.

Tsay, L.M. and Wu, M.C. 1989. Studies on the post-harvest physiology of sugar apple. Acta Horticulturae, 258, 287–294.

Durian (*Durio zibethinus* J. Murr.)

Optimum temperature: 15°, expected range: 12–20°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	3–5%	5–20%
Benefits:	Lowered CO_2 and C_2H_4 production rates, retarded ripening	Retarded ripening if combined with 10% or lower O_2
Potential for benefits:	Good	Moderate
Injurious level:	< 2%	> 20%
Injury symptoms:	Failure to ripen, grey discolouration of pulp	?
Potential for injury:	High	?

Commercial use or potential: None at this time (July 1993)

Remarks: Modified atmosphere packaging and waxing can reduce CO_2 and C_2H_4 production rates and sulphurous odour characteristic of ripe durian.

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Lychee (Litchi) (*Litchi chinensis* Sonn.)

Optimum temperature: 7°, expected range: 5–12°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	5%	3–5%
Benefits:	Reduced skin browning and polyphenoloxidase activity	Slower rates of losses of ascorbic acid, acidity, and soluble solids
Potential for benefits:	Good	Moderate
Injurious level:	?	?
Injury symptoms:	?	?
Potential for injury:	?	?

Commercial use or potential: Modified atmosphere packaging is used to a limited extent.

Remarks: Maintenance of high relative humidity is essential for reduction of water loss and browning.

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Rambutan (*Nephelium lappaceum* L.)

Optimum temperature: 10°, expected range: 8–15°C

Modified atmosphere considerations:

	Reduced O_2	Increased CO_2
Beneficial level:	3–5%	7–12%
Benefits:	Retardation of senescence, lower respiration rate	Retarded red colour loss, extended postharvest life to about one month if water loss is minimised
Potential for benefits:	Slight	Moderate
Injurious level:	< 1%	> 20%
Injury symptoms:	Increased decay incidence	?
Potential for injury:	High	?

Commercial use or potential: Modified atmosphere packaging has potential for maintaining quality.

Remarks: Maintenance of high relative humidity is essential to minimising water loss and darkening of the skin.

Selected References

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New Developments in Modified Atmosphere Packaging and Surface Coatings for Fruits

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Abstract

Modified atmosphere packaging (MAP) emerged in the 1970s as a new technology that may extend life of perishable agricultural produce. However, if proper precautions are not taken this technology may also risk the microbiological safety of the packaged food. Perforated films enable MAP to maintain H_2O-saturation with only a slight change in O_2 and CO_2. This results in reduction of water loss and alleviation of water stress without the possible deleterious effects of anaerobiosis or CO_2 damage. New trends of research are in the development of interactive or 'smart' films. These new films may be expected somehow to sense the changing internal packaging environment and admit oxygen from the outer atmosphere or allow excess CO_2 to escape. Modified humidity packaging, combined with incorporation of fungicides into films, heat treatment, etc., are new, promising lines of research. Mathematical modelling for gas exchange in MAP is based on a combination of Fick's Law and the Michaelis–Menten equation. This model enables production of the optimal parameters of a package. Surface coatings have gained some commercial uses due to the availability of edible and natural origin coatings.

MODIFIED atmosphere packaging (MAP) emerged in the 1970s as a new technology that may extend life of perishable agricultural produce and reduce its spoilage and decay. MAP involves the exposure of produce to the atmosphere generated in a package by the interaction of the produce, the package and the external atmosphere. The initial atmosphere may be either air or a gas mixture. Different additives that may affect the atmosphere may be introduced into the package before it is sealed. The main feature distinguishing MAP from controlled atmosphere (CA) is that, in the case of MAP, active human involvement stops at the moment of sealing.

MAP technology comprises a wide spectrum of techniques varying from the simple early method of individual seal packaging (Ben-Yehoshua 1985, 1991; Ben-Yehoshua and Nahir 1977), which may be considered as MAP for individual fruit, to the more intricate control of the micro-atmosphere in the new packages for various salad bar items (see Brody 1991). Seal packaging involves sealing a fruit in a plastic film with or without heat shrinking to conform to the shape of the fruit. Usually, this technique has little or no effect on the internal concentrations of O_2 and CO_2 and a large effect on the water vapour pressure, usually resulting in a near saturated package atmosphere. Ben-Yehoshua et al. (1983) found that the relative humidity (RH) of the ambient atmosphere of sealed pepper fruit was 97%. The atmosphere of the sealed fruit is a result of many factors, not the least of which are unintended holes in the film. Indeed, these minute holes may be an important reason for the success of the technique with many commodities.

The more complex forms of MAP aim at achieving a closely specified ambient atmosphere of the package by carefully selecting many relevant parameters and orchestrating them harmoniously to rapidly achieve the desired gas composition. The parameters should be selected so that the atmosphere is maintained for as long a period as the packaged commodity requires. Thus, this type of MAP is more carefully controlled than CA and makes much greater demands since all the controls have to be programmed into the package before it is sealed.

MAP is a multidisciplinary technology of maintaining freshness that utilises basic principles of chemistry, physics, plant physiology and pathology, microbiology, food science, engineering, and polymer chemistry. Better understanding of this wide scope will promote implementation of the technology.

MAP technology has developed rapidly over the past decade (Gorris and Peppelenbos 1992; Kader et al. 1989; Lioutas 1988). This rapid development is due to two contradictory trends affecting modern postharvest handling of fruits, vegetables, and other perishable produce. 1) Food distribution in developed countries now involves many perishable food items, some of which are

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minimally processed; such as shredded lettuce, carrot or celery sticks, and fresh salad mixes. Minimal processing increases the perishable nature and susceptibility to decay and desiccation, and there is consequently a greater need for quality and decay control measures. 2) There is growing anxiety among consumers about the use of synthetic chemicals to protect food from pathogens and pests to extend the life of perishable produce. One of the consequences of this public anxiety is that more and more synthetic food protectants such as certain fungicides and pesticides are being banned.

MAP technology, which utilises only the natural components of air, has achieved public acceptance due to these two trends. MAP has the advantages that synthetic chemicals are not used, no toxic residue is left, and there is little environmental impact, particularly if the plastic films used can be recycled.

Recent advances in the design and manufacture of polymeric films with a wide range of gas-diffusion characteristics have also stimulated interest in MAP of fresh produce. In addition, the increased availability of various absorbers of O_2, CO_2 (Kader et al. 1989), water vapour (Shirazi and Cameron 1992), and C_2H_4 (Ben-Arie and Sonego 1985; Scott et al. 1970) provides possible additional tools for manipulating the microenvironment of MAP.

There is extensive literature on the benefits of MAP and the dramatic extensions of shelf life for various foods (see Lioutas 1988; Kader et al. 1989). However, there are few papers dealing with the microbiological safety needed for successful MAP implementation (Genigeorgis 1985; Hintlian and Hotchkiss 1986; Palumbo 1987). Future approaches must put consumer safety first and freshness second.

Waxes and other surface coatings have long been used in handling fruits and vegetables (Ben-Yehoshua 1967; Kaplan 1986). However, because of ever-growing public resentment of toxic residues, and adverse effects of certain coatings such as off-flavour (Cohen et al. 1990) and ineffectiveness in preventing weight loss (Ben-Yehoshua et al. 1985), surface coatings were at one stage endangered. The emergence of so-called 'edible coatings' in the 1980s (Banks 1984a,b; Semper Biological Technology 1990) and natural origin coatings such as chitosan (Stossel and Leuba 1984; El-Ghaouth et al. 1991, 1992) has renewed interest in surface coatings, and more commercial uses are being implemented. This review is not intended to be exhaustive. Discussion will focus on those fields in which the most important developments have occured.

Principles of MAP

MAP is a dynamic system during which respiration and permeation occur simultaneously. Factors affecting both respiration and permeation must be considered when designing a package. Commodity mass, temperature, O_2, CO_2, and C_2H_4 partial pressures, and stage of maturity are known to influence respiration in a package (Kader et al. 1989). Type, thickness, unintended holes, and surface area of the packaging film, as well as temperature, relative humidity, and gradient of CO_2 and O_2 partial pressures across the film, are known determinants of permeation (Ashley 1985). All of these factors interact to create equilibrium levels of CO_2 and O_2 in a sealed package. Package equilibrium or steady state is defined as the point at which the commodity CO_2 production and O_2 consumption rates are equal to the permeation rates of the respective gases through a package at a given temperature. A poorly designed package will become anaerobic or develop unacceptable levels of CO_2 before equilibrium is achieved. Usually, MAP does not utilise the full potential of controlling the ambient concentrations of O_2 and CO_2. An ideal package system will equilibrate and maintain at the levels of CO_2 and O_2 that are known to be optimal for storage, transport, and handling throughout the market chain for a specific commodity.

The beneficial and detrimental effects of MAP were reviewed by Lioutas (1988) and Kader et al. (1989). The mode of MAP was handled in the review of Kader et al. (1989) as well as in other publications of his team.

Advantages and Disadvantages of Modified Atmosphere Packaging

Advantages

- Reduction of weight loss, desiccation, and shrivelling
- Delay of ripening
- Alleviation of chilling injury
- Semicentralised manufacturing options
- Expanded radius of distribution systems
- Reduction of labour and waste at the retail level
- Quality advantages such as colour, moisture, flavour and maturity retention
- Excellent branding options
- Reduction of handling and distribution of unwanted or low-grade produce
- Quality advantages transferred to the consumer

Disadvantages

- Requirement of additional investment in machinery and labour in the packaging line
- Risks of spoiled produce due to improper packaging or temperature abuse
- Possible occurrence of new risks of microbiological safety due to possible development of anaerobic pathogenic flora
- Plastic films may be environmentally undesirable unless effective recycling is installed
- MAP technology is still unavailable for most produce

The mechanism cited most for the favourable result is the change in pH related to the concentration of CO_2 (Daniels et al. 1985; Siriphanich and Kader 1986).

Effects of MAP on Disease Control

The growth and activity of microorganisms can be retarded by elevated CO_2 and reduced O_2 concentrations. At ambient temperatures, levels of up to 20% CO_2 extend both the lag and logarithmic growth phases of common spoilage organisms by as much as double (Daniels et al. 1985). Levels of below 1% O_2 and/or above 10% CO_2 are needed to significantly suppress fungal growth (El-Goorani and Sommer 1981). Elevated CO_2 levels (10–15%) can be used to provide fungistatic effects on commodities that tolerate such CO_2 levels (Kader et al. 1989).

The growth of almost all aerobic microorganisms, particularly the psychrophilic, can be retarded by elevated CO_2 and reduced O_2 (Barkai-Golan 1990; Daniels et al. 1985). Since a significant cause of deterioration of fresh and minimally processed produce is the action of psychrophilic microorganisms, retardation of their growth is highly desirable.

Individual seal-packaging reduced fruit decay by prevention of secondary rot infection which is an important factor for fruits, particularly those destined for long-term storage or shipment. An individual fruit infected by *Botrytis*, *Geotrichum*, or *Phytophthora* will rapidly induce decay in the other fruit in the same carton. Seal-packaging or MAP also changed the distribution of pathogens in citrus. Sealed fruit generally had slightly more stem-end rots and fewer moulds than those unsealed. The pathogens, particularly quiescent ones, generally start to develop rapidly in the humid atmosphere. Consequently, the balance between host and pathogens may, at times, favour the pathogen, and decay percentage rises. For this reason, adequate decay control of sealed fruit may be of paramount importance (Ben-Yehoshua 1991).

MAP by itself may sometimes be ineffective in controlling decay. Thus, additional methods to combat diseases in packages should be sought. Sealing in polyolefin Cryovac MD film of Oroblanco citrus fruit, combined with hot-water treatment, achieved reduction in both decay and sensitivity to chilling injury. Combination of seal packaging and curing (36°C, 3 days) reduced decay and sensitivity to chilling injury, healed injury, and extended the life of citrus fruits. The mode of action of curing was shown to be through: i) thermal inhibition of the pathogen; ii) induced synthesis of lignin-like materials which form a mechanical barrier to the invasion of the pathogens, and iii) preventing the degradation of natural antifungal substances.

Combined imazalil treatment and seal-packaging of citrus and pepper fruits enabled a marked reduction of decay. The imazalil could be applied in several ways: as a dip, spray, or by incorporating the imazalil into the plastic films. The films serve as a slow release reservoir of the fungicide to the produce, thus reducing the residue on the produce (Ben Yehoshua and Nahir 1977; Ben-Yehoshua et al. 1987; Miller and Risse 1988).

The film acts also as a physical barrier to slow the dissipation of volatile fungicides, such as imazalil, 2 aminobutane, and diphenyl. MAP thereby produces a microatmosphere that can be enriched with a suitable volatile fungicide so that the sealed enclosure forms a fumigation chamber to control decay over a prolonged period. Such action might be of great importance in controlling the pathogens that cause stem-end rots. These pathogens are located deep in the fruit tissue, below the button, a site difficult to reach with fungicides.

Risks in Utilising MAP

Fruits and vegetables are characterised by an elaborate microflora, consisting of many different types of microorganisms, most of which are involved in the spoilage of produce but are harmless to humans. Microorganisms that are a hazard to humans usually cannot establish a dangerous population density because they have to compete with the spoilage and other microflora. However, MAP changes the micro-environment of the microorganisms and may well impair this balance. One incidence of the growth of such toxins in shredded cabbage led to a study by the U.S. Food and Drug Administration (FDA) which demonstrated that the toxin could be developed if a high enough inoculum and temperature were present and enough time were permitted (see Brody 1991).

Refrigerated MAP slows the growth of spoilage flora, most of which are mesophiles and grow best at temperatures between 20 and 40°C, and reduces their competitive capacity. Psychrophylic pathogens like *Yersinia enterocolitica*, *Listeria monocytogenes*, *Aeromonas hydrophilia*, and *Clostridium botulinum*, which are able to grow at temperatures as low as 3–5°C, may then get a chance to proliferate (Hintlian and Hotchkiss 1986; Palumbo 1987). If inappropriate temperatures are used, even mesophylic pathogens such as *Staphylococcus aureus*, *Bacillus cereus*, *Salmonella* spp., and *Vibrio parahaemolyticus* may develop rapidly, especially on meat, fish, or dairy products (Brody 1988; Genigeorgis 1985; Hintlian and Hotchkiss 1986; Palumbo 1987).

Absence of O_2 creates conditions for the growth of anaerobic microorganisms, some of which may be pathogenic. Furthermore, by suppressing aerobic microbial growth, competition for anaerobes is diminished, leaving almost ideal conditions for anaerobes when the temperature is above 4°C, spores are present, and sufficient time elapses. Aerobes may also be suppressed by mild

heat, i.e., pasteurisation or heat filling which, coupled with low oxygen, can create an ideal anaerobic growth environment with only temperature as the barrier to prevent vegetative growth and toxin formation. Thus, a variant of MAP with mild heat, which is highly beneficial for quality retention, can create a condition of potential hazard, a subject of concern from a microbiological safety perspective. The situation is aggravated when the basic rules of sanitation and control are violated.

Contamination of fresh vegetables with large loads of pathogenic anaerobes in unsanitary minimal processing operations would be an example of applying undue microbiological stress to minimally processed produce, another instance of the need to integrate the many disciplines involved in achieving the desired benefits of MAP. Thus, good reason exists to attempt to maintain some level of O_2 in proximity to the packaged food. Recent packaging material developments are directed towards overcoming the problem of O_2 starvation (Cameron 1989; Cameron et al. 1989).

On the positive side, it should be pointed out that there have, in recent times, been almost no reports of poisoning by fruits and vegetables held in MAP. The effects of MAP on microorganisms antagonistic to pathogenic microorganisms warrants study.

MAP Application for Fruits and Vegetables

MAP of fruits and vegetables has been reviewed by Geeson (1989), Zagory et al. (1989), Kader et al. (1989), Prince (1989) and Gorris and Peppelenbos (1992). Seal-packaging in particular was summarised by Ben-Yehoshua (1991). A brief discussion on the MAP of fruits and vegetables will be presented here. The most common plastic films utilised for fruits and vegetables are low, linear low, or high density polyethylene and PVC films. Recently, various new films have been used for packaging fruits and vegetables to minimise respiratory anaerobiosis and potential microbiological hazards (see Brody 1991).

Despite many advantages of seal-packaging, adoption of this technique has been rather slow in countries dependent on machinery to apply it, and the technique has not yet reached its full potential. Possibly, non-availability of fast and reasonably-priced equipment, as well as the cost of the film, are the main reasons limiting the commercial adoption of seal-packaging. However, in China and Japan, where the film packaging is applied by hand, this technique has been adopted rapidly. In fact, Professor Huang Bangyan (pers. comm.) from the Chinese Academy of Science, Guangzhou, has reported that seal-packaging has become a common new technique for citrus fruit storage in China and its application has reduced postharvest losses and given good economic returns. Kawada and Kitagawa (1988) reviewed the current use of plastic film in the storage of citrus and other fruits in Japan. They maintained that plastic film is one of the most powerful and economical tools for minimising weight loss and when several factors are refined, it can prolong fruit life by a controlled atmosphere effect. In recent years, the use of plastic film in produce packaging has increased greatly. This is due mainly to the rapid development of new films and packaging technology, together with changes in produce marketing.

Sealed packages of many fruits and vegetables are commonly available on the shelves of supermarkets. However, this sealing was applied in many cases just before the display of the produce in the supermarket and not, as is preferable just after harvest. MAP has great advantages in developing countries because it can economically be done by hand saving the high cost of new machinery. Additionally, the need there for such a technique is much greater because of the dearth of refrigerated storage.

Recently, many more commodities have been sealed in MAP, including apple (Geeson and Smith 1989), asparagus (Aharoni et al. 1990), bell pepper (Rodov et al. these proceedings), blueberry (Beaudry et al. 1992; A.C. Cameron et al., unpublished data), broccoli (Aharoni et al. 1985), bush berry (Kader et al. 1989), cucumber (Ben-Yehoshua et al. 1978), eggplant (Temkin-Gorodeiski et al. 1990), fresh herbs (Aharoni et al. 1989), guava (Combrink et al. 1990), kiwifruit (Ben-Arie and Sonego 1985), lettuce (Ben-Yehoshua et al. 1967), mango (Rodov et al. these proceedings), mushroom (Burton et al. 1987), muskmelon (Lester and Bruton 1986), pear (Geeson et al. 1991), persimmon (Ben-Arie and Zutkhi 1992; Pesis et al. 1986), strawberry (see Kader et al. 1989), tomato (Shirazi and Cameron 1992), and other commodities (Kader et al. 1989; Kader, these proceedings).

It appears that simple sealing of produce in plastic film is still the major commercial application of MAP. It is expected that the future may bring more precise control of O_2 and CO_2 into practice.

Cleaned and cored, trimmed and precut lettuce were successfully packaged using ethyl-vinyl-acetate/low density polyethylene (EVA/LDPE) film. The film permits a guaranteed life of 2 weeks for precut lettuce stored at 0–2°C. Uncoated oriented polypropylene is now being employed, particularly in Europe, for mixed cut green salads packaged in serving-sized pouches with air to modify the internal environment by natural respiration. Other fresh produce items being packed for distribution are chopped onions, green peppers, carrot sticks, and celery (see Brody 1991).

One of the novel approaches in MAP of fruits and vegetables is the introduction of a gas mixture of desirable composition into a package before sealing.

Researchers at The University of British Columbia (UBC), Canada have been developing systems in which freshly cut fruits or vegetables were reduced in temperature to 0°C and exposed to mixtures of low O_2/ high CO_2 including argon. Some of the exceptional quality retention periods reported by UBC have been confirmed by researchers at The Liquid Air company. About three years ago, this company evaluated the potential use of 'non-conventional gases' for MAP applications. Emphasis was placed on gases belonging to the helium group, i.e., argon, neon, krypton, and xenon (see Brody 1991).

The Liquid Air company conducted experiments with foods in standard MAP conditions. In one series, sliced tomatoes were placed in gas mixtures containing either 15 or 8% O_2 with the balance nitrogen or argon. The CO_2 production rate observed differed markedly depending on whether the gas mixture contained nitrogen or argon. Whereas in cases of argon-containing mixtures, the CO_2 production was inversely proportional to the O_2 depletion, in N_2-containing mixtures, the CO_2 production was more intense, and its concentration reached very high levels at the end of the test (see Brody 1991).

Although the reasons for such differences between gas mixtures containing argon and those containing nitrogen are not yet entirely understood, the much higher solubility of argon in water as compared with nitrogen is a possible explanation. The possible interference of argon with chemical or enzymatic O_2 receptor sites is not to be excluded as these two gases have almost identical molecular diameters: 3.8 angstroms and 4 angstroms, respectively.

Modified Humidity Packaging

RH in a plastic package is usually very high. Small fluctuations in the storage temperature may result in condensation, which would greatly increase the proliferation and spread of spoilage microorganisms (Grierson and Wardowski 1978). Thus, reducing the in-package RH to an optimal amount may be critical for the success of MAP of fresh produce. Shirazi and Cameron (1987) introduced the concept 'modified humidity packaging'. They also studied (Shirazi and Cameron 1992) the feasibility of controlling RH in MAP using compounds possessing Type III sorption isotherm behaviour. Ten grams each of $CaCl_2$, sorbitol, NaCl, xylitol, and KCl sealed with one mature green tomato fruit at 20°C in simulated packages for 48 days resulted in stable RH of 35, 75, 75, 80, and 85%, respectively. RH was a function of the ratio of chemical to fruit mass. RH in the control was in the range 96–100% throughout the experiments. These investigations described a simple system that uses spunbonded polyethylene pouches for the application of this humidity control method to packages. The storage life of packaged red-type tomato fruit at 20°C was extended from 5 days using no pouch to 15–17 days with a pouch containing NaCl, mainly by retardation of surface mould development. The technique of controlling in-package RH is independent of outside RH.

Rodov et al. (these proceedings) verified the observation that addition of salt to sealed pepper in a tray reduces decay markedly.

Interactive and Microporous Films

MAP application may require packaging materials capable of passing controlled quantities of water, O_2, CO_2, and C_2H_4 in order to control the concentrations of these gases in the internal package environment and to avoid anaerobiosis. Thus was born the term, 'smart' packaging, or packaging that could somehow sense the changing internal packaging environment and admit O_2 from the outer atmosphere, allow excess CO_2 to escape, or both. This terminology then translated into active packaging which encompasses a broad spectrum of materials sensitive to the packaged produce requirements and its surrounding environment. The latter group includes families of package supplements such as in-package sachets of chemicals to absorb O_2, C_2H_4, or CO_2 and even to provide O_2 or CO_2 when the package environment has been depleted of the desired gas (Angel et al. 1992; Ben-Yehoshua 1985; Kader et al. 1989).

Microporous films which are engineered to pass low molecular weight gases such as CO_2, O_2, water vapour, nitrogen, etc., expressly for the purpose of adjusting the gaseous concentration within the package, generally fall into two categories: those which are intentionally perforated with very small orifices which pass gases at a very slow rate relative to the total area; and those which contain intentional additives that interfere with the continuity of the plastic materials and thus alter their gas transmission rates (see Brody 1991).

Those films exhibiting high gas permeability by virtue of their nature or by reason of being polymeric blends are technically not microporous. Among these are high (6–18%) EVA content polyethylene films such as Shields Bag or Cryovac, or polycyclic terpene film produced in the past by Bunzl in the U.K. Both are reported to have O_2 permeabilities of more than 6000 mL/m^2/day at standard temperature and pressure (STP). Phillips K-resin block copolymer styrene film and Dow Chemical's Attane ultra-low-density ethylene octane copolymer films with transmission of over 13,000 mL/m^2/day STP are also being suggested as high gas permeability packaging materials for MAP of respiring produce (see Brody 1991).

The concept of a packaging material with O_2/CO_2 transmissions compatible with the 'needs' of the contained produce has been advanced. Two basic types of

film materials have been prosposed, tested and to some extent, introduced on a commercial scale: microperforated and mineral filled.

Microperforated films include those of Courtaulds and Curwood. The Courtaulds film, designated P-PLUS, is manufactured by perforating a polyolefin film with very tiny orifices using laser beams. According to Courtaulds, permeabilities to O_2 and CO_2 range from 6000 to 300 000 mL/m^2/day/atm. Courtaulds claims their P-PLUS films represent a range of base film substrates displaying permeabilities precisely matching the demands of the produce. The gas permeabilities are designed to balance the respiration rate of the produce being packed.

Curwood has introduced laminations of 0.00035–0.00048 inch gauges polyester and linear LDPE film which has been microcut. These microcuts permit better flow of oxygen and CO_2 and thus minimise the probability of respiratory anaerobiosis.

The two most popular microporous materials are those of van Leer (Belgium) and FreshHold (USA) with the latter receiving major media coverage. In this type of material, the plastic polymer is admixed with an inert inorganic mineral such as crushed calcium carbonate or talc. The mineral fill is encapsulated in discrete particulates by the polymer and imparts a variety of properties such as stiffness.

Perforation Effects

Perforated films enable MAP that allows the build up of H_2O-saturation with only a slight change in O_2, CO_2, and C_2H_4 (Geeson 1989; Ben-Yehoshua 1991). These facts may be explained by considering the number of relevant molecules in gas exchange of bell-pepper fruit. One kg of pepper evolves 79×10^{20} molecules of H_2O and 3.0×10^{20} molecules of CO_2 and consumes 3.0×10^{20} molecules of O_2 per hour at 17°C and 85% RH. Thus, for each molecule of CO_2 or O_2, 26 molecules of H_2O are available for exchange. Furthermore, the access of each one of these molecules to the pores is similar and the molecular weight of these gases, which determines their relative rate of movement, is also quite similar. Consequently, although most of the molecules moving out are those of water, the large number of water molecules available for movement still allows the build up of the ambient RH to be nearly saturated. However, these pores are able to allow the relative small number of O_2 and CO_2 available for movement to be exchanged so that the pores prevent marked changes in the concentrations of O_2, and CO_2.

Perforation retains many of the good results of sealing in reduction of water loss and alleviation of water stress, without the possible deleterious effects of anaerobiosis such as off-flavours, fermentation, or CO_2 damage. Furthermore, perforation of polyolefin film enabled attainment of some of the advantages of seal-packaging of Tommy Atkins and Keitt mango fruits without inhibiting the ripening process that occurs in sealed fruit that was not perforated, as shown by Rodov et al. (these proceedings). Micro-perforated packaging techniques have also proven effective in retarding deterioration in several other crops, e.g. discoloration of washed parsnips, and improving sugar retention in sweetcorn (Geeson et al. 1988). Additionally, perforation enables MAP for highly respiring produce such as mushrooms (Burton et al. 1987). Perforation may also enable MAP for produce that is sensitive to even small changes in concentrations of O_2, CO_2, and C_2H_4.

Packaging Modelling

In order to reduce the time needed to develop a package, the use of packaging parameter prediction, i.e. a mathematical model, is highly desirable. Such a model may replace the method of 'Pack and Pray' with planned and programmed research attempting to match the best film to the commodity. Mathematical models based on the characteristics of films needed to generate or maintain optimum internal concentrations of metabolic gases would help greatly to maximise storage life of perishable produce. Such information would be valuable to manufacturers and users of films by helping them to assess and establish priorities in the selection, development, and synthesis of packaging materials. Several models have been discussed in the recent literature (Cameron et al. 1989; Emond et al. 1991; Mannapperuma et al. 1989; Lee et al. 1991). All are based on earlier work by other researchers.

The first step in modelling the packaging system is to find mathematical equations that adequately describe the processes of respiration and permeation. The package permeability to the gases is treated in most models as a physical process which obeys Fick's Law, i.e. the rate of material exchange between the internal and external atmospheres is proportional to the concentration difference in these two compartments.

Mannapperuma et al. (1989) developed a model for MAP in equilibrium conditions and showed that in this case there is a linear relation between oxygen and CO_2 concentrations, subject to a constant respiratory quotient.

Lee et al. (1991) were the first MAP modellers to treat respiration as a biochemical phenomenom in terms of enzyme kinetics. They assumed that CO_2 plays the role of inhibitor of the enzymatic reaction, and used the equation for uncompetitive inhibition mechanism. In this case, the rate of reaction (r) is equal to

$$r = V_m C_1 / [K_M + C_1(1 + C_2/K_i)]$$

where C_1 is the substrate concentration (which is O_2

concentration in the case of respiration), V_m and K_M are parameters of the classical Michaelis-Menten kinetics, Vm being the maximal rate of enzymatic reaction, and K_M is the Michaelis constant, C_2 is the inhibitor concentration (CO_2 concentration in the case of respiration) and K_i is the constant of equilibrium between the enzyme–substrate–inhibitor complex and free inhibitor. Combining this equation with Fick's Law for O_2 and CO_2 permeation, Lee et al. (1991) obtained a set of differential equations representing the mathematical model for the modified atmosphere system. They estimated parameters of this model (V_m, K_M, and K_i) from experimental data and then performed numerical calculation of the equations.

Cameron et al. (1989) used a simple Michaelis-Menten equation with no inhibition ($K_i = 0$), and introduced exponential dependence into the parameters V_m and K_M to study O_2 and CO_2 concentration in MAP as functions of temperature. They attempted to predict the conditions in which an anaerobic atmosphere would exist in the package.

Fishman, Rodov, and Ben-Yehoshua (unpublished data) investigated a dynamic model for MAP based on Fick's law and the Michaelis–Menten equation. According to the model's prediction, the CO_2 time course for most plastic films does not reach steady state smoothly but rises to a maximum and then declines to an equilibrium level (the overshooting effect). This phenomenon was confirmed experimentally. This maximum may mislead researchers searching for the equilibrium conditions needed in model studies. Accordingly, in a MAP study of equilibrium conditions, consideration should be given to the fact that the MAP system may be in the transient period for a considerable time with the CO_2 concentration temporarily exceeding that of the equilibrium. The increment between maximum and equilibrium states of CO_2 concentrations depends on the numerical parameters of the system. The predictions of this model regarding O_2 and CO_2 were found to be correct.

Their model was designed to check effects of perforation on the concentrations of O_2, CO_2, and H_20. The model showed that, in a tray holding 4 pepper fruit and with a hole of 0.25 mm, the RH was nearly saturated but the concentrations of O_2 and CO_2 were close to that in air.

Surface Coatings

Types of coatings

The practical application of coatings to fruits and vegetables after harvest has a long history. In China, as early as the 12th or 13th century, oranges, mandarins, and persimmons were dipped in molten waxes (see Zhuang 1986). Nevertheless, coatings did not attain commercial use in storage of perishable produce until the 1930s (Kaplan 1986). Many coating formulations have since been introduced and applied commercially for different produce. Coatings are mainly classified as follows.

Solvent wax. A wax based on one or more resins dissolved in a blend of petroleum solvents with plasticisers and film-forming agents added to improve shine and film flexibility. The solvent readily evaporates and a thin film is left on the surface of produce.

Water wax. There are two kinds of water waxes, i.e. resin solution and emulsion based. Resin solution waxes are composed of one or several soluble resins or resin-like materials, such as shellac or natural gums. They can be dissolved in water with or without the aid of other water miscible solvents such as alcohols and glycerine. Emulsion waxes are composed of a natural wax such as Carnauba or paraffin, or a synthetic wax such as oxidised polyethylene emulsified in a soap or detergent. The introduction of high density polyethylene into wax formulation in Israel in 1960s resulted in greater storage life of the waxed produce. It has since gained much popularity in most countries, especially citrus-producers (Ben-Yehoshua 1967, 1991).

Other coatings. Several so-called 'edible coatings' were formulated in the early 1980s. Of these, Tal Prolong and Semperfresh are best known (Smith and Stow 1984; Semper Biological Technology 1990). A chitosan coating has been introduced recently (El-Ghaouth et al. 1991, 1992).

The present state of the art

Coatings can to some extent reduce decay of produce. In many of these cases, coated fruit had less decay and longer storage life than uncoated samples (Ben-Yehoshua 1967; Curtis 1988). Decay control activity of a coating was much improved by adjuncts such as fungicides. However, there are at least two problems in the addition of fungicides. Fungicide may not be miscible with the coating solutions, particularly in the case of solvent waxes, and the application of fungicides may not meet the regulations set by the importing countries, especially for those peel-edible fruits such as apples and peppers.

Recently, El-Ghaouth et al. (1991, 1992) reported that chitosan coating could control the decay of strawberry, cucumber, and bell pepper fruits. Chitosan by itself can inhibit spore germination, germ-tube elongation, and radial growth of certain fungi (Hirano and Nagao 1989; Stossel and Leuba 1984). In addition, chitosan may induce defence enzymes such as chitosanase, chitinase, or β-1,3-glucanase. Chitosan also induces the accumulation of the phytoalexin pisatin in pea pods (Walker-Simmens et al. 1983). Chitosan has no human toxicity (Arai et al. 1968) but has an unfavourable smell (El Ghaouth et al. 1992).

Chilling injury can be alleviated by coating. Waxed Oroblanco fruit (*Citrus grandis* × *C. paradisi*) had significantly lower chilling injury incidence than unwaxed samples when stored at 1°C for 40 days.

Fruits of some deciduous trees are susceptible to a wide range of physiological disorders. Modification of internal atmosphere by the use of coatings sometimes increases the disorders associated with high CO_2 and low O_2 concentrations, such as core-flush, fresh browning, and breakdown of pome fruits (Meheriuk and Lau 1988). On the other hand, reductions in the incidence of scald and bitter pit in Cox's orange pippin apples and in breakdown and scald of pears have been reported (Smith et al. 1987). Thus, coating should be checked carefully before large-scale implementation.

Fruit flies are restricted by quarantine authorities of many importing countries. Before fruit are exported they must be treated to eradicate the flies. Coating of a standard commercial fruit wax containing the insect growth regulator methoprene can kill the adults of oriental fruit fly (Saul et al. 1987).

Effects of coating application on the quality of fruit have been found. Firmness, colour, texture, acid concentration, and ripening process are influenced to different extents by coatings (Ahmad and Khan 1987; Farooqi et al. 1988). The magnitude of effects is related to the degree of atmosphere modification, and may also be cultivar- and temperature-dependent. For pears, the effects of coating application are variable (Drake et al. 1991). For banana, Tal Pro-long coating can delay ripening and chlorophyll loss (Banks 1984a,b). One percent Pro-long delayed ripening of Alphonso mango primarily by inhibiting the development of yellow peel colour and delaying some of the ripening changes (Krishnamurthy 1989).

Mode of action of coatings

The primary objective of coating use is to reduce weight loss and shrinkage. Consequently, weight loss reduction has been recommended as the most important criterion for evaluating a coating formulation. Unfortunately, the commercial practice of coating fruits inadequately reduces transpiration, but is so effective in restricting O_2 and CO_2 transport that it may result in anaerobic respiration and off-flavour development (Ben Yehoshua 1967, 1969).

Ben-Yehoshua et al. (1985) investigated resistance of either waxed or individually sealed citrus fruits to C_2H_4, O_2, CO_2, and H_2O mass transport, anatomically by scanning electron microscopy, and physiologically by gas exchange measurements at steady state. Stomata of harvested citrus fruits are essentially closed. However, ethylene, O_2, and CO_2 still diffuse through the residual stomatal opening where the relative transport resistance depends on the relative diffusivity of each gas in air. Water vapour, on the other hand, moves preferentially by a different pathway, probably through the cuticle. The water conductance is 60-fold greater than that of other gases. During the coating operation the liquid wax flows into stomatal openings and partially or completely plugs the stomata, effectively restricting the transport of O_2, CO_2, and C_2H_4. An intermittent discontinous layer is formed on the fruit surface after waxing. Contrary to the marked effects on resistance of O_2, CO_2, and C_2H_4, waxing results in inadequate reduction of water difussion outside of the fruit. Individual sealing of fruit with high density polyethylene films reduced water transport by 90% without substantially inhibiting gas exchange, though the thickness of the plastic film was 15 μm whereas that of the discontinuous wax layer was less than 1 μm. This difference in effects of sealing and waxing explains the great risk that waxing may bring in restricting gas exchange by clogging the stomata.

Banks (1984a) found that Tal Pro-long coating could modify the internal atmospheres of bananas by reducing the permeability of the fruit skin to gases. Permeability of control fruit to CO_2 was greater than that to O_2 and C_2H_4, and this differential permeability was enhanced by coating. He suggested that CO_2 moved via pathways involving water and/or lipids, i.e. via the epidermis and cuticle.

Problems and prospects

Although coatings have been widely used for more than 50 years, there exist several problems which impede their application. First, current consumer trends toward additive free diets may disadvantage coatings. In recent years, this process has been attacked by consumers who see it as a potential threat, and the U.S. FDA has responded to those fears by requiring labeling of fruit with the listing of each ingredient in the formulation and posting it at the retail level (Anon. 1992). Second, coatings sometimes inadequately reduce transpiration, but yet are effective in restricting O_2 and CO_2 diffusion, which may cause off-flavours to develop. Additionally, coating fosters some physiological disorders such as superficial scald in D'Anjou pears. Both of the latter phenomena are related to the permeability of coatings to gases and water vapour. The emergence of edible and natural origin coatings has renewed the interest in surface coatings, and greater commercial use is anticipated. Additionally, as a relatively low cost technology, coatings may have more potential in developing countries where refrigerated storage is not affordable.

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Preharvest Effects on Postharvest Quality of Subtropical and Tropical Fruit

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Abstract

Fruit quality is largely determined before harvest, while postharvest treatments are generally aimed at maintaining this quality. Therefore an understanding of the effects of preharvest practices on quality is important, particularly in relation to storage. Preharvest factors can influence most, if not all, quality parameters. Evidence of effects on visual appearance (size, colour, blemishes), eating quality (flavour, texture), storage potential (ripening, physiological disorders, disease), and tolerance to physical disinfection and disinfestation control measures (heat, cold) are presented for subtropical and tropical fruit. General relationships were noted in temperate and tropical fruit between nitrogen and colour, disorders, and postharvest disease; fruit size and firmness, calcium, and disorders; calcium and ripening, disorders, and disease; and calcium, magnesium, and potassium. Ways of improving storage potential through fruit minerals are discussed. Such improvements could result in reduced postharvest inputs (storage and disease control). There is potential for predictive models for storage potential of tropical fruits based on minerals, as currently exists for disorder prediction in apples. However, consideration should be given to the interactions between management practices and the various balances that exist in plants, and the compromises often required in producing a quality product.

THE major fruit and vegetable quality factors are appearance, texture, flavour, nutritive value, and safety, with many components to each of these. Shelf and storage life may also be considered a quality parameter for product handlers. Most (if not all) quality parameters are significantly influenced by growing (preharvest) conditions. Monselise and Goren (1987) stated that the preharvest factors having greatest influence on quality are climate, nutrition, and plant growth regulators (PGRs). Secondary factors, such as soil quality and management, rootstock, irrigation, pruning, and crop load manipulation operate at least in part through the major factors.

There has been extensive research on the preharvest/postharvest interactions in temperate fruit and vegetables, and a number of reviews written (e.g. Winsor 1979; Ferguson 1980; Shear 1980; Sharples 1984; Beverly et al. 1993). Relatively little has been done on subtropical and tropical fruit (hereafter referred to jointly as tropical), although an increasing number of reports are indicating similar effects on these fruit (Campbell and Williams 1978; Monselise and Goren 1987; Burdon et al. 1991; Lizada 1991). This review summarises the important interactions observed in tropical fruit, with relevant information from temperate fruit. Several factors with obvious effects on quality will not be mentioned, such as the effects of variety and maturity on colour and eating quality.

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Quality Parameters

Visual appearance

Fruit size is a major determinant of plant yield, but is often not quantified despite its importance as a quality parameter. Many production factors will affect size, usually through assimilate production and competition, and there is a strong relationship between fruit number and size. Fruit size is also important in firmness and physiological disorders. These are considered later in the paper.

Fruit shape can be an important quality component when this deviates from consumer preferences. Temperature, particularly during early fruit development, can cause variations in fruit shape in 'Shamouti' orange (Monselise and Goren 1987). Temperature, high potassium (K), soil type, rootstock, and gibberellin (GA) application can also cause undesirable thick peel and puffiness in citrus (Pantastico 1975; Monselise and Goren 1987). Cytokinin and GA application during early fruit development can alter apple fruit shape (Williams and Stahly 1969), and Cultar® spray application to avocado may have similar effects. Nutritional and

temperature effects may be mediated through endogenous PGRs.

Fruit colour is strongly affected by radiation and temperature. Thus, factors which improve fruit exposure, such as north-facing (southern hemisphere), outside and top canopy, pruning and plant spacing, will often have beneficial effects on colour (assuming no sunburn). Nutrition can also have a direct effect. High nitrogen (N) is generally associated with a maintenance of green colour, and this has also been noted in mango (Smith 1989). Nitrogen application close to citrus harvest increases green colour and retards degreening after harvest (Pantastico 1975). High fruit calcium (Ca) concentrations in mango will also retard green colour loss during ripening (Wills et al. 1988). These responses generally reflect a maintenance of chlorophyll and/or retardation in other pigment expression, and a general delay in senescence. Preharvest PGR applications, such as GA and 2,4-D sprays on citrus (El-Otmani and Coggins 1991), retard colour loss through similar mechanisms.

Blemishes can result from rubbing, and insect and pathological activity. 'Physiological' blemishes result from a number of causes, but are often associated with an inability of the skin to maintain integrity and strength during fruit filling, resulting in cell damage and browning. For example, maturity bronzing in banana is thought to result from too rapid fruit expansion and disruption of epidermal cell integrity. It is particularly severe in northern Australia when fruit mature during March to June. It develops on the fruit surface a few weeks before harvest, becomes more intensive as the fruit fills, and can cause skin splitting along the ridges in severe cases (Daniells 1985). It is also more severe with moisture stress during early fruit growth, followed by adequate moisture during the latter stages (Daniells et al. 1987), and with hot, humid, overcast conditions (Campbell and Williams 1976). Campbell and Williams (1978) noted a weak association with low Ca and magnesium (Mg).

Some direct mineral responses on skin have been identified. Application of potassium (K) to citrus will reduce severity of skin creasing through a stimulation of peel growth (Baldry et al. 1982). Boron application has often been associated with a reduction in skin splitting in temperate fruit (Claypool 1975), but this has not been confirmed in tropical fruit. Also, rainfall immediately before harvest of 'Kensington' mango has been consistently related to increased skin browning following brushing or hot water dipping for disease control. Increased sensitivity is probably a result of increased turgor pressure in epidermal cells, resulting in greater cell rupture during these physical treatments.

Flavour

Flavour is influenced by assimilate supply and competition, so that factors such as tree health and leaf:fruit ratio are important. The PGR effects on mango when sprayed well before maturity [GA decreased (Khader 1991) and Cultar® increased (Khader 1990) total soluble solids (TSS)/acid ratio] may also act through assimilate competition. Of the mineral nutrients, only K has been shown to have a consistent effect on flavour, through increased acidity. This has been shown in temperate fruits, but is particularly strong in citrus (Moss 1972; Baldry et al. 1982). This does not apply to banana, where high K has often been associated with reduced acidity, but increased soluble solids (SS) (Mustaffa 1987; Munasque et al. 1990). Nitrogen is often associated with flavour in temperate fruit, and was shown to improve flavour in citrus (Baldry et al. 1982).

For non-seasonal crops such as pineapple, fruit developing through the winter months in the cool growing areas will have reduced eating quality through lower sugar/acid ratios. This can be minimised by microclimate effects such as planting on northern slopes (southern hemisphere). Withholding irrigation during the last few weeks of maturation of mango to increase SS has become a widespread practice in northern Australia. Effects on other quality parameters such as storage potential and disease incidence are not known, but may be detrimental (see 'Shelf and Storage Life').

Firmness and texture

Firmness and texture can be indirectly or more directly affected by production practices. Indirect effects may be through a general negative relationship between fruit size and firmness (e.g. Marmo et al. 1985; Palmer et al. 1991) for those fruits where cell division stops early in development. Thus, field treatments that affect fruit size predominantly (though perhaps not intentionally) through increasing cell size may have detrimental effects on firmness.

Calcium is the mineral mostly associated with direct effects on fruit firmness (see for example, Fallahi et al. 1985a). This association has not been universally observed however, which probably indicates that other factors (e.g. fruit size) interact with firmness. Most references to firmness in tropical fruit relate to the significant effect Ca has in delaying softening during ripening.

Shelf and Storage Life

Shelf life as used here refers to maximum life at room temperature, and storage life, at reduced (cold) temperature. Shelf life is usually limited by ripening and/or disease, while physiological disorders (often referred to as chilling injury) are also important in storage life.

Premature ripening and softening

There can be considerable intrinsic variation in shelf and storage life of fruit. For example, Smith et al. (1992) noted variations of 4 to 26 days in the shelf life of avocados from one orchard block at one harvest. There may be several factors contributing to this variability. For example, larger fruit can show reduced shelf and storage life, although this may also be a maturity effect [e.g. Seymour et al. (1990) in mango; Cutting et al. (1988) in avocado]. Flowering date may be important here, especially for extended flowering periods combined with single harvesting of whole-of-tree.

Calcium has been strongly implicated in ripening in temperate fruit, and there is accumulating evidence of its importance in tropical fruit (Yuen, these proceeedings). Spray applications have extended the shelf life of mango (Singh et al. 1987), and postharvest infiltration has had a similar, though generally lesser effect (Singh et al. 1987; Wills et al. 1988). Calcium infiltration delayed softening in avocado (Tingwa and Young 1974; Eaks 1985), and avocado shelf life has been positively correlated with fruit Ca (Witney et al.. 1990a; Cutting et al. 1992). These effects are partly through a delay of the respiration and ethylene climacterics (Eaks 1985) and a general retardation of senescence. Other divalent cations (manganese (Mn), cobalt (Co) and Mg in tomato) can have beneficial effects, but it is generally less than Ca (Wills and Tirmazi 1979).

Growth regulators other than ethylene can also influence ripening. Gibberellin sprays well before harvest delayed ripening in mango (Khader 1991) and softening in citrus during storage (El-Otmani and Coggins 1991). Hofman and Husband (1987) noted a decrease in endogenous GA concentration in avocado with maturity, which parallels a reduction in shelf life (Cutting et al. 1992). Abscisic acid (ABA) infiltration also reduced mango and avocado shelf life (Palejwala et al. 1988; Cutting et al. 1988). Thus, preharvest treatments need to be evaluated for their potential effects on fruit PGRs, particularly in relation to withholding irrigation (ABA effect).

There is little indication of the relative significance of these factors in determining the variability in shelf life, and it is uncertain whether these explain the extent of variations observed.

Physiological disorders

Physiological disorders encompass a range of symptoms, but are often a result of cell membrane and wall dysfunction, causing tissue collapse and symptoms such as bitter pit, senescent breakdown, water core, blossom end rot, and various tissue browning disorders (Shear 1975). They are more often expressed after low temperature, prolonged storage (i.e. chilling injury) because of increased physiological stress, although some disorders are obvious at harvest or on immediate ripening.

Many production factors can influence disorders. For example, mango disorders (see later) are significantly affected by growing conditions (Young 1957; Young and Miner 1961). Production away from the coast and higher altitude and/or temperature reduces spongy tissue incidence (Subramanyam et al. 1971; Joshi and Limaye 1986; Katrodia 1988), and is also affected by rootstock (Joshi and Roy 1985). Stem-end cavity appears to be more severe in wet conditions, especially near harvest (Wainwright and Burbage 1989; Mead and Winston 1991). Severity is greater in more mature fruit (Young 1957; Katrodia, 1988; Mead and Winston 1991), and in larger fruit (Subramanyam et al. 1971; Wainwright and Burbage 1989). Incidence of spongy tissue has been reduced by mulches that decreased radiated and reflected field heat (Katrodia and Sheth 1988).

Calcium is the mineral most strongly implicated in physiological disorders, and it plays an essential role in cell wall and membrane structure and function (Poovaiah et al. 1988). Calcium treatments, particularly repeated sprays during fruit growth, have been effective in reducing Ca-related disorders in temperate fruit. Postharvest infiltration and negative correlations with Ca in fruit from a range of sources has further confirmed the importance of Ca (e.g. Hewett and Watkins 1991; Yuen, these proceedings).

Similar Ca effects are being confirmed in tropical fruit. There is circumstantial evidence for a role of Ca in mesocarp discoloration (grey pulp, pulp spot, vascular browning) of avocado. Lower Ca content in the distal end of avocado fruit may be related to the fact that mesocarp discoloration generally appears first in this sector (Chaplin and Scott, 1980). Postharvest Ca infiltration reduced chilling injury (brown or grey mesocarp discoloration) (Chaplin and Scott 1980), and Cutting et al. (1992) identified a decrease in fruit Ca and an increase in mesocarp discoloration with maturity. Koen et al. (1990) found a negative correlation between soil and leaf (but not fruit) Ca and grey pulp, and Vorster and Bezuidenhout (1988) between fruit Ca and pulp spot.

Physiological disorders of mango are commonly expressed on ripening, and do not require low temperature storage for expression. These have been called by various names [stem-end cavity, jelly seed, soft nose, spongy tissue, premature ripening, insidious fruit rot; (Wainwright and Burbage 1989)], but some of these may be varying expressions of the same disorder (Mead and Winston 1991).

Evidence is also suggesting low Ca as a key factor in mango disorders. High Ca soil applications and high leaf Ca have been related to reduced soft nose (Young and Miner 1961; Young et al. 1962), and high leaf Ca with reduced stem-end cavity (Mead and Winston 1991). Healthy fruit had higher Ca content than affected fruit,

and healthy tissue higher than affected tissue [Gungate et al. (1979a) for spongy tissue; Burdon et al. (1991) for soft nose]. Preharvest Ca dips reduced incidence of spongy tissue (Gungate et al. 1979b), but Ca applications have not been successful in all cases (Krishnamurphy 1982). Most of these disorders appear to result from premature ripening of part of the fruit, and the beneficial Ca effect may be through its influence on the ripening process.

Potassium and Mg have also been implicated in disorders of temperate fruit, probably indirectly through Ca (Ferguson 1980). In tropical fruits, Witney et al. (1990b) noted a lower (Mg+K)/Ca ratio in Hass avocado fruit than in Fuerte, which correlates well with industry and research experience of reduced disorder susceptibility of Hass. Koen et al. (1990) identified a positive relationship between avocado leaf and proximal fruit K content and grey pulp, and a good negative correlation between leaf and soil (Mg+Ca)/K and grey pulp. Cutting and Bower (1990) observed high Mg concentration and (Mg+Ca)/K ratio in Hass fruit, with high disorder potential as indicated by flesh polyphenol oxidase (PPO) activity. Burdon et al. (1991) noted higher Ca and Mg, and a tendency toward lower K, in mango fruit from orchards with no soft nose incidence, than from orchards with high incidence. Rangwala [1975; cited in Katrodia (1988)] noted lower leaf Ca and Mg, and higher leaf K in spongy tissue-susceptible trees. This may also indicate a (Mg+Ca)/K relationship, although Katrodia (1988) suggested a minimal involvement of minerals in spongy tissue.

Low phosphorus (P) and high N content is often associated with storage disorders in apple (e.g. Brun et al. 1985), and Koen et al. (1990) associated low distal fruit P with high avocado grey pulp incidence after cold storage. The low P effect may be through greater cell size and respiration rate (Letham 1969), and lower membrane phospholipid content which reduces membrane stability at low temperatures (Ferguson 1980). This relationship does not appear to hold in mango disorders (Subramanyam et al. 1971; Burdon et al. 1991), possibly because these are expressed without low-temperature storage. High N has been associated with increased disorders in mango (Young and Miner 1961; Mead and Winston 1991) and avocado (Koen et al. 1990), possibly through increased fruit size. Boron has also been related to increased storage disorders in temperate fruit (Yogaratnam and Johnson 1982) but there is little evidence yet for a role in tropical fruit.

Disease

A number of production practices can directly influence the capacity of fruit to retard pathogen establishment or growth. Preharvest Ca sprays and postharvest infiltration have been shown to decrease postharvest disease severity in a number of temperate fruits (Conway and Sams 1987; Conway et al. 1987). Singh et al. (1987) also noted decreased mango disease with preharvest Ca sprays. These Ca effects are most likely mediated through greater resistance of fruit cell wall components to fungal enzyme degradation (Conway et al. 1988). Increased N fertilisation can also increase disease severity in apple and avocado (Abou-Aziz et al. 1975). These responses may be through opposite mechanisms to Ca (i.e. decreasing cell wall strength). Johnson et al. (1992) postulated that mango stem-end rot fungi are endophytic, and grow into the fruit through the pedicel during fruit growth. Therefore, field treatments (pruning, irrigation) which retard mycelial growth toward the fruit, but at the same time maintain or increase branch or pedicel growth, could reduce fruit colonisation. Also, Prusky et al. (1988) identified antifungal diene compounds in avocado skin which are effective in reducing *Colletotrichum gloeosporioides* development after harvest.

An understanding of the influences of preharvest factors on postharvest disease through fruit characteristics would improve natural postharvest disease control, and may be a viable alternative to, or complementary treatment with, biocontrol. Preharvest effects on other skin characteristics such as thickness of wax or cuticle (see for example, Monselise and Goren, 1987, El-Otmani et al. 1989) should also be considered.

Tolerance to postharvest physical treatments

Physical treatments (e.g. cold, heat and irradiation) are becoming more important for fruit disinfection and disinfestation. Locality and/or maturity effects have been noted in hot air treatments for disinfestation in mango (Esguerra et al. 1990; Jacobi and Wong 1992) and grapefruit (McGuire and Reeder 1992). R. McLauchlan (personal communication, 1993) also noted maturity, season, and locality effects with cold disinfestation in mandarins. Maturity and field temperature before harvest (acclimation) may contribute to these effects.

Improving Fruit Quality by Production Practices

Mechanisms for improving a number of the quality parameters are relatively well understood (e.g. size, colour, eating quality), and mainly involve general plant health, exposure to radiation (especially of the fruit itself), and appropriate leaf:fruit ratio (assimilate availability). However, these treatments can affect other quality parameters. In particular, interactions with shelf and storage life are often more difficult to identify and yet can have significant influences in fruit marketing through transport and storage. Preharvest effects on

storage life appear to be mainly through fruit size and fruit minerals.

Fruit size

Increased fruit size has been associated with reduced firmness and increased physiological disorders and postharvest disease (Richardson 1986; Wainwright and Burbage 1989; Palmer et al. 1991). Thus, practices which affect assimilate availability to fruit can also affect shelf and storage life through size. For instance, summer pruning and root pruning of apple can reduce fruit size and disorders, and improve firmness (Ferree 1992), particularly in vigorous trees (Myers and Ferree 1983). Excess N (Ferguson 1980) and irrigation (Brun et al. 1985) can also result in poor storage quality, and orchard floor management can affect fruit size and firmness, possibly through increased nutrient availability (Richardson 1986; Meheriuk et al. 1992). Rootstock effects have also been noted on firmness, internal ethylene, and storage potential (Fallahi et al. 1985a,b). However, some of these responses may be mediated through maturity. Also, improvements in firmness and storage potential do not always occur through fruit size, suggesting interactions with other factors.

Fruit mineral composition

Fruit Ca is the most important mineral in postharvest fruit storage potential. However it is also one of the most difficult to manipulate in relation to fruit concentration. Calcium nutrition is particularly important during early fruit growth (Bower et al. 1989), and management practices should be particularly targeted to maximise Ca availability to fruit during this period. Fruit Ca concentration is also a balance between Ca import into the fruit, and rate of fruit volume increase. Thus, factors which promote rapid fruit growth (see 'Fruit size') can also be important in determining fruit Ca concentration. This could be one of the main mechanisms for the frequent positive correlation between fruit size and disorders.

Fertilisation

Influencing fruit Ca by fertilisers is difficult. Soil Ca is relatively immobile, so top-dressing with Ca fertilisers may not guarantee adequate Ca in the rhizosphere. Soil Ca is absorbed into roots mainly by mass flow, but is also influenced by ion exchange phenomena so that other cations such as Mg, K, and NH^{4+} can reduce Ca uptake. Therefore, preplant Ca incorporation into the soil is important, as well as maintaining adequate balances in soil Ca, K, Mg and NH^{4+}. Fertiliser form and time of application (Ferguson 1980; Monselise and Goren 1987), and effects on other tree and quality parameters should also be considered (see 'Vegetative vigour'). Beneficial effects of other fertilisers (e.g. zinc; Vorster and Bezuidenhout 1988) may be through Ca. Frequent foliar Ca sprays are also effective in reducing disorders, but should be considered in conjunction with other options for increasing fruit Ca.

Irrigation and humidity

Water supply has been shown to influence fruit Ca content and disorders in apple, pear and avocado (Brooks 1916; Brun et al. 1985; Bower et al. 1989). These effects may be mediated through fruit size, but a direct effect on fruit Ca is also likely. Calcium translocation is predominantly by xylem mass flow, so that any restriction in soil water will reduce Ca uptake and increase intraplant competition for xylem flow (see 'Vegetative vigour'). Also, tissue Ca concentrations are generally determined by organ evapotranspiration rates, so that leaves and exterior tissues such as fruit peel, invariably have higher concentrations than flesh and wood (Brun et al. 1985, Witney et al. 1990b). Likewise, altering humidity to increase fruit evapotranspiration relative to leaves will also increase fruit Ca (Cline and Hanson 1992).

Vegetative vigour

Calcium movement is generally strongest towards terminal buds and developing leaves (Kirkby and Pilbeam 1984), partly through competition for xylem flow. Therefore, a large number of developing shoots will increase vegetative/reproductive organ competition for Ca. This will have a particularly strong effect on storage potential if shoot development coincides with early fruit growth, and is in close proximity. Thus, moderate tree vigour can produce fruit of higher Ca content and shelf and storage life than those of greater vigour (Witney et al. 1990a,b), through mechanisms other than fruit size. Also, flowering date could affect the reproductive/vegetative competition for Ca through altering relative timing of shoot and fruit development, and affect storage potential through mechanisms other than maturity. This potential dual effect of vegetative vigour on fruit minerals stresses its importance in influencing fruit storage quality.

Conclusions

In most cases, increased quality comes at a price, for example through compromises between yield and size, size and firmness, and size and storage potential. There may also be several ways of achieving similar improvements in quality, and a number of production practices may be synergistic. Effects on direct costs of production are also likely. Therefore, production systems that impinge on quality should be considered in light of

market requirements for product quality, and price (cost/benefit analysis).

One of the major objectives of studying preharvest/postharvest interactions is the prediction or 'customising' of fruit quality. This approach is particularly valuable for storage potential because of cost savings in storing only those fruit with the required storage characteristics. It would be of particular advantage in tropical fruit because of their inherently shorter storage life. They can have considerable variability in shelf and storage life (Smith et al. 1992), so that storage of only those fruit of appropriate quality would significantly increase total life.

The interrelationships between the various production practices in their effects on quality make the development of these predictive models a challenge. A large number of studies over some 20 years has used correlation and multivariate analysis to identify important preharvest characteristics affecting quality (e.g. Fallahi et al. 1985b; Gehard and Bruchou 1992), and knowledge has now reached the stage where fruit can be analysed for minerals 2–3 weeks before harvest and only fruit which meet appropriate criteria (usually based on various ratios with Ca, Mg and K) are placed in long-term storage. This approach has removed much of the variability in storage quality and outturn in English apples (Sharples 1984). Recognition of other factors, such as crop load (Ferguson and Watkins 1992), fruit position and size, uneven fruit mineral distribution (Koen et al. 1990; Burdon et al. 1991), postharvest redistribution in fruit (e.g. Perring 1985), and Ca forms in the fruit (Perring and Plocharski 1975; Saks et al. 1990) could increase the accuracy of these predictions. Consideration may also need to be given to varietal and locality effects on these models (Autio et al. 1986). The increasing circumstantial evidence of the roles of Ca, K, Mg, and N in tropical fruit indicates the potential for similar systems for predicting long-term storage potential of these fruit.

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Storage and Ripening — Session Summary

Chairman: Professor A.K. Thompson, Silsoe Research Institute, U.K.
Rapporteur: Dr Porntip Chaimanee, Silkaporn University, Thailand

A great deal of commonality was evident in the research described in the presentations in this session. These included a pragmatic approach to the subject in that the research was largely problem solving and orientated to market needs. This seems to reflect an attitude common and developing in many areas that economic considerations should be paramount. The papers illustrated several common approaches which included the disparate nature of postharvest as a scientific discipline embracing metabolism and biochemistry, through consideration of disease development and control, to the technology and engineering which must be developed to bring these factors into the industry.

Presentations were authoritative and comprehensively covered subjects, usually starting with historical perspectives and evaluating the present state of knowledge on which to determine priorities for research.

Important areas of research needs which were identified included water, minerals, and gases. Areas relevant to water included the effects of losses on storage and ripening, and the technology needed to consistently maintain suitable humidity around the crop. In terms of minerals and other chemicals in fruit, the emphasis was on the need for research into the harvest quality of crops and how this can interact with postharvest life. Establishing principles in this area would have implications in plant breeding. Modification of the chemical content of fruits postharvest also offers a potentially fertile area of research.

Much more information is needed on the effects of gases, particularly the respiratory gases, on tropical fruit. Insufficient information is available for commercial exploitations of controlled atmosphere storage for many tropical fruit. Work is needed, among other things, on cultivar and environmental conditions and how these interact with controlled and modified atmosphere storage. Systems for the control of the environment around the fruit need further research, particularly the exploitation of polymer films, so that they can have greater use within the postharvest fruit industry. To make their use more predictable, research is needed into the interaction between these materials and other factors, as well as on developing new materials and systems of modified atmosphere packaging.

Disinfestation of Tropical Fruits

Quarantine Disinfestation of Tropical Fruits: Non-chemical Options

N.W. Heather*

Abstract

This paper reviews residue-free methods of disinfestation of tropical fruits against pests of quarantine significance. The most important of these pests in fruits to be exported are fruit flies, and the basic methods which are non-chemical and hence meet a residue-free criterion are physical treatments with heat, cold, and irradiation. Worldwide, there are more than 30 species of fruit flies of the family Tephritidae which are of major importance as quarantine pests. There are however a number of pests other than fruit flies which are also of major quarantine importance. Treatments must have very high levels of efficacy to be fully effective, typically in the range of 99.99% to 99.9968% (Probit 8.7–9). At these levels they must not cause unacceptable damage to fruit. Fruits differ in their tolerance of treatments and there is thus scope to choose and manipulate treatments for the best outcomes in economic terms and product quality. Combinations of methods are possible or even a holistic, systems approach in which the contribution of all influences on pest survival in the growing and handling system are taken into account.

MOST tropical fruits are hosts of fruit flies or other insect pests that are subject to specific prohibitions by quarantine authorities of importing countries. The purpose of disinfestation treatments is to provide an assurance to the authorities of an importing country that the commodity will be free of the pest that is the target of the treatment. This was achieved for many years by fumigation with ethylene dibromide (EDB), methyl bromide (MeBr), or by treatment with insecticides. Because of chemical residues, EDB was deregistered for this purpose in the USA in 1984 (Anon. 1984), catalysing initiatives to develop non-chemical alternatives for it and other treatments that leave chemical residues.

Alternatives to chemical treatments are available. They include physical treatments with heat, cold, or irradiation, and modifications to the production system for the commodity. In the selection of a treatment, it is necessary to reconcile acceptable pest risk levels with damage caused to the commodity, as well as the additional operational costs involved.

Pest Identity and Host Relationships

The relationship between the pest and its host is of major importance (Armstrong and Couey 1989). The taxonomy of fruit flies in particular, is constantly under review and a revision of one fruit fly group of major quarantine importance, the *D. dorsalis* complex, is imminent (R. Drew, Queensland Department of Primary Industries, pers. comm.). The taxonomic identity of the pest against which a treatment is developed should be recorded by deposit of voucher specimens in a permanent reference collection to guard against future revision of a taxon. It is important to ensure that the insects used to develop a treatment are of the species which constitutes the quarantine problem. Fruit flies have speciated prolifically and many species are morphologically similar. Sometimes more than one species will infest a fruit host, leading to difficulties in identifying the major pest or the need to test treatments against more than one species.

The stages of the pest that infest the fruit are highly relevant. For fruit flies it is the eggs and larvae that are the targets of quarantine disinfestation treatments. Other stages are important in other pests e.g. mango seed weevil, thrips, mites. The stage against which the treatment must be effective can have a major influence on selection of treatment while the age within each stage can markedly influence the result of a treatment (Balock et al. 1963; Heather et al. 1991; Corcoran 1993).

Armstrong (1992) and Cowley et al. (1992) addressed the issue of host status from a regulatory viewpoint, and there are a number of model studies which undertake actual host status determination (Seo et al. 1970; Von Windeguth et al. 1976; Armstrong and Vargas 1982; Armstrong et al. 1983; Spitler et al. 1984). These studies

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show that there can be cultivars of a commodity that are not susceptible to the pest, or that there are conditions under which the host status can be negative.

Criteria for Effectiveness

The effectiveness of a disinfestation system needs to be judged against criteria agreed between an exporting and an importing country. It can be argued with strong justification that, to be effective against an insect pest, a quarantine disinfestation treatment need only prevent its establishment in the importing country (Ouye and Gilmore 1985). This translates as inability of a treated insect to survive and reproduce, and it may involve delayed mortality or some other form of inhibition of reproduction.

Efficacy Requirements

Countries such as USA and Japan typically require a disinfestation treatment for fruit flies which causes mortality almost immediately, or at least before pupation and meets prescribed standards of efficacy. This has advantages where the commodity must pass a post-treatment inspection, the production history of the commodity is not known, and the likelihood of infestation cannot be estimated. These treatments may need to achieve an efficacy of probit 9 or 99.9968% mortality (Baker 1939). Probit 9 dosage can be predicted using the regression analysis methods of Finney (1971), provided that the true response line is linear. For fruit fly experiments where the number of insects treated cannot be ascertained with certainty — that is, only survivors can be counted — a variation of probit analyses such as the 'Wadley's Problem Version' must be used (Wadley 1949). Having predicted probit 9, it is then usual to confirm that it is achievable by treating, without survivors, 30 000 or 100 000 insects of the most tolerant stage occurring in or on commercial fruit. One hundred thousand insects treated, without survivors, demonstrates probit 9 mortality at the 95% confidence level (Couey and Chew 1986).

Another approach to quarantine security is that adopted by New Zealand, which sets a maximum pest limit (MPL) the imported commodity must meet (Baker et al. 1990). This strategy is a development of the conceptual proposals of Landolt et al. (1984) who showed that, for fruit flies, acceptable quarantine risk levels could be based on the probability of a mating pair surviving a shipment.

Non-chemical Disinfestation Methods and Technologies

Heat

There are two practical ways in which heat can be applied to fruit to produce temperatures that are lethal to fruit flies or other pests but do not cause unacceptable damage to fruit (Table 1). One is to use circulated hot air, the other is to immerse the fruit in hot water (Armstrong and Couey 1989). To date, other methods of heating such as microwave technology have proven unsuitable (Seo et al. 1970; Hayes et al. 1984).

Heating with air

Historically, modern heat treatments for disinfestation of fruit against fruit flies commenced in 1929 with the work of Baker et al. (1944) (cited by Balock and Starr 1945). Their experiments treated fruit infested with Mediterranean fruit fly, *Ceratitis capitata*, (Wiedemann) and Mexican fruit fly, *Anastrepha ludens* (Loew). Subsequently, work in Hawaii (O.C. McBride and A.C. Mason, United States Department of Agriculture (USDA), internal report on project 2012, 1933), was done on the melon fly, *Dacus cucurbitae* (Coquillett) (Baker 1939). Seo et al. (1974) reported a treatment of 44.5°C for papaya against oriental fruit fly, *Dacus dorsalis* Hendel. Early treatments adopted by USDA regulatory authorities were typically over a long time (e.g. 14 hours) and at temperatures in the vicinity of 44°C (Anon. 1985).

Technologically, these treatments involved chambers of air heated by steam (hence vapour heat). The temperature was controlled by thermostat and circulated by fan (Balock and Starr 1945). Heating efficiency was enhanced by the condensation effect of the steam on the fruit. Other technology used in experiments involved a 'Carrier Machine' that used circulated heated air humidified by a water spray. Two factors acted against widespread use of the technology. Firstly, the fumigant EDB became available around 1950 (Armstrong and Couey 1989) and provided more rapid, cheaper treatments with less risk of fruit damage. Secondly, temperature control technology before microprocessors became available was bulky and comparatively unreliable. The deregistration of EDB in 1984 by US authorities (Anon. 1984) catalysed the development and adoption of alternative treatments.

Research on the development of circulated hot-air treatments has been done in many countries including Japan, USA, the Philippines, Thailand, and Australia. Japanese research involved actively circulated heated air approaching saturation with water vapour. It was referred to as 'a differential pressure vapour heat process' and targeted *D. dorsalis* and *D. cucurbitae* in green

Table 1. Quarantine disinfestation schedules with heat against eggs or larvae of fruit flies in various fruits

Pest species	Fruit	Method	Temperatures	Time	Reference
Anastrepha distincta (Greene)	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1990)
A. fraterculus (Wiedemann)	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1990)
A. ludens (Loew) (Mexican fruit fly)	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1989b)
A. obliqua (Macquart)	Mango	Hot air	48°C	1.5–3.5 hours	Mangan and Ingle (1992)
(West Indian fruit fly)	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1989b)
A. serpentina (Wiedemann) (Sapodilla fruit fly)	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1989c)
A. suspensa (Loew)	Carambola	Vapour heat	43.5–46.5°C	1–2 hours	Hallman (1990)
(Caribbean fruit fly)	Mango	Hot water	46–47°C	1.5 hours	Sharp et al. (1989b)
Ceratitis capitata (Wiedemann)	Mango	Vapour heat	43.5°C	14 hours	Balock and Starr (1945)
(Mediterranean fruit fly)	Papaya	Hot air	46–47°C	5 hours	Armstrong et al. (1989)
	Papaya	Hot water	42 and 49°C	30 min + 20 min	Couey and Hayes (1986)
	Mango	Hot water	46°C	1.5 hours	Sharp et al. (1989c)
Dacus cucurbitae (Coquillett)	Papaya	Hot air	45–46°C	5 hours	Armstrong et al. (1989)
(Melon fly)	Papaya	Hot water	42 and 49°C	30 min + 20 min	Couey and Hayes (1986)
	Momordica	Vapour heat	45°C	30 min	Sunagawa et al. (1988)
	Papaya	Vapour heat	45.5°C	30 min	Sunagawa et al. (1989)
	Egg plant	Vapour heat	Not known	Not known	Furusawa et al. (1984)
	Mango	Vapour heat	43.5°C	3 hours	Sunagawa et al. (1987)
D. dorsalis Hendel	Papaya	Vapour heat	44.5°C	20 hours	Seo et al. (1974)
(Oriental fruit fly)	Papaya	Hot air	45–46°C	5 hours	Armstrong et al. (1989)
	Mango	Vapour heat	46°C	2 hours + 10 min	Merino et al. (1985)
	Mango	Vapour heat	46.5°C	2 hours + 10 min	Unahawutti et al. (1986)
	Mango	Hot air	46.5°C	2 hours + 10 min	Unahawutti et al. (1992)
	Papaya	Hot water	42 and 49°C	30 min + 20 min	Couey and Hayes (1986)
	Capsicum	Vapour heat	Not known	Not known	Sugimoto et al. (1983)
Bactrocera tryoni (Froggatt) (Queensland fruit fly)	Mango	Vapour heat	46.5°C	2 hours + 10 min	Heather, unpublished data
B. cucumis French (Cucumber fly)	Zucchini	Vapour heat	45°C	2 hours + 30 min	Corcoran et al. (1993)

peppers, egg plant, and cucurbits according to host status (Sugimoto et al. 1983; Furusawa et al. 1984; Sunagawa et al. 1987, 1988, 1989). Work in the USA involved air at various humidities according to requirements of the fruit. Armstrong et al. (1989) used air at a humidity which reduced condensation on papaya; Mangan and Ingle (1992) used air at humidities below that at which condensation would occur on mangoes; and Hallman (1990) used water-vapour-saturated air for carambolas; Sharp (1992) reported studies on mangoes but did not report the water vapour status of the circulated air. These U.S. studies covered a range of fruit fly species including *C. capitata*, *Dacus* spp., and *Anastrepha* spp. The treatment systems used by U.S. researchers typically used air at a higher temperature in relation to the final fruit core temperature than the systems used by Japanese researchers.

In the Philippines, Merino et al. (1985) reported a

vapour-heat treatment schedule against their indigenous type of *D. dorsalis* in mangoes, which are the basis for a substantial trade to Japan. It involves heating to 46°C core temperature which is then held for 10 minutes before fruit is hydrocooled. A further treatment has been developed for Philippine papaya, using the same facilities as are used for mangoes (E. Tuazon, Bureau of Plant Industries Manila, pers. comm.).

In Thailand, a similar treatment developed against *D. dorsalis* in several cultivars of mango (Unahawutti et al. 1986) identified 46.5°C as a disinfestation temperature that did not cause unacceptable damage to fruit. They found that the cooling method affected treatment efficacy so temperature and treatment times needed to be raised to ensure 99.99% efficacy when fruit were hydrocooled. They also experimented with relative humidity of the treatment air using air of 50% RH during a preheating period and 95% RH during the final stages of treatment (Unahawutti et al. 1992). These studies illustrate the complex interrelationships of time, heat transfer, and temperature.

In Australia, studies on Queensland fruit fly, *Bactrocera tryoni* (Froggatt), and the cucumber fly, *B. cucumis* (French), with hot-air treatments using near-saturated air have resulted in treatment schedules for mangoes, zucchini, rockmelons (cantaloupe) and tomatoes (Heard et al. 1992; Corcoran et al. 1993; N. Heather, unpublished data). For these species, the mature egg is the most tolerant stage to heat (Heard et al. 1991; Corcoran, 1993). Treatment temperatures required for probit 9 efficacy range from 44°C for tomatoes to 46.5°C for mangoes.

Hot water dips

Immersion of fruit in hot water is a more efficient method of heat transfer than hot-air treatment. Dipping of fruit in water at 50–55°C is a long-standing treatment for the control of fungal diseases (Armstrong and Couey 1989), but dipping times for this purpose are typically of the order of 5–20 minutes and the effect is largely restricted to the surface of the fruit. For papaya, Couey et al. (1984) and Couey and Hayes (1986) reported a two-stage hot water treatment of 42°C for 30 minutes followed by 49°C for 20 minutes, subject to fruit selection criteria, against *D. dorsalis, D. cucurbitae,* and *C. capitata.* This was adopted by USDA regulatory authorities (Anon. 1985) and used for some years before being replaced by hot-air treatment, presumably because of fruit damage. For mangoes, Sharp and co-workers (Sharp 1986; Sharp et al. 1988; Sharp et al. 1989a,b,c; Sharp and Picho-Martinez 1990) developed hot-water dips as quarantine disinfestation treatments against *Anastrepha* spp. and, in one instance, *C. capitata.* The mango varieties involved were 'Tommy Atkins', 'Keit', 'Oro', 'Kent', 'Francis', 'Haden', and 'Ataulfo'. These authors reported that fruit were undamaged at a temperature of 46°C for dipping times typically of 90 minutes. The treatments were acceptable to USDA regulatory authorities, and were also used as a precautionary treatment on some mangoes exported from Mexico to Japan. However, Sharp (1985) reported that the treatment was not suitable for grapefruit because of fruit damage and Hallman and Sharp (1990) reached a similar conclusion for carambolas.

Where hot water dips were used for mangoes of the variety Kensington in Australia, damage occurred (K. Jacobi, pers. comm.). This damage involved starch deposits as granules or lumps in the flesh and was very similar to that recorded by Esquerra and Lizada (1990) in Philippine mangoes damaged by vapour-heat treatment. Therefore, hot-water dips require more research in Australia although E.S.C. Smith and D. Chin, Berrimah, Northern Territory, Australia (pers. comm.) showed that at 47°C for 70 minutes a hot-water dip conferred adequate quarantine security against *B. aquilonis* (May), a species very closely related to *B. tryoni.* Damage was avoided by holding fruit at ambient temperature for 24 hours after harvest before dipping.

Cold

Few tropical fruits will tolerate the low temperatures required for quarantine disinfestation against fruit flies. However, tropical species of fruit flies can infest 'temperate' fruits, which are not infrequently grown in 'tropical' areas. Typical practical temperatures for disinfestation are below 2°C at which 16–22 days exposure may be required by regulatory authorities, depending on the fly species. This does not necessarily reflect the true response of the fly species. USDA schedules (Anon. 1985) require 16 days treatment at a maximum of 2.2°C against *C. capitata* and 22 days against *B. tryoni.* Recent research (N. Heather, F. de Lima, and L. Whitfort, unpublished data) has shown no significant difference in response between the two species at 1.1°C and it is unlikely that there is any true difference in response at any cold disinfestation temperature.

Benschoter (1984) developed a treatment schedule against *Anastrepha suspensa* (Loew) in grapefruit that involved a preconditioning time at 10 or 15.5°C for 7 days followed by 12 or more days at 1.7°C. When fruit was preconditioned at 10°C, adult survivors occurred after 19 days treatment at 1.7°C, indicating the possibility of a cold acclimation effect. About the same numbers of pupal survivors resulted from preconditioning at both 10 and 15°C, but no adults ecloded after the 15°C treatment.

Burditt and Balock (1985) reported much less tolerance of cold by *D. dorsalis* and *D. cucurbitae.* Their data predicted a 10-day treatment time at 2.8°C to achieve probit 9 mortality. Burikam et al. (1992) confirmed that

in mangosteen 13 days at 6°C would achieve 99.99% mortality against *D. dorsalis*. For *B. tryoni*, Sproul (1976) and Hill et al. (1988) reported that 16 days at 1.1°C were needed to achieve probit 9 mortality against eggs and larvae. For both of these studies *C. capitata* was judged to be more tolerant of cold than *B. tryoni*, although differences would not have been statistically significant and could have simply reflected experimental site differences. Subsequent studies by Jessup and Baheer (1990) and Jessup (1992), on kiwifruit and grapes, showed that first instars of *B. tryoni* were the stage most tolerant of cold. This was confirmed in mandarins, first with *C. capitata* (F. de Lima, pers. comm.) and *B. tryoni* (N. Heather and L. Whitfort, unpublished data). Research on cold treatment is made difficult by slow and often inconsistent cool-down times for fruit to reach treatment temperatures. Also, reluctance by flies to oviposit in poor hosts, and subsequent uneven development, makes for difficulty in obtaining homogeneous response data. As experimental procedures become more precise, particularly with respect to the age of the insect stages treated, many apparent differences in response may disappear.

Cold has the potential for in-transit treatment where long sea distances to markets are involved. Acceptance has been slow, ostensibly because of imprecise temperature control and difficulties in monitoring. Israeli citrus exports are currently treated in this way (Dr Y. Rossler, Citrus Agrotechnical Services, Israel, pers. comm.). Cold storage has great potential to supplement the efficacy of other treatments such as heat (Armstrong and Couey 1989), modified atmospheres (Benschoter 1987), and irradiation (Von Windeguth and Gould 1990).

Irradiation

The potential of irradiation to disinfest agricultural and horticultural produce has been recognised since early in this century although most of the research was done in the latter half (Heather 1993). The availability of gamma radiation sources, particularly Cobalt 60, has given rise to many dose–mortality studies on insect pests and on the effects of irradiation on the organoleptic qualities of fruit and other commodities.

Reports of task forces (International Consultative Group on Food Irradiation, 1986, 1991) identified pests and host commodities for which irradiation was an effective method of disinfestation. They recommended generic and specific dosages of irradiation which would assure quarantine security based upon appropriate criteria for effectiveness.

A prerequisite to the use of irradiation as a quarantine treatment for agricultural commodities was approval of its use for foodstuffs. The joint FAO/WHO standard for irradiated foods (Codex Alimentarius Commission 1984) approved recommended doses up to 10 kGy as safe for use on any food. Subsequently, the U.S. Food and Drug Administration (1986) approved doses of up to 1 kGy for disinfestation of fresh fruit and vegetables. Many other countries followed suit and it is estimated that the process is now approved in most of the world. The USDA Animal and Plant Health Inspection Service (USDA 1989) has amended its quarantine regulations to permit the use of irradiation as a quarantine treatment.

For fruit flies, the Chiang Mai Task Force (International Consultative Group on Food Irradiation 1986) recognised that irradiation could result in the presence of properly treated but still living insects in fruit at a post-treatment inspection. Although not compromising quarantine security, they would present a problem for inspection authorities who would be uncertain of whether the treatment had been properly applied.

The problem has almost certainly been overestimated for fruit flies. The levels of infestation present in export quality commercial fruit need to be very low regardless of quarantine requirements. Most markets have a nil tolerance for this type of pest based on quality, and consignments found to contain infested units could be expected to be rejected on this basis. This highlights the principle that quarantine disinfestation treatments should not be used as a part of the pest management needed to produce a quality product. For insect pests that do not affect fruit quality the problem is more valid. Means of identifying insects which have received a delayed-lethal or reproduction-inhibiting dose of irradiation or any other treatment but are still alive at the time of inspection, need to be considered (Rahman et al. 1990).

In general, exposure of eggs or larvae in fruit to a dose of 150 Gy or less prevented emergence of adults at an efficacy of probit 9 (Burditt 1992). This was adopted as the generic dose applicable to all fruit flies of the family Tephritidae. Much greater doses would be required to cause probit 9 mortality of the stage treated (Kaneshiro et al. 1983), increasing the likelihood of damage to fruit (McLauchlan et al. 1990). Where a lower dose has been shown to achieve probit 9 efficacy it would be used, e.g. for Queensland fruit fly, *B. tryoni*, a dose of less than 100 Gy, possibly 75 Gy, has been shown to be effective (Rigney and Wills 1985; Heather et al. 1991.)

Other non-chemical options

Moffitt (1990) proposed an approach to quarantine security which examines the effectiveness of pre- and postharvest practices in removing codling moth from apples for export from USA. This approach has general applicability, including fruit flies, and warrants consideration as a way of meeting specific quarantine security requirements. The basis for the approach is to be found in the concepts of Landolt et al. (1984). There is also scope for combination treatments within the Moffitt concept.

Quarantine security should be based on pest risk (Rohwer and Williamson 1983), and disinfestation treatments should be in accordance with the risk. When the risk is not known, regulatory authorities normally require the highest security postharvest treatment available as a default position. As more information on the pest becomes available a review mechanism is needed to ensure that treatments required are not unnecessarily harsh and do not cause unnecessary reductions in the shelf life of the fruit.

Future Directions

Consumer preference for non-chemical disinfestation measures can be expected to provide continued incentive for development of physical treatments. There is considerable scope for future development of heat and cold treatments through the alleviation of damage to fruit, and low-dose irradiation needs to be more widely accepted as one of the physical treatment options. If these treatment arrays are integrated with a rationalised approach to quarantine security requirements there seems to be no reason why a treatment appropriate to logistical and quarantine considerations should not be possible for most fruit. Fledgling fruit production industries will face problems of funding the research necessary to enable them to grow through exports. This is one of the situations where a generic approach to treatments, especially towards the pest species, would have special value.

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Heat Disinfestation of Mangoes: Effect on Fruit Quality and Disease Control

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Abstract

Heat treatments have been developed for disinfestation of export mangoes (*Mangifera indica* Linn.) in a number of countries. High humidity hot-air (or vapour-heat) treatments are used commercially in Thailand and the Philippines for cultivars 'Nang Klangwan' and 'Carabao', respectively; while Mexico uses hot water to disinfest 'Tommy Atkins' and 'Keitt' mangoes. Because the window of treatment to successfully disinfest against all stages of fruit fly but maintain fruit quality is narrow, damage to mango has been recorded in some cultivars during treatment development. Factors such as fruit maturity, production region, and cultivar have been known to influence the response of fruit to heat treatment. Control of postharvest disease is often partial with heat disinfestation treatments. Consequently, application of a fungicide before or after heat treatment is needed to provide satisfactory control. In the development of heat disinfestation treatments, attention needs to be paid to both fruit quality and disease control at all stages, to produce a truly effective commercial treatment for export mangoes.

MANY mango (*Mangifera indica* Linn.) cultivars are grown commercially around the world, Mexico, Thailand, and the Philippines trading their fruit on export markets. The primary reason for disinfesting fresh mangoes is to meet the quarantine requirements of an importing country. Insect pests (e.g. fruit flies) pose a risk to the agricultural viability of a country that does not possess them. Strict standards are imposed on imported produce to minimise the risk of pest introduction.

Heat disinfestation treatments have been revived and development expanded for mangoes since the early 1980s following the demise of the fumigants (such as ethylene dibromide, EDB). Mangoes are considered to be relatively heat tolerant, when compared with other fruits such as peaches, raspberries, and bell peppers (Couey 1989). The heat can be applied to the fruit using a number of methods. The two most favoured to date are hot water and hot air, and both are used commercially to treat mangoes. With the hot-air method of application, both high (90–95%) and medium (40–70%) relative humidity treatments have been developed.

Heat disinfestation treatments have been evaluated for the control of mango diseases in countries such as the Philippines, the United States, and Australia. The focus of these evaluations has been on the two major postharvest diseases of mango throughout the world: anthracnose, caused by *Colletotrichum gloeosporioides*, and stem-end rot, caused by *Lasiodiplodia theobromae* (syn. *Diplodia natalensis*), *Dothiorella dominicana*, and other fungi.

There is little use in developing a heat disinfestation treatment that satisfies all the entomological requirements if the fruit are physically damaged, or reduced in postharvest quality through disease or physiological changes.

In this paper, we report on the effects of heat disinfestation treatments on both quality and disease control of mangoes throughout the world. We conclude by outlining some areas of research that remain to be addressed.

The Effect of Hot-water Disinfestation Treatments on Fruit Quality

Water is a more efficient heat transfer medium than air, having a higher heat transfer coefficient (Stewart et al. 1990). Consequently, quarantine hot-water treatments are shorter than hot-air treatments, because of the higher specific heat and rate of heat transfer to the fruit in water (Mangan and Ingle 1992).

Hot water is approved by the United States Animal and Plant Health Inspection Service (APHIS) for the control of fruit flies occurring in the Caribbean and Central and South America, in mangoes imported into

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the United States, and mangoes exported from Florida to other states (Nascimento et al. 1992).

Sharp and Spalding (1984) developed a hot-water treatment for Florida 'Tommy Atkins' and 'Keitt' mangoes against Caribbean fruit flies [*Anastrepha suspensa* (Loew)]. This involved submerging fruit in 46.1°C water for 45–65 minutes. They reported that ripe colour developed similarly in all mangoes, regardless of treatment and no off-flavours were detected in informal taste tests. Injury in the form of moderate to severe scald was recorded in 6% of the fruit.

Similarly, Sharp (1986) assessed 'Tommy Atkins' and 'Keitt' mangoes which had been submerged at the mature-green stage in 46.1–46.7°C water for 75 minutes. After 5 days at 25.6°C, fruit were examined for scald and pitting of the epidermis. No visible signs of damage were noted.

A more detailed physiological assessment was made by Spalding et al. (1988) for 'Tommy Atkins' and 'Keitt' mangoes following hot-water immersion. Mangoes were immersed in water for 60 to 120 minutes at 46°C or for 60 minutes at 49°C, then stored for 3 days at 13°C (to simulate domestic shipping) and ripened at 24°C. Treated fruit exhibited a higher percentage of ripe peel colour compared with untreated fruit. Ripening time, pH, total titratable acidity, ascorbic acid, and percent soluble solids were not affected. Lenticels were darker on 'Tommy Atkins' immersed in water for 120 minutes at 46°C, on 'Keitt' immersed in water for 90 minutes at 46°C, and on both cultivars immersed in water for 60 minutes at 49°C, when compared to untreated fruit. No significant scald or brown discoloration of the peel developed after any treatment. No adverse changes in either the texture or flavour of the mangoes treated in hot water were noted in the informal taste tests. They concluded that hot water at 46°C for 60–90 minutes would not harm the quality of 'Tommy Atkins' or 'Keitt' mangoes if used as a quarantine treatment.

Sharp et al. (1988) reported on hot-water treatments for the Haitian mango variety 'Francis' infested with West Indian fruit fly [*Anastrepha obliqua* (Macquart)] and Caribbean fruit fly. Fruit were submerged in water at 46.1–46.7°C for 75 minutes and then stored at 25–27°C for 8 days without being damaged. No reduction in quality was observed if fruit were treated with 46.1–46.7°C water for 2 hours and then refrigerated at 11.1°C for 7 days. Qualitative evaluations were made to assess the market value (quality) of treated fruit. Scoring was based on firmness and ripeness (using a 1–5 scale, where 1 = overripe, past use and 5 = hard, does not yield to moderate pressure). Other assessments made of quality were based on mango taste and aroma. Percentage of acceptable mangoes treated with hot water at 46.1–46.7°C decreased as exposure time increased. After 4 hours exposure, all mangoes were damaged and were not acceptable. Based on this research, a hot water treatment was approved by APHIS for 'Francis' mangoes from Haiti imported into the United States.

In a summary paper by Sharp (1988), no damage was reported to have occurred to mango cultivars 'Francis', 'Oro', 'Ataulfo', 'Tommy Atkins', 'Keitt', and 'Haden' following hot water treatments of 46.1±0.5°C for 75 minutes ('Francis') and 90 minutes (other cultivars). Confirmatory tests provided quarantine security for these mangoes from Haiti and Mexico, where large-scale commercial hot-water facilities had been built.

Confirmatory entomological tests carried out on 'Tommy Atkins', 'Keitt', 'Jubilee', and 'Kent' mangoes from Florida immersed in hot water at 46.1– 46.7°C for 90 minutes (Sharp et al. 1989a) did not provide any further detailed fruit quality evaluations.

Mango cultivars 'Oro', 'Kent', 'Tommy Atkins', 'Keitt', and 'Haden' from Mexico were immersed in 46.1°C water for quarantine treatments against Mexican fruit fly [*Anastrepha ludens* (Loew)] and West Indian fruit fly (Sharp et al. 1989b). The market quality was determined using qualitative evaluations of shrivelling, scald, taste, colour, aroma, ripeness, and firmness. 'Oro' mangoes were not damaged up to 75 minutes immersion time. However, as exposure time increased, the percentage of acceptable fruit declined. 'Kent', 'Tommy Atkins', and 'Keitt' mangoes were not damaged after immersion in water at 46.1°C for 90 minutes and subsequent refrigeration at 11.1°C for 7, 11, and 14 days. 'Haden' mangoes immersed in water at 46.1°C for 90 minutes, not refrigerated, but held at 23.9±1°C were acceptable for 12 days. It was reported that damage such as bruising, not evident before the hot-water immersion, may have been intensified by the treatment. Quality of the mangoes after treatment depended on cultivar, fruit maturity, size and shape, and handling procedures. Therefore, it was recommended that fruit be treated at the mature-green stage and handled carefully to avoid damage.

In another study by Sharp et al. (1989c), 'Ataulfo' mangoes from Chiapas, Mexico were immersed in hot water for treatment against Mediterranean fruit fly [*Ceratitis capitata* (Wiedemann)] and *Anastrepha serpentina* (Wiedemann). Market quality of the fruit was evaluated as in their previous research (Sharp et al. 1989a,b). Most mangoes (93%) were acceptable if immersed in water at 46.1°C for 90 minutes and refrigerated at 11.1°C for 14 days. Only 10% were acceptable if refrigerated for 21 days. Immature fruit treated with hot water usually did not ripen and became shrivelled. These damaged mangoes had internal vacuous areas. Overripe mangoes treated with hot water occasionally had darkened and depressed lenticels on the peel. Factors such as stage of ripeness, fruit size, and handling procedures were again mentioned as affecting market quality of the hot-water treated fruit.

The culmination of all this American research, was that hot-water quarantine treatments were put in place commercially. The physiological responses of the fruit to the heat treatments mentioned in these papers and reports have concentrated on qualitative measures, particularly damage symptoms. Mango cultivars reacted differently to hot-water immersion, which is reflected in the different treatment times at 46.1°C. The researchers also acknowledged the influence of fruit size, stage of ripeness, fruit maturity, and postharvest handling procedures on final mango quality after these quarantine treatments.

Research in Puerto Rico by Diaz et al. (1988) using hot-water quarantine treatments against Caribbean fruit fly on green-mature mango varieties 'Irwin', 'Parvin', and 'Keitt' reported no change in the physical, chemical, and organoleptic characteristics of the fruit after treatment. Fruit were immersed in 46.1°C water for 0–180 minutes and then cool stored (10–13°C) for 7–21 days. Soluble solids, pH, titratable acidity, total sugars, texture, taste, and appearance were the quality parameters measured. Differences in times to ripen were noted between the three varieties.'Parvin' fruit failed to ripen with the 180 minutes heat treatment.

A more detailed physiological assessment was conducted on 'Tommy Atkins', 'Keitt', and 'Palmer' from Florida using hot-water immersion for 90–115 minutes at constant 46°C and hot-water immersion with a gradual temperature rise at 48°C. After treatment, fruit were stored at 13°C for 7 days and ripened at 24°C for 7 days (McGuire 1991). The treatments were against Caribbean fruit fly. Weight loss, injury ratings, firmness (using an Instron), and skin colour (using a Chroma meter) were measured. No injuries developed on fruit of any variety as a result of the hot-water treatments. Weight loss was greater in heated fruit. Gradient hot-water immersion accelerated fruit softening during storage. Both treatments caused a slight (but significant) increase in yellow pigmentation of the mango skin.

Brazilian testing of 'Tommy Atkins', 'Haden', and 'Keitt' mangoes using hot water (45.9–46.3°C for 90 minutes) against the South American fruit fly [*A. fraterculus* (Wiedemann)], the West Indian fruit fly, and the Mediterranean fruit fly did not include any reports of physiological testing of the fruit response (Nascimento et al. 1992).

The 'window' of successful heat treatment can be narrow. Heat treatments can be phytotoxic at their limit. Degradation of fruit quality, appearance, and palatability (including scald, formation of fibrous pockets, and off-flavours) have been recorded under commercial conditions where fruit condition, handling, and temperatures are less controlled than laboratory conditions [unpublished data cited by Mangan and Ingle (1992)].

Australian research by Smith and Chin (1989) compared mango cultivars 'Kensington Pride', 'Irwin', 'Haden', 'Tommy Atkins', and 'Strawberry' using a range of hot-water immersion treatments between 30 and 90 minutes at 42– 48°C against the fruit fly *Dacus aquilonis* (May). Physiological characters of weight loss, maturation time, skin softness, skin colour, skin appearance, sapburn, blemish, flesh colour, smell, % sugar, pH, scald damage, and marketability were measured. All five mango cultivars could be damaged by the dipping treatment, 'Haden' and 'Kensington Pride' being the most susceptible and 'Irwin' the least. Fruit treated on the day of harvest often exhibited severe surface scalding within 5–6 days (with immersion time as low as 30 minutes). Damage was reduced by allowing 24–48 hours between harvest and heat treatment. Storing fruit at 13°C before treatment also rendered fruit unmarketable. There appeared to be no difference in measured characters between marketable treated and control (untreated) fruit.

Preliminary studies into the physiological effects of hot-water treatments on 'Kensington' mango were reported by Jacobi and Wong (1991). Fruit were immersed in water at 48–56°C for 20 minutes. Skin scalding, abnormal skin colour development with ripening, damaged lenticels, and accelerated respiration rates occurred with the 56°C treatment. The 52°C treatment shortened the fruit ripening time and caused high preclimacteric respiration rates compared with untreated fruit. However, this treatment enhanced the fruit appearance, producing a full even skin colour with no scalding when the fruit ripened.

This research was expanded to investigate the response of 'Kensington' mango from three production regions to an experimental quarantine schedule of 47°C fruit core temperature for 7.5–30 minutes against Queensland fruit fly (*Bactrocera tryoni* Froggatt) and Mediterranean fruit fly (Jacobi and Wong 1992). Fruit softening, skin colour development, and fruit injury were investigated. Hot-water treatment significantly reduced time to first softening. Colour development was slightly higher than in untreated fruit, but was uneven in some hot-water treated fruit which had been injured. Production region and/or fruit maturity influenced the response of fruit to the treatments. Hot-water treated fruit were injured externally and internally. Skin scald, starchy layer development under the skin, internal cavities, and 'ricy' (starchy) spots within the pulp were recorded across treatments and production regions. This research has since continued, investigating means of avoiding such hot-water injury using different heating regimes and pre-conditioning of 'Kensington' mango with hot air before hot-water immersion. The nature of these heat injuries has also been studied using electron microscope techniques. A program examining the carbohydrate metabolism of heat-treated mango has also been initiated (Jacobi, unpublished data).

The Effect of Hot-water Disinfestation Treatments on Disease Control

Hot-water immersion has been used commercially for the control of postharvest disease in mango for many years. Typically, immersion temperatures range from 51–55°C for times of up to 15 minutes (Pennock and Maldonaldo 1962; Smoot and Segall 1963). Fungicides such as benomyl, thiabendazole, and imazalil are often added to hot-water dips to improve disease control efficacy (Spalding and Reeder 1972; Muirhead 1976; Spalding and Reeder 1986). Because of the short duration of such treatments, they are effective in raising the temperature of only the fruit surface. While surface heating is often sufficient to kill fungal pathogens, it does not kill fruit fly larval stages which may be present anywhere in the flesh of infested fruit. This is why heat treatments developed specifically for the purpose of fruit fly disinfestation in mango involve the gradual heating of fruit over relatively long (ca. 1–2 hours) times.

Decay due to anthracnose and stem-end rot was reduced by up to 36% in 'Tommy Atkins' and 'Keitt' mangoes immersed in hot water at 46°C (65 minutes) for the quarantine control of Caribbean fruit fly (Sharp and Spalding 1984). In a more detailed evaluation of hot-water disinfestation treatments, Spalding et al. (1988) found that treatment at 46°C for 60–20 minute reduced anthracnose in 'Keitt' mangoes and stem end rot in both 'Keitt' and 'Tommy Atkins' mangoes. Treatment at 49°C for 60 minute reduced anthracnose in 'Keitt' and stem end rot in 'Tommy Atkins' mangoes. Treatment at 46°C for 60–90 minutes, did not damage market quality.

McGuire (1991) compared the disease control efficacy of hot-water and hot-air treatments developed for the disinfestation of mangoes against Caribbean fruit flies. Immersion in hot water at a constant 46°C gave better control of anthracnose in 'Tommy Atkins', 'Keitt', and 'Palmer' mangoes than exposure to forced hot air at 46° or 48°C. The hot-water treatment also gave good control of stem-end rot in 'Tommy Atkins' and 'Keitt' mangoes. In contrast, a hot-water treatment (46°C) developed for the quarantine disinfestation of 'Kensington' mangoes against Queensland fruit fly gave no control of anthracnose. Indeed it increased levels of stem end rot in fruit ripened at 22°C (Jacobi and Coates, unpublished data).

The Effect of Hot-air Disinfestation Treatments on Fruit Quality

Hot air is another method of applying heat to mangoes to disinfest them of fruit flies. The first literature report of a vapour-heat treatment for mangoes was made by Balock and Starr (1945). The treatment was designed to disinfest fruit of Mexican fruit fly with treatment periods of 8–13 hours. The first 8 hours represented the approach period needed to reach temperature equilibrium at 43.3°C. No fruit physiological measures were mentioned in this report. High humidity hot-air (HHHA), or vapour-heat treatments where the relative humidity of treatment is above 95%, are favoured by the Japanese for their imported mangoes. This technique is being used commercially in Thailand and the Philippines for the export of their 'Nang Klangwan' and 'Carabao' mangoes, respectively, to Japan. Sunagawa et al. (1987) reported an experimental vapour-heat treatment of 43.5°±0.5°C fruit temperature for 3 hours completely killing all stages of melon fly (*Dacus cucurbitae* Coquillett) without causing fruit injury. However, a 47.5°± 0.5°C treatment for 3 hours did cause some fruit injury. An experimental vapour-heat protocol has been developed in Australia for export of 'Kensington' mango to Japan (Heard et al. 1992; Jacobi and Wong 1992).

Research in the USA has concentrated on forced hot–air treatments where hot air raises the temperature of the fruit slowly, but the dewpoint temperature is maintained below the level at which surface condensation would form (McGuire 1991). Sharp et al. (1991) reported the development of a hot-air treatment device that precisely controls temperature and relative humidity inside the treatment area and on fruit surfaces. The authors suggest that condensation on fruit surfaces may have caused scald and fruit desiccation.

McGuire (1991) examined an experimental forced hot-air treatment of 46°C for 195 minutes or 48°C for 150 minutes (58–90% relative humidity) for disinfestation of 'Tommy Atkins', 'Keitt', and 'Palmer'against Caribbean fruit fly. Quantitative measures were made of the fruit's physiological responses including weight loss, injury ratings, firmness (using an Instron), and skin colour (using a Chroma meter for L a b values). Hot–air treated mangoes did not develop any injuries from any treatment (across all cultivars). Weight loss was significantly higher, fruit softening accelerated, and yellow pigmentation increased in treated fruit. The 48°C treatment was preferred over the 46°C treatment because it was tolerated well by the mangoes and provided a shorter treatment time.

Miller et al. (1991) treated 'Tommy Atkins' mangoes from Florida with forced hot air at 51.5°C for 125 minutes and then stored them for 1, 2, or 3 weeks at 12°C, followed by 21°C until fruit were soft-ripe. Quality was then compared with untreated fruit. Treated fruit lost 1% more fresh weight than untreated, and developed trace amounts of peel pitting, that were not expected to influence consumer acceptance. Total soluble solids, peel colour (based on a rating scale of 1 to 5), and flavour were similar between treated and untreated fruit. Fruit ripening was influenced by the forced hot-air treatment, with fruit reaching the soft-ripe stage approximately 1 day earlier than untreated fruit.

Mexican 'Haden', 'Tommy Atkins', 'Kent', and 'Keitt' mangoes were evaluated for quality after forced hot-air quarantine treatments against West Indian fruit fly involving a seed surface temperature of 48°C for 101–213 minutes (Mangan and Ingle 1992). Evaluation criteria included external and internal appearance, colour, pulp odour, flavour, texture, and overall quality. Consumer panels found no difference in taste, odour, or overall acceptability of treated fruit. In some cases, superior ratings of appearance factors were given to heated fruit compared with controls. Mangoes stored at 15°C for 1–2 weeks after forced hot-air treatment were not different to controls. It was suggested that heat-treated fruit may be more susceptible to damage from commercial handling procedures than untreated fruit.

Some physiological responses by mango to vapour-heat treatments have been reported by Mitcham and McDonald (1992). The authors do not state specific mango varieties or treatment conditions. Respiration rate increased during heat treatment and remained elevated several days after treatment. CO_2 accumulated to 13% and O_2 decreased to 7% in the internal atmosphere of vapour-heated mangoes. Ethanol, methanol, and acetaldehyde concentration increased, electrolyte leakage was higher, and ethylene-forming enzyme (EFE) activity decreased immediately after heat treatment. However, 3 days after treatment, electrolyte leakage decreased to control levels and EFE activity recovered. The treatment also reduced the rate of ripening. The authors suggest this may be due in part to a reduction in polygalacturonase and cellulase activities. They concluded that mango recovered from vapour-heat quarantine treatments and the technique may be beneficial in extending shelf life.

Vapour-heat treatments using Japanese technology have been developed for commercial usage by Thailand and the Philippines for export mangoes.

At present, Thailand exports 'Nang Klangwan' mangoes to Japan using a vapour- heat treatment of fruit core temperature being raised to 46.5°C and maintained for 10 minutes, with treatment chamber temperature set at 47.5°C and relative humidity 100% (Unahawatti et al. 1986). In association with the large-scale disinfestation tests, specific fruit injury tests were carried out simulating air and sea shipments to Japan. These tests involved heating the fruit core to 48.5°C for 0–120 minute. Parameters of weight loss, appearance, pulp colour, taste, brix, and acidity were measured. Vapour-heat treated mangoes lost slightly more weight than untreated fruit, but this was concluded not to affect marketability. The appearance, aroma, and flavour of treated 'Nang Klangwan' mangoes was not impaired, and in some cases was improved over untreated fruit.

Research continues in Thailand into vapour-heat treatment for other mango cultivars to potentially expand their export market to Japan. Cultivars 'Rad', 'Pimsen Dieng', and 'Nam Doc Mai' are being tested (Jacobi, unpublished data).

A vapour-heat treatment protocol using Japanese technology was developed in the Philippines for disinfestation of export 'Carabao' mango to Japan (Merino et al. 1985). The target pests were oriental fruit fly (*Dacus dorsalis* Hendel) and melon fly. The treatment involved raising the fruit core temperature to 46°C and holding it there for 10 minutes. Treatment time averaged 1 hour 46 minutes to 1 hour 56 minutes with relative humidity exceeding 95% within 15 minutes. As part of the protocol submission to the Japanese Government, fruit injury tests were carried out. The following quality parameters were measured: weight loss, appearance, pH, acidity (% citric acid), brix (sugar content), colour, aroma, and flavour. The treatment regime for these tests was more severe than the recommended vapour-heat protocol. Fruit were subjected to a fruit core of 46, 47, and 48°C for 0, 1, and 3 hours. The tests also simulated storage conditions of air and sea shipment to Japan. With all tests, no significant differences were observed between treated and untreated mangoes in all parameters measured. The researchers concluded that the vapour-heat treatments did not injure 'Carabao' mango and did not adversely affect palatability or shelf life of the fruit.

Esguerra and Lizada (1990) have investigated the quality of vapour-heat-treated Philippine 'Carabao' mangoes in more detail. Fruit from different production regions and at two maturity stages were subjected to vapour-heat treatment at a pulp temperature of 46°C for 10 minutes, with the fruit then ripened at 25°C. Peel colour development was not accelerated by treatment, except in immature fruit from one of the production regions. A greater proportion of vapour-heat-treated fruit attained full yellow colour. No adverse effect on visual quality was observed at table-ripe stage. Internal breakdown (IB) is a disorder where spongy tissue is present in the inner mesocarp of the mango. Vapour-heat treatment induced this disorder in 'Carabao' with symptoms not apparent until table-ripe stage. No external symptoms were visible on IB-affected fruit. The researchers suggest that susceptibility to this disorder was influenced by fruit maturity. Vapour-heat treatment also increased respiration rates, with some fruit having reduced oxygen and increased carbon dioxide levels internally. Fruit uninjured by the heat treatment had physicochemical and sensory characteristics comparable with those of untreated fruit. Fruits from different production regions varied in their response to treatment.

Australian researchers have developed an experimental vapour-heat protocol suitable for disinfesting Queensland fruit fly and Mediterranean fruit fly of 'Kensington' mango for the Japanese market (Heather et al. 1991). Physiological studies have been carried out into the response of 'Kensington' fruit to the treatment.

Several parameters were measured, including total solids (%), eating quality, time for fruit to soften, skin colour development, and fruit injury, over a range of vapour-heat treatments from fruit core 47°C for 7.5–30 minutes and three production regions. The treatment did not alter total solids or eating quality, but did reduce the time for fruit to soften. The rate of skin colour development was slightly higher for vapour-heated fruit. Fruit injury, in the form of external skin scald, varied in severity with production region. For one region, no scald was recorded, while for another, low levels (2–8% of total fruit treated) occurred with most treatments. It is important to note that the recommended protocol for treatment was set at fruit core temperature 46.5°C held for 10 minutes. The physiological studies were carried out considerably in excess of the disinfestation schedule, allowing for a 'window' of treatment.

In addition to this protocol development, Jacobi and Wong (1992) have reported on supplementary studies into the physiological response of 'Kensington' mango to vapour-heat treatment. The reduction of softening time and the increased skin colour development of vapour-heat treated fruit were confirmed. Production region and/or fruit maturity were found to influence the response of fruit to the treatment. This research has been expanded to investigate the effect of fruit maturity, and to simulation trials testing the recommended vapour-heat protocol in association with cool storage (Jacobi, unpublished data).

The Effect of Hot-air Disinfestation Treatments on Disease Control

Esguerra and Lizada (1990) evaluated the disease control efficacy of a high humidity hot-air (HHHA) treatment developed for the disinfestation of 'Carabao' mangoes against oriental fruit fly and melon fly. The incidence of anthracnose and stem-end rot was significantly reduced in mangoes heated to a core temperature of 46°C for 10 minutes, although the onset of decay was not delayed by the treatment.

Coates et al. (1993) also found that HHHA treatment gave good control of anthracnose in 'Kensington' mangoes ripened at 23°C, although treatment efficacy was reduced when fruit were cool-stored for 14 days before ripening. A combination treatment consisting of HHHA followed by either hot benomyl or unheated prochloraz gave complete control of anthracnose in cool-stored mangoes. Stem-end rot was not satisfactorily controlled by HHHA treatment. A supplementary hot benomyl treatment was required for acceptable control of this disease.

Treatment of mangoes with forced hot air (58–90% relative humidity) at 46° or 48°C for the quarantine disinfestation of Caribbean fruit flies gave some control of anthracnose in the varieties 'Keitt' and 'Palmer', but no control in 'Tommy Atkins' mangoes (McGuire 1991). Hot-air treatment at 46°C reduced stem-end rot levels in 'Keitt' mangoes only, while treatment at 48°C reduced levels in 'Palmer' mangoes only.

Future Research Needed

With the continuing worldwide trend away from the use of postharvest fungicides, more emphasis needs to be placed on the development of heat treatments which control both insects and pathogens in mango and other fruit crops. Such treatments may need to combine short-term exposure to high temperature for the control of pathogens with the gradual heating required for fruit fly disinfestation. Future development of heat treatments should also include investigations of the heat transfer characteristics of fruit cuticle and stem-end tissues, so that heat penetration to the infection site can be maximised.

At present, there is still a large number of questions to be answered as regards quality of heat-treated mangoes. A number of similar trends has emerged from the reports of quality around the world. The influence of production region, cultivar, fruit maturity, fruit size, stage of ripeness, and postharvest handling procedures are mentioned by many researchers where heat treatment has been examined experimentally or used commercially. Few basic physiological studies into the response of mango to heat treatments have been reported.

An understanding of carbohydrate metabolism and softening processes, through studies of enzyme systems (e.g. amylase, polygalacturonase, and cellulase) may help explain the fruit behaviour. Numerous basic physiology studies have been conducted on heat-treated papaya (Paull 1990). Heat–shock protein development, chloroplast activity, ethylene forming enzyme (EFE) activity, nucleic acid metabolism, and wall–degrading enzymes are some of the fruit physiological components that can be studied to provide answers to changes taking place within the fruit as a result of heat treatment.

The differing response of mango to the heating medium (i.e. air or water) is also little understood. Research into heat transfer rate within the fruit and its effect on mango physiology are untapped areas of study. The internal atmosphere of the mango may provide answers to some of the injuries observed. For example, the internal breakdown observed in some heat-treated Philippine 'Carabao' mangoes by Esguerra and Lizada (1990) has been associated with elevated CO_2 and reduced O_2 levels within the fruit (Gautam and Lizada 1984).

Basic physiology research will provide an insight into the changes occurring within the mango's various biochemical and molecular systems in response to heat treatment and may make possible a modification of the fruit response. Pre-conditioning of mango to withstand

heat treatment is a practical demonstration of what can be achieved. While trends observed through empirical experimentation are important, when backed up by basic research they will enable effective quarantine treatments to be developed which maintain fruit quality and satisfy market requirements.

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Preharvest Fruit Fly Control: Strategies for the Tropics

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Abstract

Infestation by fruit flies (Tephritidae: Diptera) is common in the tropics and is a major constraint to the production and export of tropical fruits. Recent studies have shown that there are several species of economic importance in Southeast Asia, some of which have not been described before. New host records also reveal a previously unknown distribution of pest species in the region. Current control procedures include cover sprays of insecticides, spot sprays of protein baits, orchard sanitation, and fruit wrapping, and seek to prevent direct damage to fruits or are aimed at population suppression, mostly in individual orchards. These field control techniques enable production of fruit of sufficient quality to meet the needs of domestic consumption as well as that for export to markets where fruit flies are not quarantine pests. Export to markets where fruit flies are quarantine pests is a more complex situation and is primarily facilitated through additional postharvest or quarantine disinfestation treatments. More effective strategies for the production of fruit for the domestic as well as the more stringent but lucrative export markets are discussed.

TROPICAL fruits are attractive commodities and are being increasingly developed for domestic consumption as well as for export by many countries in the Asia and Pacific region. It was estimated in 1988 that this region had an annual fruit production of about 84 million tonnes which accounted for about 26% of the world's production, and with an annual growth rate of 4% (Singh 1991). The region also has a rich diversity of native and introduced fruits, some of which have already found lucrative international markets, and several others have good potential for commercial development. Countries like Thailand (US$909 million), Philippines (US$348 million) and India (US$106 million) earn considerable income from exports of fruits (Singh 1991).

Against this backdrop of a rapidly expanding fruit industry, we find that the region is also home to several species of highly damaging fruit flies (Tephritidae: Diptera). Some of these such as the oriental fruit fly, *Bactrocera* (previously *Dacus*) *dorsalis* (Hendel), and the melon fly, *B. cucurbitae* Coquillet, are well known and recognised as major pests of international quarantine significance. Recent taxonomic and host range studies have also revealed new pest species and species complexes in most Southeast Asian countries (Drew and Hancock 1993). The success of any fruit industry, whether it be for domestic consumption or for the export market is heavily dependent on sound fruit fly control during the preharvest stage. This paper will examine the various problems associated with the development of high quality fruit industries in a region with several damaging species of endemic fruit flies. In addition, it will look at the various management strategies, using existing control techniques, that can be used to overcome the present problems. Suggestions are also made for more effective management of these notorious pests.

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Distribution of Economic Species

Apart from adventive populations, the global distribution of pestiferous tephritids appears to be geographically distinct. The *Anastrepha* species are currently confined to south and central America and the West Indies where they infest a wide range of fruits. The genus *Rhagoletis* is found in South and Central America and in the temperate areas of Europe and North America. The genus *Ceratitis* which includes the notorious Mediterranean fruit fly (medfly) is believed to have originated in Africa. It has spread to many parts of the world including Western Australia but has not been reported from Asia. The genus *Dacus* is mainly from Africa and associated with flowers and fruits of Cucurbitaceae or pods of Asclepiadaceae. The *Bactrocera* spp. (formerly included in *Dacus*) are native to tropical Asia, Australia, and the South Pacific (White and

Elson-Harris 1992). This genus causes the greatest economic damage and is most important to countries in Asia and the Pacific and shall accordingly be treated in greater detail in this paper. A summary of the global distribution of fruit fly species within the five major genera is given in Table 1.

Tropical Asia, which includes Indonesia to the west of Irian Jaya, the Ryukyu Islands of Japan, and China south of the Yangtze River, forms the *Oriental Region*. This region, with its rich diversity of plant and animal life, has about 160 genera of tephritids, including about 180 *Bactrocera* spp. and about 30 *Dacus* spp. (White and Elson-Harris 1992). Australia and the New Guinea area form the *Australasian region*, and New Zealand and the Pacific Islands the *Oceanic Region*. About 130 genera are found in these regions including about 270 *Bactrocera* spp. and 27 *Dacus* spp. (White and Elson-Harris 1992). Fortunately the number of species causing economic damage is far less and 39 species of *Bactrocera* are currently recognised as being of major or potential economic significance. The Oriental, Australasian and Oceanic regions share many climatic and vegetational similarities. These similarities are favourable to the spread of pestiferous tephritids from one country to another. Details of the various pest species found in these regions have been summarised from Drew and Hancock (1993) and White and Elson-Harris (1992), and are given in Tables 2, 3 and 4.

Problems Associated with Fruit Flies in the Tropics

Fruit produced in a country is usually directed to any of three main markets. It can be grown for domestic consumption, exported to foreign countries where quarantine is not a problem, or it can be exported to countries where quarantine is a problem and requires prescribed postharvest or quarantine disinfestation measures. Without sound fruit fly preharvest control, fruit production for any of these three markets will not be possible. This section describes the major problems associated with fruit flies.

Species complexes

The oriental fruit fly, *B. dorsalis*, one of the world's most damaging tephritids, was for a long time considered widespread in all Southeast Asian countries. Recent studies, however, on the taxonomy of fruit flies in southern Asia (Drew and Hancock 1993) have revealed a vastly different picture of the pest species and their host ranges and distributions. The *dorsalis* complex comprises adults that are morphologically very similar and often difficult to tell apart. Drew and Hancock (1993) list 52 species in this complex in tropical Asia, of which fortunately only eight are of economic importance. Details of their distribution and host range are given in Table 2.

The most significant aspect of this study is that the oriental fruit fly is not present in Malaysia, Singapore, Brunei, Indonesia, or the Philippines, as was previously thought. Its distribution is more northern and limited to India, Sri Lanka, China, Taiwan, northern and central Thailand, Laos, Vietnam, Myanmar, and Cambodia. While this information is unlikely to change or affect existing quarantine-related restrictions on exports of fruits from this region, it has raised several important issues for countries in the region .

Each country appears to have its own pest species. For example, the carambola fruit fly (designated as Taxon A until formally described) is found in most countries of Southeast Asia except the Philippines, which has its own pest species, temporarily called Philippine B, not found elsewhere. *B. caryae* is presently found only in southern

Table 1. Global distribution of species within the five major genera of tephritids (summarised from White and Elson-Harris 1992)

Genus	Number of species found in various regions[a]					
	Oriental	Australasian/ Oceanic	Afro-tropical	Neotropical	Palaearctic	Nearctic
Bactrocera	180	270	14	1	13	–
Dacus	30	27	170	–	5	–
Ceratitis	–	1	65	1	1	–
Anastrepha	–	–	–	180	–	20
Rhagoletis	–	–	–	21	22	24

a Oriental = Tropical Asia, including Indonesia to the west of Irian Jaya, the Ryukyu Islands of Japan, and China south of the Yangtze River
Australasian = Australia and New Guinea
Oceanic = New Zealand and the Pacific Islands
Palaearctic = Europe, temperate Asia, Middle East, and North Africa
Nearctic = Canada, USA, and northern mountains of Mexico
Neotropical = remaining areas of the Americas (South America, etc.)

Table 2. Fruit flies of economic significance in the *Bactrocera dorsalis* complex.

Scientific name	Common name	Lure	Distribution	Commercial Hosts	Comments
B. caryeae	–	methyl eugenol (ME)	Southern India	Citrus, guava, mango	Serious pest
B. dorsalis	Oriental fruit fly	ME	Southern China, Taiwan, Sri Lanka, India, Myanmar, northern and central Thailand, Vietnam, Laos, Cambodia, Hawaii	Citrus, carambola, guava, mango, papaya, peach, pear	Major pest of international quarantine importance
B. occipitalis	–	ME	Philippines	Mango	Serious pest of mango. Other host data lacking
B. dorsalis complex (A)*	Carambola fly	ME	Andaman Islands, Indonesia, Malaysia, Singapore, Taiwan. Adventive in Suriname and French Guiana	Carambola, guava, mango, breadfruit, and several other fruits	Major pest. First record of *Bactrocera* spp. in S. America
B. dorsalis complex (B)*	Papaya fly	ME	Malaysia, Indonesia, southern peninsular Thailand	Banana, carambola, citrus, mango, papaya and others	Major pest
B. dorsalis complex (C)*	–	ME	Philippines	Breadfruit, mango	Major pest. Host data lacking
B. dorsalis complex (D)*	–	ME	Sri Lanka	*Garcinia*, mango	Serious pest. Host data lacking
B. dorsalis complex (E)*	–	–	Northern Thailand	Guava, peach, pear	Serious pest

* Drew and Hancock (1993) for complete species names.

Table 3. Fruit flies considered major or serious pests in the Oriental, Australasian and Oceanic regions.

Scientific name	Common name	Lure[a]	Distribution	Commercial Hosts	Comments
• *Bactrocera arisetosa*	–	–	Papua New Guinea	Cucumber, pumpkin, tomato, watermelon	Serious pest
• *B. correcta*	Guava fruit fly	ME	India, Nepal, Pakistan, Sri Lanka, Thailand	Polyphagous: guava, mango, peach, rose-apple, sapota and others	Major pest
• *B. cucumis*	Cucumber fruit fly	–	Australia	Cucurbits, tomato, papaya	Serious pest
• *B. cucurbitae*	Melon fly	CUE	Oriental Asia, New Guinea area. Adventive in eastern Africa, Hawaii, Mauritius, Réunion, Iran, Solomon Is.	Highly polyphagous. Gourds, luffa, cucumber, melons, pumpkins, and a wide range of other cucurbits and some some non-cucurbit hosts	Major pest. Long considered as one of the world's most damaging tephritids
• *B. decipiens*	–	–	New Guinea area: New Britain	Pumpkin	Serious pest of pumpkin. Potential pest of other cucurbits
• *B. depressa*	–	–	Japan (Ryu Ku Islands), Taiwan	Cucumber, pumpkin, tomato, watermelon	Serious pest
• *B. facialis*	–	CUE	Tonga	Polyphagous. Avocado, bell pepper, citrus, guava, tomato and others	Major pest
• *B. jarvisi*	–	CUE (weak)	Australia	Highly polyphagous. Apricot, banana, guava, mango, peach, pear, persimmon and others	Major pest
• *B. kirki*	–	CUE	South Pacific: American and Western Samoa	Polyphagous. Bell pepper, carambola, citrus, guava, mango	Major pest
• *B. latifrons*	Solanum fruit fly	CUE	China, India, Pakistan, Sri Lanka, Taiwan, Laos, Thailand, Malaysia, Vietnam. Adventive in Hawaii	Chilli, tomato, and salinaceous crops	Serious pest
• *B. melanota*	–	CUE	S. Pacific: Cook Islands	Citrus, guava, mango	Major pest
• *B. musae*	Banana fruit fly	ME	Australia: eastern Queensland, Papua New Guinea, Solomon Is., Bismarck Archipelago	Banana, guava, papaya	Major pest of banana. Eggs laid in immature green fruit
• *B. neohumeralis*	–	CUE	Australia, Papua New Guinea	Polyphagous. Apple, apricot, citurs, guava, tomato, and others	Major pest, often simultaneously infesting fruit with *B. tryoni*
• *B. passiflorae*	Fijian fruit fly	–	S. Pacific: Fiji, Tonga, Niue Island	Avocado, breadfruit, citrus, guava, mango, papaya	Major pest
• *B. psidii*	–	CUE	S. Pacific: New Caledonia	Citrus, guava, mango	Serious pest
• *B. tau*	–	CUE	Oriental Asia	Cucumber, luffa, and a range of other cucurbits	Serious pest. Potential major pest of cucurbits
• *B. trivialis*	–	CUE	Indonesia (Irian Jaya and Sulawesi), Papua New Guinea. Australia: Torres Strait islands	Guava, grapefruit, peach	Serious pest
• *B. tryoni*	Queensland fruit fly	CUE	Australia: eastern Queensland and eastern New South Wales. Adventive in Papua New New Guinea and New Caldeonia	Highly polyphagous. Infests almost all commercial fruit crops except pineapple	Major pest.
• *B. tsuneonis*	Japanese orange fly	–	China, Japan (Ryu Ku and Kyushu Islands)	Citrus	Serious pest of citrus
• *B. tuberculata*	–	ME	Myanmar, S. China, Thailand, Vietnam	Mango, peach	Serious pest; host data lacking
• *B. umbrosa*	–	ME	Indonesia, Malaysia, Philippines, southern peninsular Thailand, Papua New Guinea, Solomon Islands, Bougainville Island, New Caledonia, and Vanuatu	Breadfruit, jackfruit	Serious pest
• *B. xanthodes*	–	ME	Cook Islands, Fiji, Tonga, Vanuatu, Western Samoa	Breadfruit, bell pepper, citrus, guava, papaya, tomato	Major pest
• *B. zonata*	Peach fruit fly	ME	India, Sri Lanka, Laos, Vietnam, N. Thailand (rare)	Polyphagous. Apple, citrus, guava, mango, sugar-apple, papaya, and others	Major pest

Source: Compiled from White and Elson-Harris (1992)
[a] ME = methyl eugenol; CUE = cue-lure, 4-(D-acetoxyphenyl)-2-butanone

Table 4. Fruit flies that are potential pests in the Oriental, Australasian and Oceanic regions.

Scientific name	Common name	Lure[a]	Distribution	Commercial hosts	Comments
B. albistrigata	–	CUE	Indonesia (Java, Lombok, Sulawesi, Sumatra), Peninsular Malaysia, southern peninsular Thailand	Water–apple, rose–apple and Malay–apple (all *Syzygium* sp.)	Potential pest of other *Syzygium* sp.
B. aquilonis	–	CUE	Australia: Northern Territory and northern areas of Western Australia	Polyphagous. Apple, carambola, guava, mango, soursop, plum, peach, tomato and others	Overlapping and possibly hybridising with *B. tryoni* over much of its range
B. caudata	–	CUE	Oriental Asia	Pumpkin flowers	Potential pest of cucurbits
B. curvipennis	–	CUE	S. Pacific: New Caledonia, Vanuatu	Citrus	Potential pest of citrus
B. distincta	–	CUE	S. Pacific: American and Western Samoa. Fiji and Tonga	Breadfruit, star–apple	
B. diversa	–	ME	China, southern India, Sri Lanka, Thailand	Flowers of pumpkin, luffa and gourds	Potential pest of cucurbits
B. frauenfeldi	–	CUE	Australia (Cape York Peninsula), Papua New Guinea, Solomon Is., Bougainville and Stuart Is., South Pacific: Belau, Kiribati, Marshall Is., N. Marianas	Breadfruit, guava, Malay–apple, mango	Potential to become a problem in horticultural industries
B. minax	Chinese citrus fly	–	Bhutan, southern China, India (western Bengal and Sikkim)	Citrus	

Source: compiled from White and Elson-Harris (1992).
[a] ME = methyl eugenol; CUE = cue–lure

India and Sri lanka while *B. occipitalis* occurs only in the Philippines. All eight species listed in Table 2 are major or serious pests and it is important to prevent adventive populations from establishing in areas where they currently do not exist. Adventive populations of Taxon B have recently invaded Australian territory in the Torres Strait and are being targeted for eradication (R.A.I. Drew, pers. comm. 1993). Such a situation highlights the need for countries in the Asia and Pacific regions to reexamine their quarantine procedures to ensure that new pest species of fruit flies do not spread to their countries.

Damage

Unlike temperate regions that have cold seasons that interrupt fly breeding, tropical regions are warm and allow continuous cultivation. Coupled with monoculture of fruits, this provides ideal conditions for fruit flies to multiply rapidly. If left unchecked, it is common to find that fruit flies build up to very high numbers and can destroy some fruit crops completely. Unprotected carambola readily suffers 100% damage (Vijaysegaran 1983). Damage to young fruits may cause premature fruit drop and oviposition puncture marks blemish the fruit and reduce their market value. Measures taken to control fruit fly damage also add to the cost of production. Tolerance to fruit fly damage is also extremely low. A few larvae in a fruit, perhaps just one, is often sufficient to render it unsuitable for storage, sale, or human consumption.

Another problem often overlooked is bacterial decay and contamination of fruit. Associated with oviposition and larval feeding are bacteria of the family Enterobacteriaceae (Drew and Lloyd 1991). Some of these such as *Klebsiella oxytoca* and *Enterobacter cloacae* are commonly found in the gastrointestinal tract and faecal matter of vertebrates. Consumption of large quantities of these bacteria, as would be found in heavily infested fruit, is not hygienic and should be avoided. Fruit produced in backyard and home gardens often have high levels of larvae and the effects of unknowingly eating infested fruit needs further investigation.

Fruit flies do not distinguish between fruit produced for local consumption and that produced for export. The losses caused are the same at the preharvest level and it is a fallacy to assume that fruit produced for the domestic market can sustain higher levels of fruit fly damage. Appropriate control measures have to be instituted to ensure clean fruit for all markets.

Quarantine-related restrictions to export

Tropical fruit such as carambola and papaya from Southeast Asia are currently exported without postharvest disinfestation treatments to several countries in Europe where fruit flies are not quarantine pests. These two crops are often grown in areas that have high endemic populations of these pests. Good fruit fly control procedures, plus a stringent postharvest quality control scheme to ensure that fruits meet the high quality requirements of importing countries, results in exported fruits that are almost free of fruit flies. However, despite the high quality control acceptable to importing countries in Europe, without prescribed quarantine disinfestation treatments, these fruits still cannot penetrate large and lucrative markets like Japan and the USA. The presence of even a single species of fruit fly of quarantine importance in the producing country is sufficient to restrict exports. Having several damaging species and species complexes greatly exacerbates the problem.

From the data on the economic species, their host ranges and distribution given in Tables 2, 3, and 4, it is apparent that, even with the Asian region, there are several highly damaging species whose spread to new areas would pose additional problems to the fruit industry. The question of how this risk can be minimised (by quarantine or other means) deserves greater attention than so far received.

Management Strategies

Fruit flies are endemic to almost all countries in the Asia–Pacific region. Each country has its own pest species and constantly faces further danger from new introductions. There are two broad strategies for combating the problem. The first involves 'living with the problem' and is achieved by using a combination of population control/suppression techniques that prevents direct damage to the fruit and reduces damaging populations of flies to tolerable levels. This approach appears to be practiced widely in many fruit-growing regions of Asia where fruit flies are endemic. The second strategy is to 'get rid of the problem' and is achieved by developing and implementing a preharvest quarantine system that enables production of fruit totally free of fruit flies. The two strategies are summarised in Figure 1 and described in greater detail in the following section.

Population control/suppression

A number of specific techniques can be used to achieve control or suppression.

Natural enemies

In nature, fruit flies have many enemies that feed on them. The eggs, larvae, and puparia are attacked by a number of parasitic Hymenoptera, particularly by species of Opiinae belonging to the family Braconidae (Christenson and Foote 1960; Wharton and Gilstrap 1983). Adults of some *Bactrocera* spp. have a Strepsip-

teran parasite (Drew and Allwood 1985). The larval parasites have been well studied and, in biological control programs, several species have been collected from their native areas and introduced to areas where the pest flies occur. These efforts have been reviewed by Wharton (1989). Commonly used are parasites belonging to the family Braconidae which include the genera *Biosteres* and *Opius* (Wharton 1989). The actual success achieved by these various biocontrol programs is difficult to assess. Apart from the reports from Hawaii (Newell and Haramoto 1968; Haramoto and Bess 1970) most tephritid biological control projects have failed to provide adequate documentation of effort (Wharton 1989). In individual orchards it is unlikely that biocontrol agents by themselves can provide the degree of control required by the industry. Vijaysegaran (1983) recorded high levels of parasitisation in carambola over an 18-month study period but still ended up with over 90% damage to fruits. Interest in parasites has been renewed by efforts in Hawaii to use them as an adjunct

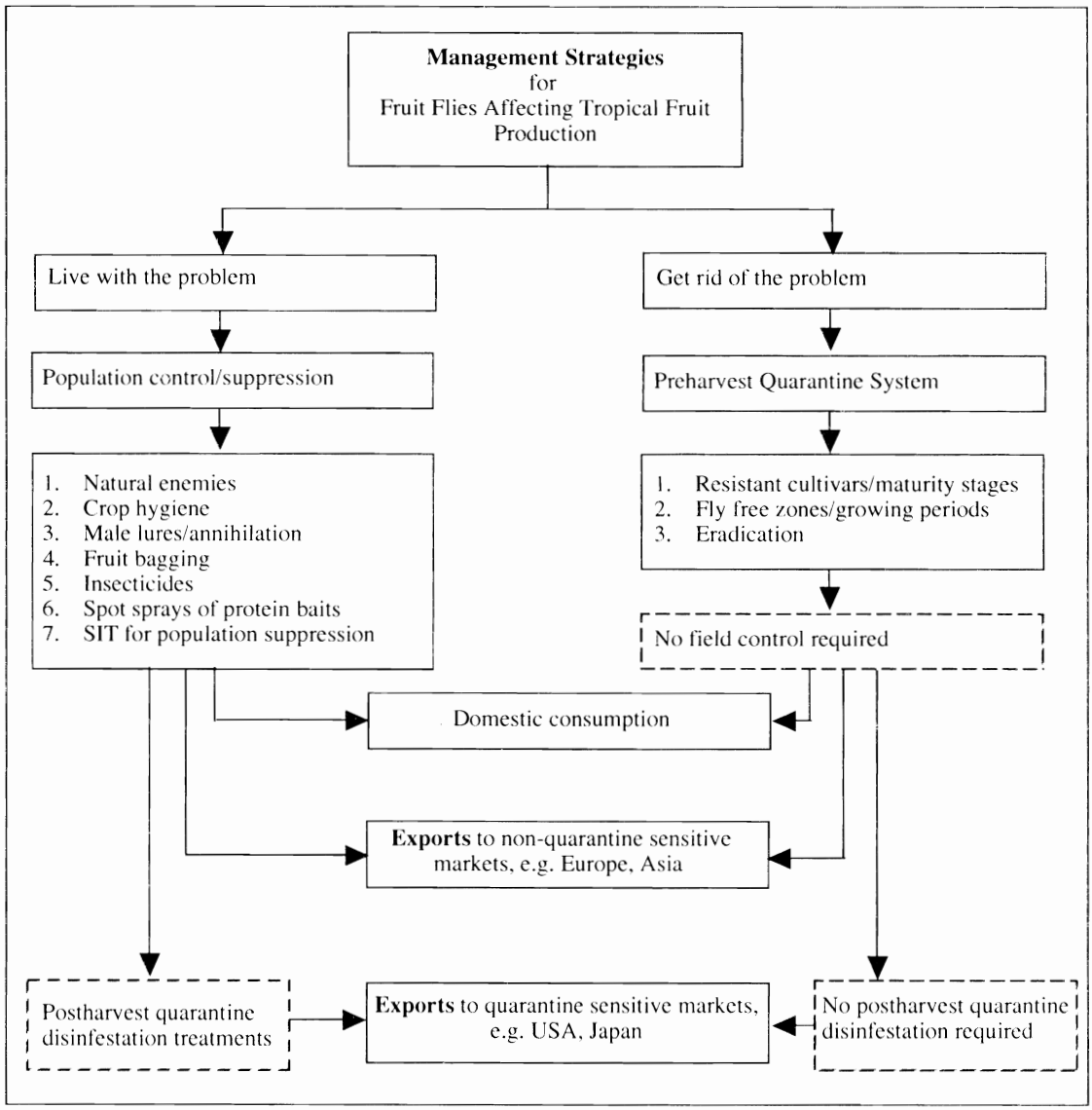

Figure 1. Flowchart outlining the two major strategies for managing the fruit fly problem, the respective techniques in use, and the resulting markets open to tropical fruits.

to the release of sterile flies in Hawaii (Vargas and Spencer 1991). Augmentative release of parasites mass reared in the laboratory has been shown to be effective in suppressing native populations of medflies in Hawaii (Wong et al. 1991).

Less is known about predation. Birds and rodents have been recorded as feeding readily on fruit fly larvae in fallen forest fruits. Ants (Wong et al. 1984) and other ground dwelling insects such as Coleoptera, Neuroptera, and Hemiptera (Bateman 1972) probably do significant damage to larvae in fallen fruits and pupae in the soil.

The sum total of the effect of parasites and predators is probably significant in nature. However, the level of control exerted by these agents is far below the demands of the fruit-growing industry. A few or even a single larva in a fruit is enough to have it rejected for consumption and the more stringent export market will not tolerate any larvae in fruit. It is unrealistic to expect natural enemies to provide such a high degree of control. Nevertheless, their presence should be encouraged in orchards and supplementary methods that are not deleterious to them should be adopted.

Crop hygiene

The equable tropical climate, combined with an abundance of host fruits under monoculture situations, enables uninterrupted breeding of fruit flies throughout the year. Several of the damaging species of fruit flies exhibit the characteristics of 'R-selected' pests, i.e. they have a short life cycle, breed rapidly, and multiply to high numbers when food is abundant. Breeding of fruit flies in unwanted fruit in tropical orchards is probably the biggest source of damaging populations. This has been reported for carambola (Vijaysegaran 1983) and mixed fruit cultivation (Serit and Tan 1986).

It is thus very important to prevent breeding of flies by removing and destroying all unwanted or fallen fruit. Such fruit can be destroyed by burning, or by burying in at least 15 cm of soil. In areas where several individual orchards are close to each other, it is important for all orchards to observe crop hygiene, for one neglected orchard can be the source of problems for the rest. Crop hygiene is not easy to implement and enforce but it is important to realise that it has to be integrated into the overall management of the orchard. If governmental or institutional support can be gained to implement and enforce an area-wide crop sanitation program, fruit fly populations can be effectively reduced and managed with other techniques.

Male lures/attractants

The males of some species of fruit flies are strongly attracted to certain chemical compounds, some of which occur in nature. These compounds have been called 'parapheromones' and a historical account of their discovery and attraction for various species of flies is given by Cunningham (1991). Methyl eugenol (ME) is perhaps one of the best known lures and is a constituent of many common plants. Males of many *Bactrocera* species are so strongly attracted to ME that they will feed on it until they die. Another attractant, Cue-lure (4-[D-acetoxyphenyl]-2-butanone), is not found in nature, but its closely related analogue, the so-called raspberry ketone, does occur in plants.

The strong attraction of males to their respective 'parapheromones' has been put to good use in male annihilation programs. Its effectiveness was first demonstrated on isolated islands, with the successful eradication of the oriental fruit fly from the 85 km^2 island of Rota in the Marianas (Steiner et al. 1965). Similar success followed on the islands of Saipan and Tinian where fly populations had first been reduced by the sterile insect technique (Steiner et al. 1970). Eradication programs in Japan (Kawasaki 1991) have relied on ME-assisted male annihilation and in Taiwan (Chiu and Chu 1991) ME has been used in population suppression programs.

Seven of the eight species of flies in the *dorsalis* complex are attracted by ME (Table 1) and it is an exciting proposition to attempt to control flies using this lure. However, attempts at male annihilation in non-isolated situations have not been as spectacular. Qureshi et al. (1981) achieved 99% suppression of *B. zonata* in a 10 ha guava orchard in Pakistan but were able to reduce the fruit infestation to only 63% below that of untreated control. Ibrahim et al. (1979) reported a 20% reduction in fruit infestation in a 0.5 ha carambola orchard in Malaysia after 5 weeks of trapping. I have repeated these experiments at higher trap densities and over a longer period (1 year) and have not been able to obtain any reduction in damage (MARDI 1981). Balasubramaniam et al. (1972) claim to have reduced the infestation by oriental fruit fly in a 5 ha plum orchard from 20% (control orchard) to 3% (treated orchard) by male trapping alone. Cunningham and Suda (1986) tested male annihilation over much larger areas of a 62 ha papaya orchard and achieved 99% reduction in populations of male oriental fruit fly but were able to obtain a reduction of only 44% in levels of fruit infestation.

The use of methyl eugenol in individual orchards in an assortment of traps (tin cans, used plastic containers, plastic bags, etc.) is common in many Southeast Asian countries. However, when used alone in this manner for the protection of individual orchards, especially where fruit flies are endemic, male lures appear to be of little value. While traps provide impressive catches of males, this alone has not been proven to be sufficient to disrupt mating. Large numbers of gravid females, unaffected by the lure, are always present, both as resident populations and migrants from surrounding areas, and ready to oviposit in and damage fruits.

Male annihilation may be more effective if carried out over large areas and could be useful for species such as the carambola fly that are predominantly found in cultivated areas and not in the rainforests. This has yet to be tested. The long-term effects of suppressing male populations is not known and the selection of non-responsive strains has been questioned (Ito and Iwahashi 1974; Cunningham 1991) but never answered.

The simultaneous use of male lures and protein baits was found to be more effective than either method used alone for the control of Queensland fruit fly, *B. tryoni* (Bateman et al. 1973). Such combined treatments are more likely to provide the degree of control required by the industry and should be tested in the tropics.

Fruit wrapping/bagging

Wrapping or bagging of individual fruits to prevent oviposition and produce fruits of high quality appears to be a strategy restricted to the Asian region. The bags provide a continuous physical barrier to egg-laying from the time of bagging to harvest. Bagging is used extensively in carambola production in Malaysia which exported about US$10 million worth of this fruit in 1988. It is also used extensively in Taiwan for a variety of fruit (Cheng and Lee 1991) and, in the Philippines, for mango (Hapitan and Castillo 1976).

Fruit wrapping is effective and enables production of high quality fruit with good cosmetic appeal. It is also simple to apply, highly effective, and has no deleterious side effects. There are some limitations, however, to the adoption of this technique on a large scale. Firstly, trees have to be a manageable height. Secondly, and perhaps the major constraint, is that fruit wrapping is labour intensive. The labour requirements for carambola have been reported by Vijaysegaran (1985). While it is not expected that fruit bagging will be extended or will be applicable to all fruit types, it will remain as a control system that enables production of certain high-quality fruits such as carambola and mango.

Insecticides

When used to control fruit flies and other important insect pests that plague fruit production, insecticides are usually applied to thoroughly drench the fruit and foliage, and are referred to as cover sprays. Adult flies are killed when they come into direct contact with the applied insecticide or deposits which are left on the fruits and foliage. In addition, some insecticides have a systemic or penetrative action and are absorbed into the fruit, killing any larvae and eggs that may be present. Fenthion and dimethoate work well in this fashion and are commonly used as cover sprays in fruit production (Fletcher and Bateman 1982). They have also been shown to be effective as postharvest dips for controlling *B. tryoni* in tomatoes (Heather et al. 1987). Their use in a postharvest disinfestation role as a logical follow-on to their use in field control has been presented by Heather (1989).

In small orchards or domestic gardens that have no control over breeding populations of flies in the general area, cover sprays of insecticides provide control against gravid females from surrounding areas. Cover sprays of insecticides are reported to be commonly used in India (Agrawal and Mathur 1991) and the Philippines (Rejesus et al. 1991). A few insecticides are also effective in preventing emergence of adults from pupae when applied to the soil (Shaw and Riviello 1961; Mohamad et al. 1979). However, because of its harsh effects on ground flora and fauna, soil application of insecticides is usually carried out only in emergency situations to contain outbreaks in an eradication program (Hagen et al. 1981) and is not generally recommended as a control procedure for fruit flies in individual orchards.

While insecticides are effective, their application may have deleterious effects on non-target or beneficial organisms (predators, parasites, and pollinators) and may lead to residue problems in the harvested product. Greatly reduced fruit set and increased numbers of deformed fruit due to poor pollination have been observed for cover-sprayed carambola (Vijaysegaran, unpublished data). Consumers are also becoming increasingly conscious of chemical residues in food. Most tropical fruits become increasingly attractive to fruit flies near maturity at which time they require the greatest protection. Cover sprays of insecticides close to harvest pose a constant risk of excessive residues. Fruit flies are not the only pests affecting tropical fruit cultivation. Some other pests require frequent cover sprays of insecticides. In such a situation, fruit flies are also controlled and it may be difficult to find suitable alternative controls. When fruit flies are the sole or major pest, however, the use of insecticides alone as a long-term fruit fly control technique is unwise. Horticultural industries in the tropics should seek to minimise the use of insecticides by development and introduction of supplementary or alternative control strategies.

Bait sprays

The concept of attracting pestiferous flies to a poisoned bait and killing them before they oviposit in fruits dates back to the latter part of the previous century. Roessler (1989) provides a historical overview and a detailed account of the development and use of bait sprays around the world. Until 1952, the variety of substances used as baits included, for example, sugars, molasses, syrups, fruit juices, and ammonia. In 1952, Steiner first used hydrolysed proteins together with sugar and parathion and demonstrated field control of fruit flies in Hawaii (Steiner 1952). Several commercial

formulations of protein-based baits have since become available and hydrolysed and autolysed yeast is now also widely used.

Protein baits work on the fact that immature flies, particularly the females, need proteins to reach sexual maturity. They therefore seek out proteinaceous substances in the field and are highly attracted to proteinaceous solutions applied to the foliage of host and non-host plants. A small amount of poison (usually an insecticide) added to the bait will kill them before they reach sexual maturity. Bait sprays are effective and have been used for control in orchards as well as in eradication programs.

In Malaysia, brewery waste has been successfully modified into a commercial fruit fly bait. Application of this bait with malathion as the insecticide in spot sprays of 40 mL per tree to only the foliage has provided excellent control of the carambola fruit fly (Vijaysegaran 1989). Such spot sprays avoid application to the fruit and have been shown to be safe to pollinating insects and other beneficial organisms. Increased fruit set and formation due to better pollination together with better control of other pests such as mites and lepidopteran fruit borers have also been recorded. Bait spraying, particularly the use of hydrolysed protein or autolysed yeast has proven highly successful in the USA (Steiner et al. 1961) and Australia (Bateman 1982)

Bait spraying is an effective way of suppressing damaging fly populations and should be extended to and tested on the variety of fruits cultivated in the Asian region.

Sterile insect technique

The sterile insect technique (SIT) has been used to eradicate fruit flies in several parts of the world. Early examples were the eradication of melon fly from the Mariana Islands (Steiner, et al. 1965) and Kume Island in Japan (Iwahasi,1977) as well as oriental fruit fly from Guam (Steiner, et al. 1970). The most recent success is the large eradication program in Okinawa, Japan, that has permitted declaration that Japan is free of oriental fruit fly and melon fly (Kawasaki 1991).

SIT has been extensively investigated in 13 species of tephritids (Hooper 1989). Its use is also supported by the International Atomic Energy Agency. SIT is not a simple procedure. Its application involves significant time and money and a high degree of technical expertise. There are several discrete components of the SIT that must be investigated to ensure success of the project and these have been reviewed by Hooper (1991). Important components include: appropriate diets and mass-rearing techniques to produce 500–1000 million individuals per week; suitable techniques to sterilise flies; handling, transport and release methods; and methods to evaluate the progress of the control or eradication program.

In the Asian region, apart from the successful programs in Japan (Kawasaki 1991), SIT has been attempted in Thailand (Sutantawong 1991) and the Philippines (Manoto 1991) only on a pilot scale. As any one fruit type or a collection of fruits increases significantly in an area of production and becomes an important export commodity, the need for more effective fruit fly control will arise and SIT will invariably be one of the options considered. It is thus important to examine the case for and against the use of SIT against the backdrop of the fruit industry in the Asian region.

In this respect, the use of SIT as a population suppression technique has been suggested by Hooper (1991) who sees no reason why it should not be used as a component of a population suppression program providing it is cost effective. Although it is initially expensive, SIT has the advantages of being target specific, with virtually no untoward environmental side effects. It has, however, traditionally been attempted against a single species in an area. The Southeast Asian region, with its species complexes, poses a great challenge for SIT. A somewhat similar situation exists in Australia, where elimination by SIT of the major pest, *B. tryoni*, could lead to resurgence of lesser known species that occupy the same hosts. The value of SIT unless directed at all infesting species has been questioned under these circumstances (Fletcher and Bateman 1982).

Preharvest Quarantine System

A quarantine system as defined by Armstrong (1991) is a systems approach utilising various individual actions or treatments sequentially so that their combined effects will provide acceptable statistical probability of quarantine security. Examples of preharvest quarantine systems that generally preclude the need for or modify the severity of postharvest quarantine treatments are as follows:

1. Certified non-host cultivars or maturity stages

Host-plant resistance is an important strategy in pest management in other crops that has been given very little attention for tephritids and is a largely underexploited control strategy (Greany 1989). Although fruit flies have a very wide host range, they do not infest certain types of fruits. Durian, for example, is not attacked probably because it has a thick and hard rind that ovipositing flies cannot penetrate. The ripe pulp, however, is capable of supporting larval development (Vijaysegaran, unpublished data). Apart from such physically endowed resistance, other fruits have chemical as well as physical barriers to fly attack.

Citrus

One of the best understood mechanisms of resistance to tephritid damage occurs in citrus fruit (reviews by Greany et al. 1983, 1985). Susceptibility to fly damage is known to vary according to the species of fly, the degree of peel senescence, and the fruit type or cultivar. Relationships between fly oviposition behaviour and the oil content and softness of the peel are discussed by Greany (1989). Some citrus, such as California grown 'Eureka' and 'Lisbon' lemons, are totally resistant and do not host medflies even at commercial maturity (Spitler et al. 1984). Manipulation of resistance using plant growth regulators has been demonstrated (Greany 1989). Many tropical fruits also show varying degrees of susceptibility to fruit fly damage in their native areas. Practically no research has been conducted to exploit host plant resistance in tropical fruits and this is thus a challenging area for the future.

Pineapple

There are no reports of commercially marketed pineapple hosting fruit flies and it has been established in Hawaii that cultivars with 50% or more 'Smooth Cayenne' parentage are resistant to fruit flies (Armstrong et al. 1979; Armstrong and Vargas 1982). Based on its non-host status pineapple may be traded freely between countries and usually does not face quarantine restrictions related to fruit flies.

Banana

Many varieties of banana, even when grown in areas with high endemic populations of fruit flies, are not infested at the mature-green stage. Mature-green 'Mas' bananas grown in Malaysia have been exported for several years without quarantine treatments to Japan. Japan also accepts mature-green bananas from Central American countries where the medfly and several species of *Anastrepha* occur. In Hawaii, the banana cultivars 'Brazilian', 'Valery', and 'Williams', and 'Sharwil' avocadoes are also not infested at the mature-green stage (Armstrong 1983; Armstrong et al. 1983).

Although none of the economic species in Asia or the Americas infests green banana, a species of fruit fly, *B. musae*, which is currently found in southeastern Queensland, Papua New Guinea, and probably in Sulawesi, Indonesia (White and Elson-Harris 1992), does. It is a major pest in these regions as it lays its eggs in mature-green banana (*Musa paradisiaca*) and dwarf banana (*M. acuminata*) (Drew 1982). The eggs hatch as the fruits ripen. The possible spread of this pest to the major banana-growing regions of the world should be considered a serious threat.

Papaya

Papaya is infested to varying degrees by the oriental fruit fly, *B. dorsalis*, in Hawaii, depending on the fruit ripeness (Seo et al. 1982). Mature-green fruit are not attacked and resistance has been related to two compounds that are released from damaged, unripe papayas. These are linalool and benzyl isothiocyanate (BITC) (Seo et al. 1983), the former being quite toxic to the eggs and larvae (Greany 1989). Seo et al. (1983) showed that the latex produced by green papaya is an emulsion of benzylglucosinolate, a precursor of BITC. They suggested that the concentration of BITC was related to the susceptibility of papaya because of its toxicity and deterrence to oviposition. In Malaysia, the cultivar 'Exotika Malaysia' is widely grown and enjoys a good export market. It is often cultivated in areas with high endemic populations of flies, and high quality fruit free of fly infestation is achieved by harvesting just before colour break.

Other fruits

Greany (1989) provides examples of other fruits, including apples, mangoes, and avocadoes, that exhibit varying degrees of resistance to fruit flies. In tropical regions the intensity of fly attack also varies according to the fruit type. Vijaysegaran (1991) listed the intensity of damage for fruit flies to the fruits of major economic importance in Peninsular Malaysia (Table 5).

Fruits such as carambola and guava are very heavily infested (up to 100% crop loss in unprotected situations); others such as banana, sapota, and papaya are only infested when ripe; still others, such rambutan, mangosteen, and langsat, are rarely infested — usually only when they are cracked or ripe on the tree. The export of fresh rambutan and mangosteen faces quarantine restrictions because of these rare infestations. However, it also suggests that there may be good opportunities to select and develop resistant cultivars and determine maturity stages resistant to fly attack, as has been done for bananas. Such resistance would enable production of fruits without the need for chemical and other field control measures as well as export without postharvest quarantine disinfestation treatments.

Although the concept of certified non-host cultivars or stages of maturity is acceptable, the data required to demonstrate quarantine security may be far more difficult to develop and have accepted than a quarantine treatment, and the research data acceptable to one country may not be acceptable to others. For example, Japan accepts mature green bananas without quarantine disinfestation treatments but the USA and Australia do not. Nine years of research was required before the first 'Sharwil' avocado shipment was exported from Hawaii

Table 5. Characteristics of fruit fly damage to fruits of major economic importance in Peninsular Malaysia (Vijaysegaran 1991)

Common name	Scientific name	Host status[a]
A. Non-seasonal		
Carambola	*Averrhoa carambola*	1
Guava	*Psidium guajava*	1
Citrus	*Citrus* spp.	2
Jackfruit	*Artocarpus heterophyllus*	2
Passion fruit	*Passiflora edulis*	2
Soursop	*Anona muricata*	2
Watermelon	*Citrullus vulgaris*	2
Banana	*Musa sapientum*	3
Ciku	*Manilkara achras*	3
Papaya	*Carica papaya*	3
Pineapple	*Ananas comosus*	5
B. Seasonal		
Mango	*Mangifera indica*	1
Cempedak	*Artocarpus champeden*	2
Duku/Langsat	*Lansium domesticum*	4
Mangosteen	*Garcinia mangostana*	4
Rambutan	*Nephelium lappaceum*	4
Durian	*Durio zibethinus*	5

[a] 1 = Severely infested up to 100% in unprotected situations.
2 = Infestation usually light to moderate and can be tolerated but with occasional cases of heavy damage
3 = Severely infested if fruits are left to ripen on the tree. Picking early at the mature green stage overcomes fly damage.
4 = Fruits very rarely attacked except when they are overripe or cracked or damaged on the tree
5 = Non-hosts of fruit flies

without treatment (Armstrong 1991). Clearances given are not permanent and may be reversed for many reasons. Based on about 30 years of inspections of imported strawberries, the USA accepted that they were not a host for medfly but reversed its position in 1983 (Armstrong 1991).

2. Certified fly-free zones or growing periods

Australia is a good example of a country that has several damaging species of fruit flies but is still able to export, to the USA and New Zealand, fruit produced in areas which have been certified to be free of fruit flies. Currently, there are four areas from which fruit and vegetables may be exported under area-freedom certification with respect to the following economic species: *B. tryoni, B. neohumeralis, B. aquilonis, B. musae,* and *C. capitata*. Area freedom is maintained by monitoring and quarantines on host movement. In the event of an outbreak of any of the fly species listed, area-freedom certification is suspended for all fruits and vegetables within an 80 km radius of the infested area for 12 months from the last detection date. Declaration is made if two or more adults are captured within 14 days or if one larva is found in fruit. Eradication procedures based on additional baiting and trap and fruit monitoring are also carried out by government authorities (Horrigon and Patton 1991).

The USA also accepts fruits from Chile without quarantine treatments provided they are from certified medfly-free zones which were established by large-scale insecticide control programs and maintained by approved monitoring/detection protocols (Armstrong 1991).

The concept of a fly-free zone is an attractive one and can be a great asset to fruit production and exports. It must be realised that the establishment and maintenance of fly-free zones involves a great deal of institutional effort with regard to survey, detection, and quarantine, together with adequate procedures for rapidly eradicating outbreaks. Its application to the tropical countries of Southeast Asia needs careful consideration and planning in view of the multiplicity of economic species, their wide host ranges and distribution, abundance of alternative hosts, and the difficulties related to quarantine procedures. Research is presently under way in Hawaii to determine if a fly-free zone can be established using a number of techniques for three species of economically important fruit flies (Vargas and Spencer 1991). This project will be useful to tropical countries as it will determine for the first time if a fly-free zone can be established and maintained in such climates, as well as providing information on the size of buffer zone required around the fly-free zone.

3. Eradication

Most countries that have very successful horticultural industries either do not have fruit flies or have embarked on procedures to eliminate them. A good example is the State of California, USA which has a large fruit industry supported by an extensive fruit fly survey, detection, and eradication service. Adventive populations of oriental fruit fly, medfly, melon fly, and several other species of tropical fruit flies are regularly intercepted and eradicated by State authorities.

Japan has eradicated the oriental fruit fly from all its islands and is in the final stages of eradicating the melon fly from its southernmost islands (Kawasaki 1991). The medfly was eradicated from Mexico (Hendrichs et al. 1982) and the government has expanded this to a large national campaign for the elimination of four native species of *Anastrepha* (Zavala et al. 1991). The medfly eradication program in Guatemala has enabled 57% (62 000 km^2) of the country to be free of the pest and progress is being made towards total elimination (Linares 1991).

Eradication can be achieved by a number of means. Target populations can first be reduced by insecticide cover sprays, bait sprays, or male lures or a combination

of these treatments (Bateman 1982). Multiple releases of sterile males are then made to eliminate the remaining population of wild flies. As horticultural industries expand and contribute more to export earnings the social and political pressure to eliminate the pests will also increase. Both Thailand (Sutantawong 1991) and the Philippines (Manoto 1991) have embarked on pilot projects on the use of SIT. Shiga (1991) has argued that based on the successful eradication programs in Japan, eradication could be considered for tropical regions in Asia, but emphasises the need for basic biological and ecological studies on the various species.

In the tropics the presence of several damaging species and species complexes poses a complex situation and careful planning is required before embarking on any eradication program. The sheer cost and logistics of the exercise will probably be difficult to justify unless the fruit industry being targeted is very large and productive. Despite the formidable challenges to the use of SIT supported by other integrated pest control procedures, the concept of eradication will continue to be an area of consideration for Southeast Asian countries.

Concluding Remarks

Fruit cultivation in the tropics is hampered by a serious fruit fly problem. Recent taxonomic studies, supported by host range and distribution data, show that the oriental fruit fly, *Bactrocera dorsalis*, is more subtropical in its distribution than was previously thought. Eight species in the *dorsalis* complex of flies have been identified as being of major economic significance in the tropics. Some species in this complex are widespread in their distribution while others are currently restricted to certain countries in the Southeast Asian region. Other damaging species not in the *dorsalis* complex (e.g. *B. zonata, B. correcta*) could also spread to new areas.

Despite the presence of a number of highly damaging species, fruit production is made possible in the region through the use of a number of control and population suppression techniques. Using these techniques, either singly or in an integrated manner, fruit growers are able to produce high quality fruit to meet the needs of the domestic market as well as the non-quarantine sensitive markets in Asia and Europe. Export to quarantine sensitive markets such as Japan and the USA is facilitated primarily through the use of additional postharvest quarantine disinfestation treatments. However, such treatments besides adding to the cost of production, are presently available for only very few types of tropical fruits.

Total or partial resistance to fruit flies is exhibited by a number of tropical fruits. Such resistance has been exploited in banana, pineapple, and papaya cultivation. Other fruits such as mangosteen and rambutan are listed as hosts when fully ripe but are rarely attacked earlier. Although fruits exhibiting such resistance may not be accepted by quarantine-sensitive markets, there is great potential for such resistant fruits to be produced and marketed for domestic consumption or for non-quarantine sensitive markets. Host-fruit resistance has been largely neglected and should be given greater emphasis in breeding and selection programs.

A technique of spot spraying with a mixture of autolysed yeast (hydrolysed proteins may also be used) and insecticide has been very successful in carambola cultivation in Malaysia. The technique greatly reduces the application of insecticide, is safe to beneficial organisms, is easy to use, and is effective. This technique should be extended to other countries in the region as it provides excellent and safe control of fruit flies.

Currently fly control in the region is practiced more on an individual orchard basis. Area-wide population suppression programs organised with institutional support should be implemented and will undoubtedly give better control of flies in fruit-growing areas. The concept of eradication and area freedom is appealing and has its advantages. However, in the current tropical environment, the application of these concepts needs careful planning and much basic research.

Based on the experiences of other fruit industries where fruit flies are a problem, the implementation of a postharvest quarantine system (resistant cultivar status, area freedom, etc.) requires many years of research and also faces many difficulties. While working towards these goals, a good strategy for developing fruit industries would be to increase domestic consumption of fruits as well as exports to non-quarantine sensitive markets.

Quarantine regulations in all countries in Southeast Asia and many other countries in Asia currently do not consider the free movement of most fresh fruits between them as posing any quarantine risk with regard to fruit flies. This has most probably been based on the older knowledge and distribution of fruit flies. However, recent taxonomic and distribution studies suggests that the spread of damaging fly species to areas or countries where they do not currently occur is indeed an issue to be considered seriously in Asia and the Pacific. This issue will become more important if and when large area population suppression programs or eradication efforts are initiated. To what extent plant quarantine should and can be practically exercised without creating a barrier to free trade needs an extensive review and is beyond the scope of the present paper.

The ultimate objective of all studies, whether they be in the area of preharvest control, postharvest disinfestation, or taxonomic surveys and detection studies, is to reduce the damage and economic losses in fruit cultivation and to increase the sales and market outlets for fruits. Some of the recent information on the taxonomic status and distribution of economic species may be

viewed as problematical in the short term. However, in the long term development of fruit industries in the region, it is undeniable that this information will form the basis for better decision making and improved control of these noxious pests.

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Disinfestation: Effect of Non-chemical Treatments on Market Quality of Fruit

Krista C. Shellie and Robert Mangan*

Abstract

Changes in fruit quality associated with disinfestation temperature treatments, insecticidal controlled atmospheres and irradiation are reviewed in this paper. A schematic model for the incorporation of fruit quality evaluations during development of disinfestation treatment protocols is also discussed. In general, heat treatments increase fruit respiration rate and result in a reduction of respirable substrates in the fruit. The method of heat application may influence fruit physiological response. Chilling injury commonly develops in tropical fruits as a consequence of disinfestation cold treatments. Pre-treatment temperature conditioning and intermittent warming have been used successfully to avoid development of chilling injury symptoms. Insecticidal controlled atmospheres (0.5–3% oxygen, 5–20% carbon dioxide) at low temperatures have been reported to reduce fruit respiration, delay ripening, maintain flesh firmness and inhibit decay. The effect of irradiation on fruit quality is dependent on the commodity, irradiation dose, and irradiation dose rate. Irradiation appears to delay ripening and maintain flesh firmness in mango. Non-chemical disinfestation treatments can potentially extend marketable shelf life and enhance financial returns, or deleteriously affect fruit market quality, increase spoilage, and shorten marketable shelf life. Fruit quality changes must be routinely evaluated during development of new disinfestation treatments to ensure that the recommended schedules maintain or enhance the market quality of fruit, in addition to providing quarantine security.

FRESH horticultural commodities that are hosts for quarantine-restricted insects and are grown in infested regions sometimes need to be disinfested before being marketed in insect-free areas. Global concern about environmental quality and a heightened awareness of food safety has already eliminated use of the fumigant ethylene dibromide, and will most likely result in loss of the popular chemical fumigant methyl bromide by the year 2000 (USDA 1993). A major advantage of non-chemical commodity disinfestation is that it can prevent introduction of insect pests into insect-free regions without adversely affecting the environment or leaving potentially harmful residues in treated fresh produce.

Quality maintenance of harvested fresh produce is dependent upon conservation of existing energy reserves in the harvested produce, conservation of product moisture content, maintenance of cellular structural integrity, and normal ripening in climacteric fruits. Non-chemical disinfestation treatments can modify postharvest quality and marketable shelf life by altering: commodity respiratory rates or pathways; commodity moisture contents; ripening processes in climacteric fruits; and various biochemical pathways. A review of some of the major physiological changes associated with single, non-chemical commodity disinfestation treatments is presented in this paper. Discussed disinfestation treatments are orientated towards elimination of tephritid fruit fly eggs or larvae located inside fresh horticultural products.

Fruit physiological responses to disinfestation treatments are commodity and often cultivar specific. The physiological response of a particular cultivar may also be modified by season, growing location, or harvest maturity. The large influence of genetic and environmental factors has made quantitative study of physiological changes quite difficult. The wide range of commodity and cultivar tolerance to non-chemical insecticidal treatments has necessitated development of commodity- or cultivar-specific treatment protocols. Our laboratory in Weslaco, Texas, USA develops non-chemical disinfestation treatment protocols for commodities that are a host to *Anastrepha* species. The schematic model followed in our research unit for developing these protocols is presented to illustrate how we evaluate fruit quality while developing treatment protocols.

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Fruit Quality After Disinfestation

Heat treatments

Disinfestation heat treatments can be distinguished from heat treatments for control of postharvest diseases in that the former last longer and thoroughly heat the commodity. Common ways of heating a commodity to insecticidal temperatures include: 1. exposure of the fruit to relatively static heated air that is either water saturated (vapour), dry [<60% relative humidity (RH)], or moist (up to 90% RH); 2. exposure to forced heated air that is either water saturated, dry, or moist; and 3. submersion in hot water at either constant or graduated temperatures.

A relatively static (two air exchanges per minute) heated water-saturated air treatment (vapour heat), first developed in the late 1930s (Balock and Starr 1945), required 8 hours for a commodity to reach insecticidal temperatures. Heat is transferred from the air into the commodity during vapour-heat treatments, by the latent heat of evaporation that is released when the water vapour condenses on relatively cooler fruit surfaces. Total treatment time for relatively static vapour-heat treatment was as long as 16 hours (Couey 1989). A treatment of this duration was not only commercially undesirable, but it also excessively stressed the produce and lowered product quality. As technology became available to increase air speed (2 m/second) within the treatment chamber (Sharp et al. 1991), the length of time required to obtain insecticidal temperature doses has been reduced to four hours or less.

The most desirable disinfestation treatment, from a commercial perspective, is one that heats a commodity to insecticidal levels in the shortest period of time without damaging the commodity. The method by which heat is applied to a commodity will determine the rate at which heat will be transferred into the commodity (Fig. 1). When similarly sized mango, grapefruit, orange, and papaya fruit were either submerged in 48°C constant temperature hot water, exposed to 48°C forced moist air, or exposed to 48°C forced vapour air until the centre temperature of the coolest fruit reached 46°C, heat was transferred into all commodities fastest using hot-water submersion and forced vapour–air treatment. Heat is transferred into the commodity at a slower rate during forced moist-air treatment because the fruit surface temperature remains cooler than during either constant temperature hot-water immersion or during forced vapour-heat treatment (Fig. 2). During forced moist-air treatment, the dewpoint is maintained 2°C below the coolest fruit surface temperature, thus preventing condensation on the surface of the fruit (Sharp et al. 1991).

Faster heating of commodities appears to enhance mortality of *Anastrepha* larvae (R.L. Mangan, unpublished data). The effects of commodity heating rates on postharvest quality have not been well documented. Although constant temperature hot water dips and

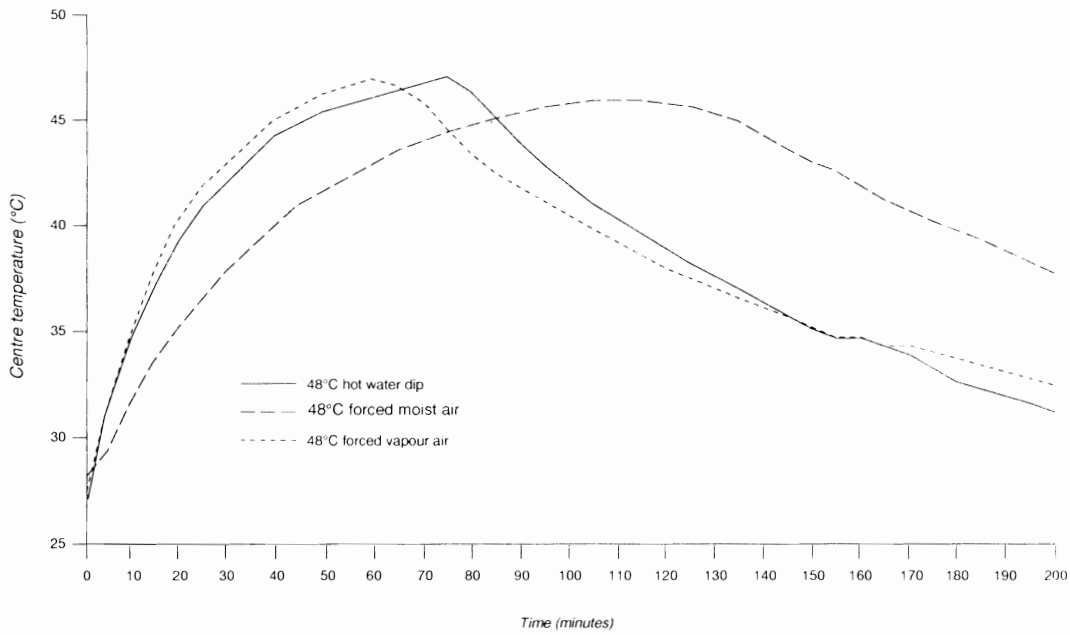

Figure 1. Mango heating rate during hot-water, forced moist-air, and forced vapour-air treatments. Means of 4 runs, with 3 fruit per run.

forced vapour-heat treatments offer shorter treatment times, some commodities cannot tolerate high fruit surface temperatures. Graduated temperature water dips or forced moist-air treatments could be alternative treatments for heat-sensitive commodities (McGuire 1991).

The method by which heat is introduced into a commodity and the dose of heat applied (temperature and duration) are the variables that most influence commodity physiological response. Even though forced vapour air and hot water transfer heat into the fruit at a similar rate, fruit physiological responses are likely to be quite different. For example, when fruit is submerged in hot water, oxygen becomes unavailable for fruit respiration and the internal oxygen concentration may decrease to as low as 4% during a 2-hour treatment (K.C. Shellie, unpublished data). However, during forced vapour heat, the fruit may never become oxygen stressed since oxygen is readily available to fruit tissues. The additive value of reduced oxygen levels in fruit tissues to insect mortality during heat treatments has not been quantified. Neither have the physiological consequences of low oxygen stress during short-term, high-temperature heat treatments been studied in detail.

Not all commodities heat at the same rate when subjected to an identical heat treatment (Fig. 3). Similar sized grapefruit, orange, papaya, and mango were treated in a 48°C forced-vapour air chamber until the centre temperature of the coolest fruit reached 46°C. Even though the papaya and mango fruit were slightly larger than the citrus, the papaya and mango fruit heated at a faster rate than the citrus. Fruit density appears to be related to fruit heating rate. For example, mango and papaya fruit were the more dense (1.03 and 0.91 g/mL, respectively) and reached a centre temperature of 46°C before oranges and grapefruit which were less dense (0.88 and 0.80 g/mL, respectively).

Some general physiological responses of commodities to insecticidal and fungicidal heat treatments have been reviewed by Paull (1990a). Paull (1990a) emphasised that commodity thermotolerance could be moderated by season, growing location, heating rate, fruit size, and maturity at harvest; and that thermotolerance could be related to heat-shock response and presence of heat-shock proteins (Paull and Chen, 1990). Heat-induced senescence (accelerated yet normal ripening) or abnormal ripening are documented physiological responses to heat stress in climacteric fruit (Paull 1990a). A reduction in chlorophyll and chloroplast activity (Chan and Forbus 1988), a reduction in ethylene production (Chan 1986a,b), a reduction in cell wall degrading proteins (Chan and Tam 1982; Paull and Chen 1983), and a disruption in ripening-specific mRNAs (Picton and Grierson 1988) have been associated with heat stress. Electrolyte leakage has been observed to increase following heat stress, implying that cell membranes may be adversely affected (Lurie and Klein 1990). A reduction in titratable acidity attributed to increased fruit respiratory demands during heat treatment has been reported in

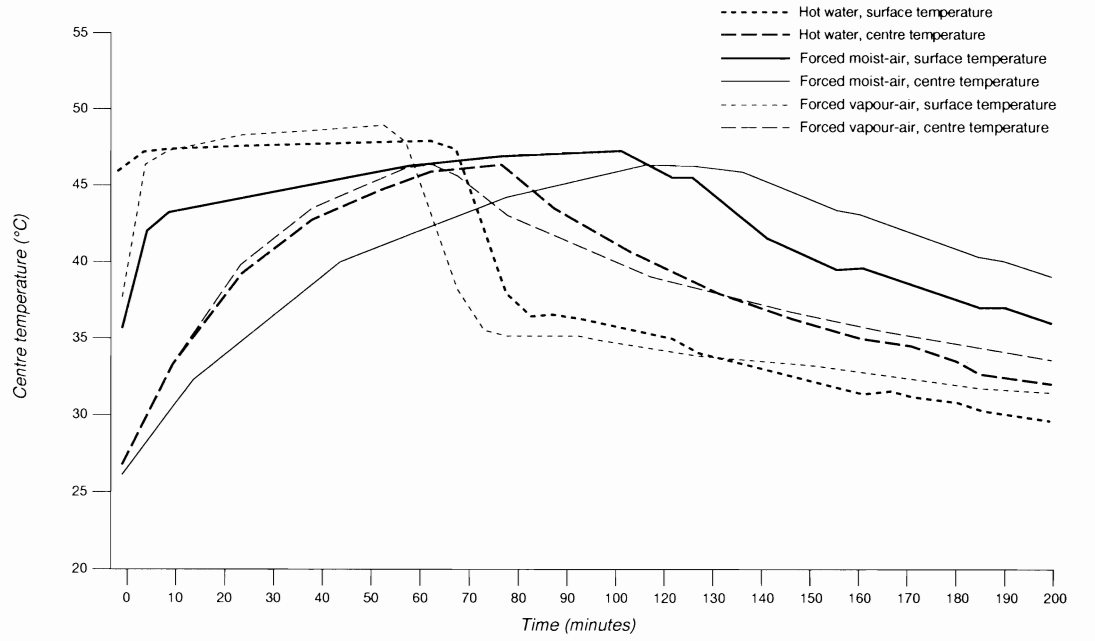

Figure 2. Grapefruit heating rate during hot water, forced moist-air, and forced vapour-air treatments. Means of 4 runs, with 3 fruit per run.

citrus (McGuire 1991; Shellie et al. 1993) and apples (Klein and Lurie 1992).

Heat-shock proteins produced after exposure to temperatures in the range 34–42°C for a short (hours) period, have been reported to alter commodity thermotolerance (Paull 1990a). The heat-stress profile influences heat- shock protein production, again emphasising the importance of heating rates on commodity physiological response. A better understanding of the conditions required to induce production of heat-shock proteins in a commodity, while not providing larvae inside the commodity the opportunity for also acquiring thermotolerance, may lead to optimisation of heat treatments and the maintenance of postharvest product quality.

Cold treatments

A major disadvantage of cold treatments for insect disinfestation is that cold-sensitive tropical and subtropical commodities develop a physiological disorder known as chilling injury when subjected to temperatures below 10 and 4°C, respectively. Cold treatments also involve the storage of fruit for weeks. Long treatment times could cause a marketing bottleneck if the fruit cannot be treated during transit. Mandatory cold storage for insect disinfestation also limits the amount of remaining marketable-commodity shelf life.

The visual symptoms of chilling injury for many commodities have been well described (Paull 1990b), but the physiological changes that lead to the development of visible symptoms are still poorly understood. No single symptom can indicate the presence of chilling- injured tissue (Saltveit and Morris 1990). Commonly observed symptoms include: surface lesions, pitting, scald, and large sunken areas; increased electrolyte leakage; and elevated production of carbon dioxide and ethylene. Climacteric fruits with chilling injury may fail to ripen normally and display accelerated senescence. The stage of fruit ripeness influences the likelihood of visual chilling injury symptom development. Visual symptoms generally appear after the fruit is transferred to a warmer, non-chilling temperature.

Chilling injury symptoms may be alleviated or modified by temperature manipulation or atmosphere modification. Conditioning chilling-sensitive commodities by holding them at slightly above the critical chilling temperature (low temperature conditioning) (Hatton 1990; Wang 1990), or holding them at temperatures known to induce production of heat-shock proteins (high-temperature conditioning) (Klein and Lurie 1992), appears to increase chilling tolerance. Intermittent warming during storage at chilling temperatures also alleviates symptoms of chilling injury (Cabrera and Saltveit 1990). Development of chilling injury can also be reduced by lowering oxygen and raising carbon dioxide levels before or during exposure to chilling temperatures (Forney and Lipton 1990).

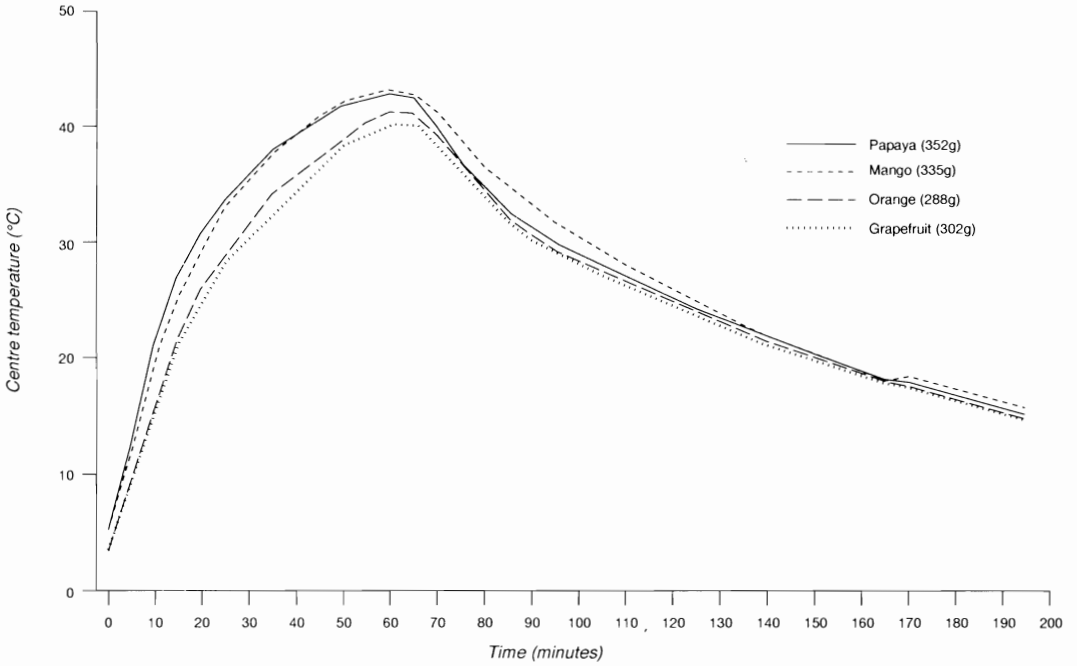

Figure 3. Commodity heating rates during forced vapour air treatment. Means of 4 runs, with 3 fruit per run.

Insecticidal controlled atmospheres (CA)

Insect tolerance to very low oxygen and/or very high carbon dioxide varies according to species. For effective insect control, the oxygen level should be at or below 1%, and the level of carbon dioxide should be between 20 and 30% (Ke and Kader 1991). Increasing the storage temperature during exposure to CA increases insect mortality (Whiting et al. 1991).

Commodity tolerance to CA is quite variable and is influenced by storage temperature, levels of oxygen and carbon dioxide, commodity respiration rate, commodity resistance to gas diffusion, and commodity soluble solids content (Ke and Kader 1991). Exposure to CAs that are within commodity tolerance limits has been shown in general to decrease fruit respiration, decrease ethylene production, and decrease postharvest decay. Symptoms of CA damage include internal or external browning, pitting, off-flavour development, ethanol accumulation, failure to ripen, and increased susceptibility to decay.

Controlled atmospheres combined with cold storage offer little advantage over insecticidal cold treatments to offset their additional costs. The potential for controlled atmospheres as a disinfestation treatment is in combination with moderate heat treatments. Little information is available concerning insect mortality or commodity tolerance to short-term insecticidal controlled atmosphere heat treatments. More research in this area is needed.

Irradiation

A minimum dose of 150 Gy was adopted by the Food and Agriculture Organization/International Atomic Energy Agency International Consultative Group on Food Irradiation in February 1986 for fruit fly of the Tephritidae family (Loaharanu 1992). The criterion for effectiveness of irradiation as a quarantine treatment was determined to be non-emergence of a normal adult capable of flight. Data indicate negligible phytotoxic effects of irradiation at 150 Gy for many commodities. Larger irradiation doses are required to kill eggs or larvae. However, phytotoxicity symptoms start to develop as the irradiation dose is increased.

A major factor limiting the commercial application of irradiation as a quarantine treatment is that at irradiation doses that prevent emergence of a normal adult capable of flight, live larvae still remain inside the irradiated commodity. Port inspectors may encounter live larvae in irradiated produce and have no way of determining at the time of inspection that the encountered live larvae will not emerge as a normal adult capable of flight. Calculating the size of the proventriculus relative to the supraesophageal ganglia was suggested as a potential technique to identify irradiated Queensland fruit fly larvae (Jessup et al. 1992), but this technique has not received official approval. Future research focused on developing a simple, rapid assay that can be performed by port inspectors to quickly distinguish between effectively irradiated and non-irradiated larvae would greatly enhance the attractiveness of irradiation as a quarantine treatment.

Commodity tolerance to irradiation varies according to growing location and season, cultivar, fruit maturity, irradiation dose, and irradiation dose rate (Burditt 1982). Phytotoxic responses to irradiation include surface pitting, surface browning, internal cavitation, and flesh softening (Morris and Jessup 1994). Surface browning has been attributed to increased activity of polyphenol oxidase. Flesh softening has been associated with degradation of pectin to lower molecular weight components. Irradiation doses that do not elicit a phytotoxic commodity response have resulted in extension of shelf life of climacteric fruits by delaying the ripening process (LaCroix et al. 1991).

Fruit Quality Evaluation During Development of Treatments

Our main objective when developing commodity disinfestation treatments is to develop a protocol which ensures no more than 1 in 100 000 survival. However, for a protocol to be commercially feasible, the treatment regime must not adversely affect the market quality of the fruit, or be economically prohibitive. Unfortunately, it appears that commodity tolerance to disinfestation treatments is quite variable. Therefore, the unique tolerance of each commodity must be individually evaluated. In an effort to ensure that treatment protocols are commercially feasible, we evaluate phytotoxicity at two steps during the development of a treatment protocol (Fig. 4). Fruit quality is evaluated during fruit tolerance testing and during confirmatory fruit quality tests.

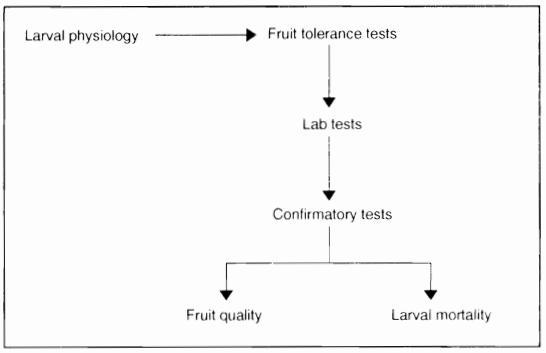

Figure 4. Treatment protocol development

The first step in developing treatment protocols is to identify the physiological limits of insect tolerance to the applied stress. Once this information is known, fruit can be subjected to various treatment doses that are near

the physiological tolerance of the insect. The main objective of fruit tolerance tests is to identify the maximum dose for which the quality of untreated (control) fruit is not significantly different from the quality of fruit treated at various doses near the putative physiological tolerance limit of the insect. The maximum dose for which no significant deleterious quality changes were apparent is selected for treatment efficacy tests with laboratory-infested fruit. Confirmatory testing of fruit quality and larval mortality is the final step in treatment protocol development. Confirmatory quality tests provide the opportunity to verify results of fruit tolerance tests with fruit from a different growing season, location, or with a different harvest maturity.

Fruit tolerance tests

Since small and large fruits may react differently to treatment, fruit should be size-graded into commercial classification of small and large fruit. To allow observation of interactions between environmental growing conditions or fruit maturity at harvest and disinfestation treatment doses, as many harvests as possible, from various growing locations, should be evaluated throughout the growing season. Treated and control fruit should be subjected to cold storage and subsequent storage at ambient temperature to simulate commercial marketing, transport, and retail storage conditions. Shelf life, incidence and severity of decay, and market quality should be evaluated after termination of ambient temperature storage. We evaluate a minimum of 3 replications of each treatment dose, using between 10–25 fruit in each treatment group. The market quality traits we routinely evaluate include: external and internal colour; fruit firmness; soluble solids concentration; weight change after treatment, storage, and ripening; percent titratable acidity; organoleptic traits; and incidence and severity of postharvest decay. External and internal colour is quantitatively measured with a portable Minolta Chromameter using the L* A* B* colour mode. Colour measurements should be reported as lightness (L*), Chroma $[(a^2 + b^2)^{1/2}]$, and Hue $(\tan^{-1} b/a)$ (Little 1975; Francis 1980) A common error that often results in erroneous conclusions is to analyze A* and B* values as independent variables rather than using the interrelated A* and B* values to properly calculate Chroma and Hue (McGuire 1992).

Standard methods are used to measure fruit firmness, soluble solids concentration, weight change, and percent titratable acidity. Fruit firmness is most precisely measured using an Instron, but is commonly measured using the less-precise portable force gauge. Firmness should be reported in Newtons and the type of tip used for force measurements should be clearly identified. Soluble solids content is usually measured using a bench-top refractometer. Soluble solids readings can be influenced by fruit temperature and the part of the fruit from which the sample is obtained. Therefore, multiple subsamples from various locations in one fruit should be pooled and homogenised and the soluble solids concentration of the conglomerate sample should be reported. Many bench-top refractometers have automatic temperature correction, but correction for temperatures above or below 20°C can be manually calculated from available tables. Percent weight change is simply determined by weighing the fruit at various stages during the treatment process, subtracting post-treatment weights from pre-treatment weights, dividing by pre-treatment weight, and multiplying by 100. Percent titratable acidity is expressed as percent of the predominant acid (usually malic or citric acid) after titration of a known weight of tissue with a known normality of sodium hydroxide (usually 0.1 or 0.3 N) (Helrich 1990). Organoleptic traits, such as flavour and appearance, and disease severity can be measured using a hedonic scale and treated as integer level numbers for statistical analysis. Cause of the disease symptoms should also be determined. We conduct untrained consumer preference tests using a minimum of 25 judges per preference panel (Shellie et al. 1993) We randomise the treated and control fruit into numbered stations and ask panelists to evaluate quality characteristics at each station using a 9 cm line scale anchored on the far left with 'dislike extremely' and on the far right with 'like extremely'. The 9 cm line has tick marks every 3 cm to discourage panelists from always marking the centre of each line.

Confirmatory quality tests

The experimental design for confirmatory fruit quality testing is similar to the experimental design for fruit tolerance tests except that the only treatment dose evaluated is the effective dose identified during lab tests. The quality of treated fruit is compared with the quality of non-treated control fruit.

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Proposed Standardisation of Protocols for Quarantine Treatment of Fruit

Nordin Mamat and Mokhtarud-din Husain*

Abstract

Most countries have strict plant quarantine regulations to prevent the introduction and dissemination of new or exotic pests to their countries. These regulations can cause problems to some exporting countries because of the different requirements by different importing countries. To overcome this problem a standard quarantine treatment protocol should be agreed on by both the exporting and importing countries. This paper highlights several recommendations on fruit treatment which should be considered in any plant quarantine treatment protocol. The treatment should be effective against the target pest in the host product and have no adverse effects on quality, storage life, and should not cause physical injuries. Lastly it should not have any harmful residues. These requirements apply to all conventional commodity treatments including vapour-heat treatment, fumigation and irradiation.

QUARANTINE authorities in most countries are empowered to take measures to prevent introduction and dissemination of new pests into their regions. As such, plant quarantine's main task and function is to undertake sanitary measures on a consignment of plants, plant products, or any other media that may harbour plant pests. To prevent the introduction of these pests, some countries have adopted strict regulations applying to the importation of fresh agriculture commodities.

Commodities from countries with quarantine pests, especially fruit flies of the Tephritidae family, must be treated to ensure that such pests cannot be introduced into other territories. Currently, commodities are treated by fumigation, temperature manipulation, modified or controlled atmosphere storage, or insecticide dips, or by a combination of these.

Commodities that are host to quarantine pests may also be acceptable if they meet one or other of the following criteria.

- The exporting country is free from the quarantine pest.
- The commodity is from a fruit-fly-free area. In a country which is known to have fruit fly, an area can be declared as fruit fly free if no fruit fly have been detected in the area (within a 40 km radius) for a period of at least a year. Fruit must be packed and completely sealed in the area and directly exported without stopping in any fruit-fly-prone areas.
- Mature-green stage fruits: Fruits at mature-green stage are not susceptible to fruit flies. Thus, they are acceptable for importation.

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Quarantine Requirements for Export of Fresh Agriculture Commodity

A country or area wishing to export to another area needs to fulfil the quarantine requirements of the importing country. Among quarantine requirements are the following:

1. Data on the species, ecology, and distribution of insects of quarantine significance in an exporting area, specifically those of concern to quarantine authorities of an importing country.
2. Data on the probable level of infestation in commercial marketable fruit at the time of harvest. For example, fruit harvested at the mature-green stage may be resistant to infestation by fruit flies, but vulnerable at half-colour stage. Such fruit may have a low probability of infestation and thus may require a less vigorous disinfestation schedule.
3. Data on life cycles for each pest and the effects of environment (temperature and humidity) upon development. These data may be important when establishing efficacy of treatment methods.
4. Minimising risk of reinfestation during postharvest handling by practising area sanitation in field and packing operations.
5. Providing insect-proof packaging to protect treated product from reinfestation.

6. Data on tolerance of products to combinations of treatment, packaging, and handling and storage systems.

Procedure for Establishment of Plant Quarantine Treatment

The research needed to establish plant quarantine treatments is in two parts. Preliminary or laboratory tests are followed by confirmatory tests conducted under real or simulated commercial conditions. Any treatment proposed must take the following factors into consideration.

1. Effectiveness against target pest species in the host product at expected levels of infestation. Effectiveness is based on 100% mortality.
2. Avoidance of adverse effects on quality and storage life and undesirable changes in chemical composition of commodities.
3. Avoidance of harmful residues or changes in the nutritional qualities of the commodity that will have an adverse effect on consumers.
4. Commodities which are packed before or after treatment must be accompanied with adequate insect control (security) measures to prevent reinfestation.
5. Insects tested should be of species relevant for that particular fruit cultivar.
6. The equipment used in the experiments should be checked regularly so that reliable and consistent results are obtained.

The general steps for establishing a plant quarantine treatment are shown in Figure 1.

Proposed Standard Research Protocols for Disinfestation of Fruits

Aspects to be considered in a standard research protocol are as follows.

Experimental conditions

Selection of fruit cultivar and test insects

Test insects and fruit cultivars should be of the relevant species collected in the particular country.

Mass rearing and immune development study of insects

Mass rearing of the identified pest species and maintaining as high a percentage of hatchability of the eggs as possible. Study and document hatchability of the eggs, rate of development of each immature stage, and the life cycle of the insects. (All immature stages of the pest must be included in the study.)

Use 300 individuals per developmental stage (100 individuals per fruit for large fruits or 50 per fruit for small fruits). At least three replications showing consistent development rate are needed. The fruits chosen must be of equivalent sizes and weights.

Maintenance and calibration of equipment

Equipment used in the experiment must be well maintained and calibrated periodically to ensure reliable and consistent results.

Sample size and replication

The size of the samples varies with the particular test as follows.

- The preliminary disinfestation and injury test requires 1000–1500 individuals per developmental stage per treatment per replicate.
- Commercial disinfestation and injury test requires 3000 or more individuals of the most resistant developmental stage per treatment per replicate.
- Simulation at commercial scale requires 30 000–100 000 individuals of the most resistant developmental stage per treatment per replicate.

All treatments must be replicated at least three (3) times

Treatment conditions

All experimental conditions (preparation of test insects, exposure to temperature, packing, handling of the test material after treatment, etc.) must be standardised.

Data analysis

A probit analysis on the average mortalities in relation to the exposure time and doses must be carried out and the data statistically analysed.

Other conditions

Conditions specific to conventional treatments are described in Appendix I.

Preliminary disinfestation and fruit injury studies

Effective temperature/ doses range

Evaluate effectiveness of a range of temperature/ doses to give 100% mortality.

Identify the most resistant developmental stage of the insects for each treatment method

Test all stages, i.e. eggs, 1st, 2nd, and 3rd instars with 5–7 different doses at different exposure times and temperatures.

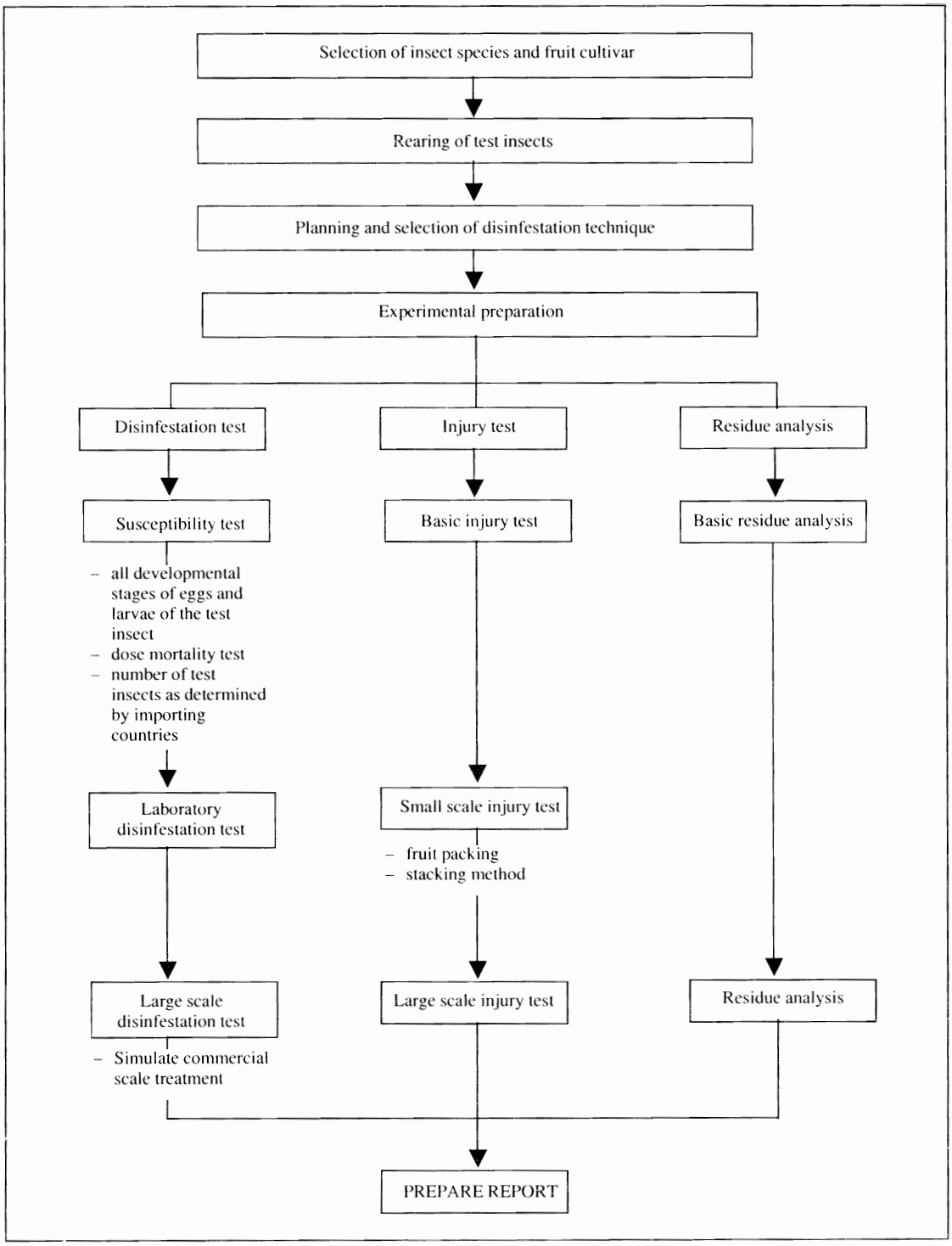

Figure 1. Steps for establishing a plant quarantine treatment

Hot water dipping of naked insect stages (only for VHT)

In physical treatments such as heat, additional studies on the tolerance of naked insects (all stages) to hot water dipping at 45°C are required. Mortality is assessed 24 hours later.

Determine suitable/optimum holding/exposure time required for each treatment method

Reconfirm efficacy of selected dose/temperature and exposure time to induce 100% mortality to test insects

Determine the injury/residue level in the treated fruits

Injury studies must be evaluated at or above 2–2.5 times the minimum dosage that provides quarantine security. At least 30 fruits per dosage/temperature are required. Three sets of data showing the doses and exposure times that cause/do not cause injuries are required. The studies must include the various maturity indices of the fruits, length of time after harvest, treatment temperatures/doses, and storage conditions after treatment. Fruits are analysed for their internal and external appearances, brix, acidity, aroma, taste, and weight loss. Occurrence of diseases before/after treatment is also evaluated.

Commercial disinfestation and fruit injury studies

Confirmation of effective temperature/dose and exposure time

Steps must be taken to confirm that the specific temperature/dose and exposure time satisfy the Probit 8 security level involving a larger number of insects (more than 3000 individuals).

Physicochemical properties of fruit

It must be ensured that the temperature/dose and exposure time do not cause injury to the fruits or exceed maximum residue limits (MRLs).

Simulation commercial scale disinfestation and injury/ residue studies

Confirmation of effective dose

Large-scale tests on the most resistant stage using larger numbers of test insects (30 000–100 000). It must satisfy the Probit 9 security level (99.9968% mortality). The test should be replicated three times. All fruits containing insects are examined by cutting the fruit to check the recovering larvae. (Number of live insects per treatment is compared with the number obtained in the untreated control.)

Reconfirm suitability of the treatment method

Should include studies of efficacy, injury, residues, and cost.

Simulation study to determine adaptability of the treatment

To determine the adaptability of the treatment as an integral component with other postharvest handling procedures (field handling, packaging, transport, storage, etc.). At least 100 fruits per handling procedure or transport, such as by air or sea.

Writing of reports

Results should be reported in a systematic form. The report should include an analysis and evaluation of the results. Appendix II gives further details.

Conclusion

A standard protocol for treatment of commodities such as fruit should be agreed upon between both the importing and exporting country. Once harmonisation of regulations is achieved, i.e. the international standards/ recommendations are accepted by the respective governments, trade barriers are likely to fall, leading to facilitation of international trade in agricultural products.

Further Reading

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Appendix I. Experimental conditions applicable to conventional treatments

Fumigation treatments

1.1 Load factor

All fumigations are conducted with a load factor not exceeding 50% i.e. the fruit to be fumigated occupies less than 50% of the volume of a fumigation chamber.

1.2 Circulation and aeration of air–fumigant mixture

The circulation fans must be operating continuously throughout the exposure period. After fumigation, fruit are aerated until no gas is detected.

1.3 Temperature

The test is conducted at the lowest temperature which is likely to occur at harvesting. Air temperature within the chamber and fruit pulp temperature are monitored using temperature recorders.

1.4 Gas concentration

During commercial disinfestation experiments, gas concentrations are monitored in each test fumigation. Samples are drawn from more than three locations within the chamber and the reading is taken just before introducing and at 0.5-, 1.0-, 2.0-, and 3.0-hour time intervals afterwards.

Vapour-heat treatments

1.5 Temperature

Temperature of the sensor and recorder for each replication of the test should be calibrated, and the testing bath temperature and fruit temperature should be measured on a regular basis.

1.6 Treatment condition

The temperature of the testing bath, the desired fruit temperature at the approximate centre, and the period during which the desired fruit temperature is maintained should be established. These should be based on the results of the basic disinfestation test and the basic injury test.

1.7 Method of cooling

After treatment cool the fruit either by shower cooling or air cooling (fan).

Irradiation treatments

1.8 Pre-irradiation treatment

There are no special requirements for treatment or handling of fruits before irradiation except that fruit trees were planted under good agronomic practises, fruits are of good quality, and that the field heat is removed as soon as possible.

1.9 Packaging

Packaging is normally done before irradiation and material customarily used must be satisfactory i.e. able to prevent reinfestation. The size and shape of containers are determined in part by certain aspects of the irradiation facility, as they relate to dose distribution within the container.

1.10 Irradiation facilities

Facility requirements and operation, process parameters, and critical operational control points should conform with the Codex General Standard for Irradiated Foods and the Recommended International Code of Practice for Operation of Radiation Facilities Used for Food Treatment.

1.11 Ionising radiation

Ionising radiation which may be employed in irradiating fruits is limited to:

a. gamma rays from radionuclides Cobalt-60 or Caesium 137;
b. electrons generated from machine sources operated at or below an energy level of 10 MeV; and
c. x-rays generated from machine source operated at or below an energy level of 5 MeV.

1.12 Radiation dose

Dose measurement, or dosimetry, is important in the control of the irradiation process and to ensure that a prescribed dose is used. Absorbed dose and dose distribution in bulk density of fruits are determined when pre-packaged fruits are irradiated to ensure that the minimum absorbed dose satisfies the quarantine requirement while the maximum absorbed dose is not phytotoxic. Unit for absorbed dose is Gray (Gy).

Appendix II. Guidelines for the reporting of the research protocol

The data obtained from the laboratory should preferably be presented in the following manner:

- name of the experimenter and organisation responsible for the test(s);
- objective of the test(s);
- chemical name and formulation;
- insect pest(s) and fruit cultivar against which tested;
- sample size and number of replicates tested;
- evaluation method and equipment;
- dosage applied and duration of exposure of tested insects and fruit;
- dates of assessment;
- statistical analysis;
- interpretation and discussion on the results of the test(s).

Disinfestation of Tropical Fruit — Session Summary

Chairman: Dr Jennifer Sharp, USDA
Rapporteur: Dr Chris Yuen, University of New South Wales, Australia

In this session, we heard discussions and reviews on:

- nonchemical means to eliminate quarantine pests from commodities, presented by Mr Vijaysegaran on behalf of Dr Neil Heather;
- the effect of treatments as heat on mango quality and disease control, presented by Dr Lindy Coates on behalf of Mrs Keryl Jacobi et al.;
- controlling fruit flies in the field by preharvest field control strategies by Mr Vijaysegaran;
- the effects of irradiation, controlled atmosphere, and temperature treatments on fruit quality, especially for mangoes by Dr Shellie; and
- the need to standardise research protocols by Mr Nordin Mamat

Collectively the speakers targeted pest disinfestation and fruit quality. Disinfestation means quarantine security. Quarantine security is a level of pest control that aims to prevent the establishment of a pest in an area where it is not present. Security is maintained in part by the development of quarantine treatments. Examples of quarantine treatments include:

- temperature management — hot air, vapour heat, hot water, cold temperature refrigeration, dry heat, quick freezing
- irradiation — gamma, electron, and X rays
- microwave — radio frequency
- fumigation — methyl bromide, sulfural fluoride, phosphine
- insecticide dips — dimethoate
- controlled atmosphere — low oxygen, high carbon dioxide, nitrogen
- physical barriers — shrink wraps, packages; and
- systems approaches — pest-free zones, non host, eradication, biological control

Statistically, effective treatments must ensure 99.9968% mortality or no more than 3.2 survivors of a treated population of 100 000 at the 95% confidence level. Realistically, no pest can be found alive in a shipment or load. If a pest is found alive, the shipment risks being destroyed by regulatory agencies. Approved treatments must not damage the condition or quality of the treated commodity, reduce shelf life, or leave harmful residues.

Disinfestation by gamma irradiation of tropical and subtropical fruits has been documented for many major fruit flies (Tephritidae). Data show that <150 Gray will prevent emergence of fruit fly larvae from irradiated commodities. The uniformity of control by irradiation suggests the acceptance (approval) of a generic dose by regulatory agencies worldwide.

Disinfestation by heat at temperatures ≥ 46°C has been documented for many fruit flies infesting papaya, citrus, mangoes, guavas, and carambolas. The uniformity of control suggests the acceptance of a generic heat treatment for Tephritidae.

Disinfestation by cold temperatures 1.1–2.2°C for many days has been documented for many fruit flies infesting citrus, carambola, and lychee. The control suggests the acceptance of a generic cold temperature storage treatment.

Such approved protocols would reduce research costs and allow funds to be used to develop additional treatments. The acceptance of generic quarantine treatments for fruit fly control and the development of generic research protocols for other quarantine treatments were recommended as topics for international discussion.

Contributed Poster Papers

Part 1 — Overview Issues

Postharvest Studies on Some Tropical and Subtropical Fruits in Pakistan

Wasim A. Farooqi*

VARIED types of agro-climatic conditions exist in Pakistan, where fruits of tropical, subtropical and temperate origin are grown. From an estimated area of 456 000 ha, about 3.955 Mt of fruit are produced annually. Out of this produce, 1.609 and 0.776 Mt are citrus and mango, respectively (Anon. 1992a).

Due to inadequate availability of basic infrastructure for postharvest handling, storage, distribution, and lack of technical knowledge, about 20–30% of the produce is wasted between orchard and the consumer, this loss amounting to millions of rupees annually (Farooqi 1990). This loss also robs the growing population of fruit, resulting in malnutrition. Moreover, the quality of exported fruit deteriorates before it reaches its destination, resulting in lower prices on the international market. This situation prompted research on postharvest aspects of fruit, the results of some of which are summarised in this paper.

Application of Postharvest Technology

Effect of low temperature

Refrigeration is the principal means for extending the shelf life of most fruit. However, tropical fruits are sensitive to postharvest chilling if they are stored at temperatures below 10°C (Farooqi and Qureshi 1976; Farooqi 1990). The results of studies on mango and citrus follow:

Mango. 'Samar Bahisht' (Pakistan) and 'Sensation' (USA) varieties of mango were subjected to chilling temperatures (2–8°C) and their effect on the development of skin-injury, time to ripen, taste, and flavour were recorded after transferring to ripening temperature (20±2°C) for 5 days. 'Sensation' mango grown in the Punjab province proved more ($P < 0.01$) chilling sensitive than 'Samar Bahisht' grown under the same ecological conditions (Farooqi et al. 1985a; Farooqi 1989). The peel of mango was more damaged by lower temperatures than was the whole fruit (Farooqi 1986).

Citrus. The effect of low temperature (2°C) on 3 commercial cultivars viz: 'Kinow' mandarin,'Eureka' Lemon, and 'Marsh' grapefruit was studied. After exposure for 3, 6, and 12 days, the fruit were transferred to room temperature (25±2°C) and examined for quality after 5 days.

The results showed that fruit of 'Eureka' lemon was most sensitive to chilling injury followed by 'Marsh' grapefruit and 'Kinow' mandarin. The rate of respiration (evolution of CO_2) and ethylene production of Kinow fruit was enhanced due to chilling, indicating tissue damage (Farooqi et al. 1987a).

Effect of waxing

The effect of waxing on 6 commercial citrus cultivars viz. 'Feutrell's Early' and 'Kinow' mandarin *(Citrus reticulata* Blanco), 'Pineapple' and 'Valencia' oranges *(Citrus sinensis* Osbeck), 'Eureka' lemon *(Citrus limon* Burm) and 'Marsh' grapefruit *(Citrus paradise* Mad.) using three commercial wax emulsions viz. 'Fruitex' (Pak. product), and Britex 561 and SB–65 (U.S. products), was studied during storage at refrigerated and non-refrigerated temperatures. Changes in external appearance, weight loss, respiratory activity (on Kinow only), biochemical constituents such as ascorbic acid, acidity, and reducing, non-reducing, and total sugars, and sugar acid ratio (SAR), were determined (Farooqi 1983). Application of a thin layer (2 µm) of wax on the fruit surface improved the cosmetic appearance of the fruit and helped to reduce weight loss. Waxing also reduced the rate of respiration and ethylene production in Kinow during storage (Farooqi et al. 1988a). Incorporation of antifungal agents in the wax emulsions minimised microbiological spoilage due to *Penicillium* spp. but had no effect on *Alternaria* rot. Waxing created the problem of off-flavour when the fruit was stored at temperatures above 20°C. It was therefore found necessary to tailor the thickness of wax coating to the fruit variety and the temperature expected during storage and marketing (Farooqi 1983).

Chemical modifications

Mango. Thiabendazole (TBZ), benomyl, captan, and antracol (all fungicides) were applied on the fruit by dipping before storage so as to control anthracnose and

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stem-end rot. No significant reductions in these problems were recorded. However, dipping fruit in warm water at 55°C for 5 min. significantly controlled disease incidence (Farooqi 1989).

Dipping hard green-mature mangoes in malic hydrazide solution (1000 ppm) for 2 min. helped to delay the ripening of fruit (Rashid and Farooqi 1984).

Citrus. Dipping of citrus fruit Kinow and Eureka in 2–4 dichlorophenoxy acetic acid (2,4–D) kept the 'buttons' intact and green at concentrations of 500 and 300 ppm, respectively (Farooqi 1983). Application of TBZ at 5000 ppm on citrus fruit was found to control fruit rot due to *Penicillium* spp. The application rate was later reduced to 1000 ppm (Farooqi et al. 1988b). Postharvest residues of TBZ were determined in the peel, pulp, and juice of treated Kinow fruit. After 3 weeks storage, no residue of TBZ was detected from the pulp and juice (Farooqi et al. 1975). However, 3 ppm of TBZ were detected in the peel, an amount falling within limits set by WHO/FAO (Farooqi 1986).

Control of 'black-rot' in stored citrus fruit

During extended storage, citrus fruit become black from the inside. The disease-causing organism has been identified as *Alternaria citri*. The disease is insidious and cannot be detected unless the fruit is cut. Since the fruit appears outwardly sound, affected fruit cannot be sorted out, presenting a serious problem to the fruit trade and juice-processing industry. Most postharvest treatments had failed to control this pathogen 'in vivo' and 'in-vitro'.

Application before storage of an indigenous product, 'antibiotic F' derived from a local strain of *Bacillus subtilis* AECL 69, was found to be effective in controlling this disease (Farooqi et al 1981a; Farooqi 1983). The process has been patented (Farooqi et al. 1988b). The bioactivity of antibiotic F was not detectable in the pulp and juice. It could be traced in the peel for up to 7 days but was undetectable there after 2 weeks. Studies on the control of black-rot using antibiotic F have been carried out on a larger scale with some success (Farooqi and Ahmad 1992).

A study on the influence of pH on the incidence of black-rot in stored citrus fruit revealed that attack by this disease was more pronounced on sweeter than acidic fruit. Citrus fruit should therefore be harvested at an earlier stage of maturity, and not be delayed (Farooqi et al. 1985b,c).

Radio-pasteurisation

Mango. Exposure of hard green mangoes to gamma irradiation (from ^{60}Co) at a dose of 300 Gy delayed the ripening of mango fruit by 5 days during storage at room temperature. At this dose, no phytotoxic effect on the peel of irradiated fruit, loss of any nutritive content or deterioration in taste and flavour was recorded.(Ali et al. 1968; Farooqi et al. 1974a).

Citrus. The effect of radio-pasteurisation on Kinow mandarin at doses of 1–3 kGy was studied. Doses of 1 kGy (100 Krad) and above resulted in phytotoxic problems in the peel of irradiated fruit reducing consumer acceptability (Farooqi et al. 1974b, 1987b). Although other parameters remained normal at this dosage, the treatment could not, because of skin injury to fruit, be recommended for practical use.

Effect of packing

Mango. The effect of 5 types of lining material viz: newsprint, tissue paper, wax paper, cellophane, and polyethylene films 0.098, 0.015, 0.024, 0.030, and 0.030 mm thickness, respectively, were studied during storage at room temperature (Farooqi et al. 1979). It was observed that weight loss of fruit held in cellophane and polyethylene-lined containers was significantly reduced ($P<0.01$) followed by waxpaper, newsprint, and tissue-paper-lined containers. Wooden boxes were more suitable for local marketing, while cardboard boxes were preferred for export trade.

Citrus. The effects of the same types of packaging/lining materials on the quality of citrus fruit were studied during storage at room temperature (20 ± 2°C) as well as in cold storage (5±1°C). The trend of weight loss and its impact on the appearance of citrus fruit were similar to that reported for mango (Farooqi et al. 1979; Farooqi 1983).

Controlled atmosphere (CA) storage

In an experiment on 'Langra' mango, hard green-mature fruit were kept under nitrogen (N_2) for 2 weeks during storage at room temperature (25–30°C). The fruit remained hard green. However, on transfer to air, the fruit failed to ripen normally: patchy softening of pulp with 'off-flavour'. This problem might be due to oxygen (O_2) deficiency. There is a need to carry out research on the effect of CA storage on mango so that its shelf life can be increased, permitting shipment to distant markets.

From Laboratory to the Field and Market

Field and export trials on citrus and mango have been carried out in collaboration with private sector agencies with encouraging results. A summary of the results of these trials follows.

Studies at farmers' field level

Kinow fruit were harvested and divided into 3 lots of 500 each. One lot was treated with a patented process (Farooqi and Ahmad 1981), the second lot was wax-coated using 'Fruitex', and the third was held under normal storage conditions as a control. The 3 lots were kept in the orchard, the grower collecting observations for 3 weeks during storage in a field shed (25–30°C). It was reported that both processed and wax-coated fruit remained in good condition for 3 weeks, as compared with the control, which deteriorated within 10 days. Off-flavours were recorded in waxed fruit. A good external appearance was maintained in the processed fruit and the flavour also remained normal. Therefore, a panel of judges preferred processed fruit over fruit from the other two treatments (Asi et al. 1989).

Studies on export citrus

Ten tonnes of Kinow fruit were processed with the NIAB's patented process (Pak. Pat. 127370) at a commercial grading plant together with other lots treated by conventional means. These fruits were labelled and put in the export chain. Fruit packed in cardboard boxes were transported from the orchard to Karachi port by road (1100 km), then packed in pallets and shipped by reefer container (5±1°C) to Singapore. The trip from orchard to destination took 25 days. It was reported by the exporting agency that the quality of processed Kinow was higher than the other lots at outturn (Anon. 1992b). The indigenous postharvest technology proved more useful for the preservation of Kinow than other techniques used by the exporter (Farooqi 1993).

Studies on export mangoes

During 1990, a pilot scale export trial was carried out in collaboration with GTZ (Germany) and FPCCI (Pakistan). Ten thousand boxes of 4 kg each of 'Sindhri' and 'Sunara' varieties of mango from Sindh were processed, packed in LD containers (20–25°C) and exported by air to Frankfurt (Germany). The processed mango was rated excellent on arrival at the port and therefore fetched premium price in the international market (Farooqi and Qureshi 1991).

Quality of Fruit and Juice

Aromatic compounds

The quality of fruit is dependent not only upon its external appearance but also on its taste and flavour. Flavour is determine by several aromatic compounds. Therefore, volatile compounds of Kinow mandarin and some grafted varieties of mango grown in Pakistan were estimated using a static gas chromatography head space method (Asi et al. 1989).

Mango. The volatile compounds identified were ethanol, ethyl acetate, butanol, hexanol, α–pinene, myrcene, limonene, and an unknown compound. The concentrations of these compounds varied between different varieties, such as 'Anwar Ratol', 'Fajri', 'Malda', 'Desi', 'Samar Bahisht', and 'Langra' and has been described elsewhere (Hussain et al. 1993).

Citrus. The compounds identified in Kinow mandarin and Valencia orange included methanol, ethanol, α-pinene, β-pinene, limonene, linalool and citral. Limonene was found to be the major fraction in both varieties followed by β-pinene and α-pinene. The concentration of citral, the most important flavour-active constituent of citrus oil, was 0.46 and 0.49% in Valencia and Kinow, respectively.

Citrus juice quality

The influence of root stock, time of maturity, juice extraction method, and storage time on the bitterness of juice was studied in Valencia orange. It was found that the root stock, time of maturity, and the storage period had a significant effect on the bitterness (Mahmood et al. 1975; Tariq et al. 1974) of the juice, which is used in making several fruit products.

Quality improvement

Research to improve the quality of existing mango and citrus varieties for better consumer and industrial acceptability has been initiated in NIAB.

Mango. The germplasm of some 60 indigenous varieties has been maintained for screening for better taste, appearance (colour), shelf life, and resistance to insect pests and diseases.

Citrus. The high seed count (25–30 seed/fruit) of Kinow mandarin is one of its drawbacks. Moreover, in the juice extraction industry, the limonin from the crushed seeds makes the juice bitter and impairs its quality. Therefore, research on the induction of seedlessness in Kinow through bud-irradiation has been undertaken and a sparse-seeded (3–5 seed/fruit) material identified for multiplication and commercial exploitation (Anon. 1992b).

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Potential of Value-added Fruit Products in Papua New Guinea

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PAPUA New Guinea (PNG) is geographically suited for the production of most tropical and some temperate fruits because of its wide range of climatic conditions and soil types.

The fruit processing industry has not however developed to a recognisable level in the country because production of most fruits in PNG is currently based at the village level. Production statistics for fruits have been inadequate, assessments being approximate for particular regions. The figures reported often do not include local subsistence level production, especially kitchen garden production, leading to wide variations in national or regional estimates. This is very important, as smallholders dominate the fruit-growing sector in PNG, the majority being subsistence farmers.

Banana is the most important fruit grown because it is an important staple. Pineapple, watermelon, and papaya are other fruit species grown in the food garden. Others such as mango, guava, orange, and passionfruit are largely grown in home-lots or near the houses. There is some commercial production of fruits, that is, production to earn an income rather than production to meet local food requirements, primarily by expatriate farmers and institutions. Some of these have plantations of five or more hectares to supply the formal domestic market at hotels and supermarkets. The Markham Valley Farms in Lae, for example, has some 500 fully bearing guava trees, mangoes, papaya, and carambola.

National Fresh Fruit Production Estimates

Because of the fragmented structure of the food production sector in PNG, it is very difficult to estimate the reliability of the total production of fruits. The 1988 Urban Market Survey gives data on the marketed quantities of various staples, vegetables, and fruits for consumption primarily in the urban centres. Across the country, nearly half of the traded crops in the markets were staples (42%), with vegetables (27%) and fruits (24%) accounting for a total of 29 600 t of produce for 1988. Of fruit (7134 t), mau bananas (1187.8 t), oranges (837.8 t), mangoes (538.8 t), papaya (896.1 t), and pineapples (706.9 t) accounted for 60% of the production.

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Regional Fresh Fruit Production in PNG

A feasibility study on fruit juice production in PNG, completed by the International Food Industry Consultants (IFICON) in 1990, proposed the establishment of three major production centres: Mt Hagen for citrus, Rabaul for mangoes, and Port Moresby for pineapples. This proposal conceals a complex situation which the consultants did not consider and which will eventually lead to the failure of the projects should they be implemented. PNG is mountainous and rugged and includes so many offshore islands; air transport is often the only feasible means of moving goods and people and this is expensive. In addition, fruit trees scattered throughout thousands of forested hectares of land are of little practical value to a processor. The fruit trees must be concentrated on a scale of quality commensurate with processing requirements.

There are no statistics available covering the fruit-growing areas or the production of fruits, but a feasibility study conducted for Morobe Provincial Government (Ihekoronye 1993) showed that the growing areas for fruit, and therefore, the production are expanding. However, the limiting factor for increasing fruit production is that demand for fresh fruit originates only from the fresh fruit markets. At the moment, there are no fruit processing industries in PNG, so the fruits are either consumed by the grower families, traded in the market, or wasted. The fresh fruit market in PNG is an established institution where individual growers market their own produce.

Based on the amount of fruits sold in fourteen urban markets in PNG, Lae market alone accounted for about 36% of a national average production of 7930 t (1992 estimate). Production of fruits in the Markham Valley region and Lae district constitutes 26.6% of the national fresh fruit output, sufficient for a viable fruit products industry in the area, with the additional advantage of allowing processing of all fruits at one plant rather than three different plants at various locations.

The areas of fruit production in the Morobe Province are extensive and involve all districts in the region. Identifiable clusters of fruit growing areas in the province are shown in Table 1. From the list of fruits grown in the area, those amenable to processing and whose supplies could be depended upon are: mau banana, mango, pineapple, papaya, passionfruit, guava, and watermelon.

Table 1. Fruits grown in Morobe Province

1. Lae/Huon District

   Pineapple, guava, passionfruit, mandarin, papaya, mango, banana, rambutan watermelon, cucumber, soursop, lemon, avocado, cashew, laulau, rock melon, tomato, tree tomato, strawberry, blackberry.

2. Kaiapit District

   Mango, pineapple, watermelon, lemon, orange, rambutan, passionfruit, guava, tomato, tree tomato, cucumber, laulau, banana, avacado.

3. Mumeng District

   Papaya, pineapple, watermelon, passionfruit, cucumber, strawberry, tomato, tree tomato, guava, rambutan, lemon, orange, mandarin, laulau, banana, avacado

4. Wau District

   Papaya, pineapple, watermelon, orange, mandarin, tomato, strawberry, tree tomato, guava, rambutan, lemon, laulau, banana, avacado

5. Menyamya

   Papaya, banana, pineapple, avacado, orange, mandarin, tomato, tree-tomato, passionfruit, cucumber.

6. Finschaffen District

   Papaya, banana, pineapple, mango, avacado, orange, tomato, passionfruit, cucumber, watermelon, lemon, laulau, rambutan

7. Kabwum District

   Papaya, banana, pineapple, mango, avacado, orange, mandarin, tomato, passionfruit, cucumber, watermelon, lemon, laulau, rambutan

Table 2 provides estimates of the number of households growing the above food crops and the number of food crop gardens in the area.

The provision of raw materials (fresh, processable fruits) has been emphasised because the supply and cost of fresh fruits are crucial determinants of the profitability of a fruit-processing enterprise.

Strategies for Increasing and Sustaining Supply

1. Provide incentives through credit, input supplies, and a price guarantee scheme and subsidies to encourage farmers in the rural areas to grow at leasts a few additional hectares of fruits for the fruit industry. Table 3 shows a projected five-year production plan from such a scheme given that 10, 5, 8, and 20 contract growers each cultivate 20, 10, 8 and 10 ha, respectively, of pineapples, mau bananas, and guavas.
2. Encourage cooperative organisation among contract out-growers. Problems traditionally associated with cooperatives must be confronted.
3. Establish a sole or nucleus plantation in order to secure a reasonable degree of self-sufficiency within the processing facility. This is an attractive option particularly a nucleus plantation which will supply only a part of the requirement while serving as a demonstration farm from which independent growers could acquire new and improved skills. Table 3 gives the production envisaged from such a farm. The projections made in these proposals are conservative, although achievement of the expected outputs in the respective fruit crops would lead to an almost fourfold increase in the supply of pineapple and papaya to the industry.

Establishing a processing facility without securing the supply of fresh fruit is not advisable. Bearing in mind the objective of securing supply, one would imagine that the ideal solution would be for the factory to own an orchard for 100% of the required quantity of fruits. But many local factors such as availability of land, soil fertility, and risks of pests may mitigate against this in favour of a nucleus estate.

Table 2. Food gardens: numbers of households and gardens, and percentage of food gardens under different crops in Morobe Province, PNG

District/province	Finschafen	Kabwum	Lae	Menyamya	Mumeng	Mutsing	Wau	Morobe
Number of households	9 513	6 046	8 147	9 105	2 800	5 677	3 352	44 640
Number of gardens	50 186	17 330	30 615	19 603	9 719	26 285	12 041	165 879
Banana								
Cooking	85	80	91	98	68	83	53	84
Mau (eating)	60	56	74	52	21	42	73	57
Papaya	71	49	69	14	50	53	30	55
Peanut	7	1	6	5	5	2	25	6
Pineapple	14	15	26	7	13	15	13	15
Guava	4	2	3	3	19	6	7	7
Mango	3	2	6	6	4	9	4	8
Watermelon	4	3	19	2	3	7	6	7

Table 3. Projected production of processable fruit and nuts in Markham Valley and Lae districts; with outgrowers and nucleus estate

Commodity	Quantity (t)				
	Year 1 1996	Year 2 1997	Year 3 1998	Year 4 1999	Year 5 2000
Mango	60.24	60.30	60.36	60.42	60.48
Papaya	1854.80	1859.90	1865.00	1870.14	1875.30
Mau banana	1203.50	1204.20	1205.30	1206.30	1207.40
Guava	330.03	330.04	330.05	330.05	330.60
Pineapple	3407.73	3412.01	3416.42	3420.80	3425.30
Peanut	406.90	413.90	420.50	427.49	441.90
Sunflower seed	225.00	330.05	330.09	330.14	330.18

Market Prices of Fresh Fruits

The price paid to obtain fresh processable fruits has a crucial bearing on the viability of a fruit products industry in PNG. The open market prices for these fruits are related to the fruit season, with peak prices at the beginning and end of the season. Table 4 lists yield and seasonal availability of fruits in Morobe Province. The processor can offer a higher price if the price of his output rises enabling, him to operate within a less rigid financial constraint. Failure to respond to fluctuations in the prices paid for fresh fruits will result in a shortfall of supplies.

Choice of Products

Choice of products is one of the first major decisions that the potential manufacturer has to make. It will be necessary to consider in detail the possible market, the availability and seasonal nature of fresh fruits in PNG, the scale of operation and equipment required, and the availability and cost of technical backup and advice. It is necessary to visit local shops and supermarkets to look critically at the fruit products on sale. Reviewing the import statistics, along with visits to retailers, will give a quantitative as well as a qualitative view of which products are normally consumed.

A very loose estimate of the market capacity based upon statistical information indicates the consumption of 3 million litres of fruit juice drinks, 210 t of jams, and 30 t of marmalade per annum with an import value of 5–7 million kina. The products with greatest potential are therefore:

- Papaya, mango and pineapple juices (also fruit pieces in syrup)
- Fruit jams and jellies based on mau banana, papaya, pineapple, guava, etc.
- Pickled fruits; brined and then subsequently pack-pasteurised in vinegar.
- Fruit chutney based on mango, pineapple, guava, etc.

Table 4. Seasonal availability of fruits in Morobe Province

	Yield (t/ha)	Months before fruiting	Season
Pineapple	35	8	Oct–Mar
Passionfruit	10	6	April–June
Guava	30	13	Nov–Dec
Mango	30	42	Nov–Feb
Papaya	25	13	All year
Citrus	20	40	Feb–May

Scale of Operations

It is very difficult to define exactly the differences between, for example, cottage, small-scale, and medium-scale operations. One cannot think only in terms of output as this will depend on the time it takes to produce a given product. Similarly, statistics such as turnover will depend on the country in question and the final product value. When selecting the scale at which to produce in PNG, there is no clearly defined level of technology in use. Such shibboleths as 'appropriate' or 'intermediate' technology do not apply. However, whatever type of process or equipment is used, it must be appropriate to the needs of the customer and the producer; it must suit the individual situation to allow the processor to make full productive use of the technology.

Labour

Given the technology and supervision required for a fruit-processing enterprise, it is envisaged that the venture would be heavily dependant on expatriate management at the initial development phase. However, local personnel would be trained to eventually assume responsibility for its control. Success in fruit processing in PNG is a management challenge. The task of training personnel to understand industrial processing, to be conscious of product quality and to be aware of hygiene

and contamination is the challenge which will determine success or failure for any enterprise in the country.

Economics and Cost Considerations

Economic and financial analysis provides a practical measurement to assess the profitability of a given project for a given time period and their likely impact on potential investors and beneficiaries. However, in view of the complexity of factors involved within PNG, a detailed explanation of this topic is not possible here. For example, local circumstances make it impossible to compile cost and price data in an orthodox fashion.

PNG Government Policies for Industry and Trade

While it is not possible to describe all these policies here, some of the most significant features are that they support an open economy, a liberal trade regime, and financial stability. They are designed to improve PNG's international competitiveness, as well as promote private sector investment. Industries may be granted both general protection and infant industry protection. General protection may be accorded to both new and existing industries in consideration of their contribution to general economic development, to the socioeconomic objectives of the government (including export growth, import substitution, and employment creation) and to the utilisation of domestic raw materials. Infant industry protection can be given to new industries and to those established in the past four years in order to provide short-term protection against foreign competition. A fruit products industry stands to benefit from these policies.

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The Economic Potential of Interventions to Reduce Postharvest Losses of Tropical Fruits and Nuts in Papua New Guinea

L.B. To Viliran*

PAPUA New Guinea (PNG) is a tropical island country sharing a land border with Indonesia's Western Province of Irian Jaya. It is located near the equator lying between latitudes 1° and 12°S and between longitudes 141° and 169°E.

The climate is generally hot with very high rainfall. PNG is rich in natural resources such as copper and gold, and possesses commercially viable oil and gas reserves. With a land area of 463 000 km^2, 75% of its land surface is covered by rainforests yielding exportable timber (Stein 1991).

Some 85% of the country's population of 3.9 million people directly or indirectly derive their livelihood from agricultural activities, operating in the informal sector and on communally owned land at a subsistence level. There is also a small, modern sector with large farms and plantation-scale production allowing modern industrial processing. Agriculture, being PNG's economic backbone, generates 40% of gross domestic product and around 35% of total exports if forestry products are included (Figs 1 and 2). Stein (1991) reported that approximately three-quarters of the farm population produce one or more of the leading export cash crops — coffee, cocoa, copra, and palm oil, deriving an average of 60% of their cash income from this activity. Cash crops are viewed by most farmers as a sideline or supplement to subsistence cultivation. Production of tropical fruits and nuts has enormous untapped potential for the economy of PNG.

Potential Fruit and Nut Industry in PNG

Production

PNG has a favourable agro-climatic environment with well-distributed rainfall and sunshine. This factor contributes to favourable production of banana, papaya, citrus, rambutan, soursop, durian, mangosteen, pineapple, passionfruit, avacado, lanzone, marang, etc. There is a distinct dry season for the production of, for example, mango, grape, and cashew nut. Lychees, macadamia nuts, longans, custard apples, peaches, apples, nectarines, citrus, and other crops can be cultivated in PNG's tropical highlands and islands close to 20°S latitude. New land for agricultural use is plentiful, as is rural labour.

Table 1 lists some fruits indigenous to PNG. Current fruit production is limited by the absence of infrastructure and services in the remote areas of PNG. Lack of fruit-processing facilities compounds the problem. Nevertheless, PNG has the potential to meet existing limitations in these areas. The domestic market for fruit juices is approximately 3 ML per annum. Table 2 summarises the pattern of domestic consumption of fruit juices. If carbonated soft drinks, juices from imported concentrates, and cordial drinks are added, the actual consumption reaches more than 3 ML (Peipul 1989).

Processing

A case study centering on the Cottees Pty Ltd passionfruit-processing facility in the highlands of PNG illustrates the problems encountered in the establishment of fruit industries in PNG (Vloeberg 1989). Production at the facility gradually increased, reaching a peak of 620 t between 1953 and 1960. However, because of the establishment of coffee gardens, production then gradually declined. General Foods took over from Cottees Passiona in 1970 to save the industry but their interest decreased until the final closure of the facility in 1974. The government then purchased the facility in an attempt to revitalise the industry, but this was unsuccessful. Fresh passionfruit purchases indicate that passionfruit production fell below 100 t in 1979. This case study highlighted passionfruit as one of the few fruit crops with the potential for export (as pulp) and for processing for the domestic market.

There are a number of reasons for encouraging fruit processing in PNG:

- the short storage life and perishability of fresh tropical fruits;
- provision of an outlet for seasonal surpluses,
- fruit import substitution, and associated employment opportunities;
- marketing assistance to growers through price stabilisation; and
- diversification of PNG's exports.

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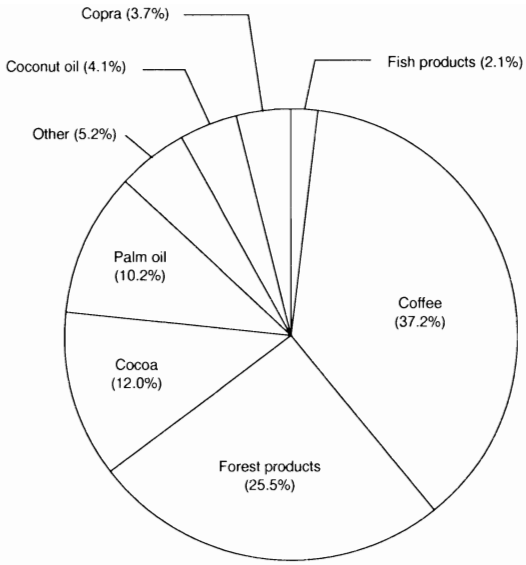

Figure 1. Composition of Papua New Guinea's agricultural exports in 1989. Figures are percentages of total agricultural exports by value. Source: Stein 1991.

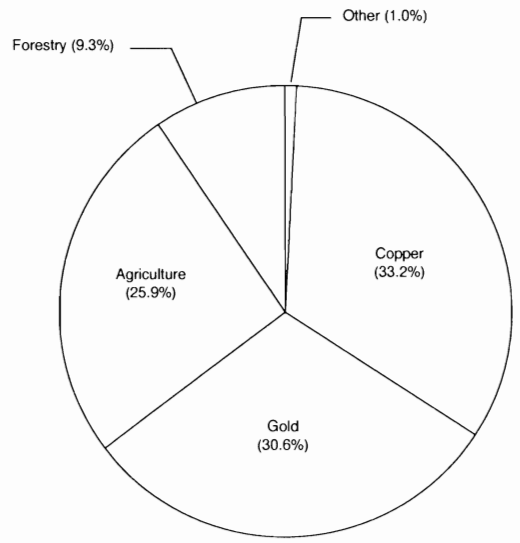

Figure 2. Composition of Papua New Guinea's exports in 1989. Figures are percentages of total exports by value. Source: Stein 1991.

To meet these objectives management in the fruit processing industry needs to overcome problems of lack of technical expertise in industrial processing, and to encourage awareness of product quality, hygiene, and contamination issues. Inventory management requires a good understanding for sustainable processing within seasons and over the full year. Technology (machinery and equipment) must be appropriate and easily operated, and be backed up by readily available spares and service (Peipul 1989).

Proposed Strategies

PNG Department of Agriculture and Livestock (DAL) policy on fruit and nut development reaffirms the need to identify economic alternatives and technical options to replace and/or complement some of the commodities currently produced in the country (Sai'i 1989). The current situation confronting the main export commodities has forced PNG to seek alternatives and make a concerted effort to diversify its economy.

Feasible social and economic strategies need to be established for a fruit industry, together with necessary technological expertise. A comprehensive package must be considered that includes credit lines and a tariff system to provide incentives to the sector. Technological expertise can be drawn not only from developed countries, but also from countries such as Thailand and Brazil which have developed successful fruit industries. A tariff system is also needed to provide incentives for capital needed. Equipment must be imported to develop the industry. The government must accept this as one of its roles in facilitating the industry. The credit system operating in PNG should be directed toward supporting the establishment of a fruit industry. The banking system must accept the fact that diversification and new industries require innovative financing with a long-term outlook and a willingness to introduce a credit-line to meet the demands. A full comprehension of the overseas markets, demand/supply, seasonality, quality, pricing, and quarantine regulation is also needed. PNG has yet to provide an indication of its ability to compete with major export countries taking into account the current efforts being made in the local fruit and nut industry. The development of sophisticated marketing techniques by highly competitive exporting countries is a challenge to PNG.

There is potential for the establishment of a nut industry in PNG including cashews, macadamias, and especially some of the native nuts such as okari (*Terminalia kaernabcii*) and galip (*Canarium indicum*). Galip and okari nuts are gathered throughout the lowlands. The opportunity for PNG to participate in the nut industry is favoured by the high demand on the world market for cashew nuts which has driven the price to US$6–7/kg of kernel. The latest fruit and vegetables import figures of approximately 1400 t per annum do not fully account for total consumption. Marketing therefore is one of the main constraints affecting any potential expansion in this area (Sai'i 1989).

Table 1. Some indigenous fruits of Papua New Guinea

Species	Name	Distribution
Baccaurea papuan	Mabewa	Lowlands; 2 cv. at Kerevat
Burchella obovata	Bukubak	New Britain; 1 cv. at Kerevat
Bridelia tomantosa	Aruais	Western Province
Citrus polyandra	Citrus	Manus, New Ireland, Coastal, 1 cv.
C. papuana	Citrus	at Aiyura
Microcitrus warburghii	Citrus	Lowlands
M. daileyii	Citrus	Lowlands
Conyoncarpus cribbianus	Mundroi	Manus Islands
Uracontomelon dao	New Guinea walnut	Coastal areas
Ficus copiosa	Fig	Widespread
F. dammariosis	Fig	
Flacourtia inermis	Lovi-lovi	Coastal areas
Mangifera fortidea	Mango	Widespread
M. minor	Mango	
Parinari nonda	Engam	Lowland forests
Pormetia pinnata	Taun	Lowlands
Rubus fraxinifolius	Red raspberry	Highlands
R. moluccanus	Red raspberry	Highlands
R. rosifolius	Red raspberry	Highlands
Spondias cytherea	Golden apple	Lowlands, 1 cv. at Kerevat
Syzgium aquem	Rose apple	Lowlands
S. jambos	Rose apple	Lowlands
S. malaccensis	Laulau/Malay apple	Widespread
S. samarangense	Water apple	Lowlands

Source: French 1986.

Table 2. Domestic fruit juices distribution

Flavour type	Percentage (%)
Orange	40
Grapefruits	2
Other citrus and mixtures containing citrus	10
Pineapple	9
Tomato	3
Apple	7
Grape	1
Mixes of fruit and/or vegetable oil	9
Single flavour and mixes other than those containing citrus	18

Source: Peipul 1989.

PNG has an agronomic advantage in being able to cultivate a wide variety of fruits. In the Highlands region citrus is cultivated, mango in the New Guinea Islands region, and pineapple and mango in the Papuan region. With the current low prices for the four major export commodities on the world market, diversification becomes necessary by creating new skills as well as employment. Though PNG is not self-sufficient, there is an opportunity for import substitution. The Department of Trade and Industry (DTI) sees the fruit juice industry as worthy of support. The recognition of this potential, together with the interest of local investors, has prompted the determination by the DTI in seeking possible development of this industry on a commercial scale (Peipul 1989). In 1988, PNG imports of fresh or dried fruits and nuts, fresh and preserved fruit, and fruit preparations totalled 56 500 t, valued at 4.6 million Kina (1 Kina ≈ US$1).

Constraints

There are various constraints to the growth and development of the fruit and nut industry in PNG. Poor infrastructure, fragmented market, inadequate and expensive transport and communication, lack of adequate skills and local entrepreneurship are difficulties to be overcome. Another constraint to development is PNG's rugged geography, which limits land available for agriculture. Another stumbling block lies in the rights to land use. Stein (1989) reported that 97% of the land is commonly owned, with proprietary interests being vested in groups with customary claims to specified sites. There are limited individual rights to land use, which discourages land improvement measures by farmers and, even where an investment demand exists, their financing.

Conclusions

DAL and the agricultural sector see diversification of the economy as an urgent alternative to an increasing unemployment problem and lack of commercial opportunities for smallholders. Fruit processing is one area that could be promoted. Nucleus estates could be established, in order to guarantee supply, supported by research assistance in production, processing, and pest control. A marketing strategy is also needed. An integrated approach is needed to the development of a fruit and nut industry in PNG.

Acknowledgments

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Aspects of Marketing of Tropical Fruits in Temperate Climates

Rajat Roy*

TROPICAL fruits and vegetables are now readily available in Britain. The outlets are both the large supermarkets and the 'corner' shops owned by members of the immigrant communities. The following are some of the tropical fruits sold, their country of origin, and their prices in supermarkets:

- Cape gooseberries, Colombia, 99p† per quarter pound (112 g)
- Kiwifruit, North Africa, 59p for four
- Lychees, South Africa, 84p per half pound (225 g)
- Passionfruit, South Africa, 59p for four
- Small papayas, Kenya, £1.19 each
- Mangoes, Kenya, £1.09 each
- Persimmons, Israel, 25p each.

The Need for Quality Standards

Some other fruits available are mangosteens, kumquats, and guavas. The prices being asked are much higher than in their country of origin. One accepts that the cost of transportation to and distribution in Britain is a factor responsible for higher prices, but the consumer has a right to expect products of consistent high quality compatible with the prices being asked. At the present time, this quality is not always in evidence. The lack of marketing information from the original supplier on standards of quality and specifications is matched by the ignorance of some consumers on expectations of flavour, size, texture, modes of consumption, and what are reasonable prices to pay.

Supermarket Systems

Some of the supermarkets do, however, now have commendable systems of monitoring quality, and provide consumers with information on the fruits. Sainsburys, one of the largest supermarket chains in Britain, has this to say about the provision of information to consumers:

> ... you can imagine that the controls of fruit quality from source to our stores is critical if we are to give our customers the best quality product with respect to flavour and shelf life.

In furtherance of this aim, the following are some of the critical control points monitored by Sainsburys.

- Sourcing — use of correct country
- Agronomy — check agronomic practices as regards varieties, harvesting methods, and modes of transport
- Postharvest handling — time and temperature of transport
- Shop display — date coding
- Consumer education — display materials.

To ensure that such controls are in place, codes of practice and specifications are agreed to with suppliers.

Tesco's, another leading supermarket chain, insists on implementation of codes of practice and specifications with the original supplier. The parameters of such specifications are appearance, internal condition, organoleptic qualities, labelling, packaging, and weights or counts. Further, Tesco's technologists liaise with suppliers regarding sourcing, seasonality, and varietal changes. For tropical fruits they concentrate, in particular, on the following aspects.

- Harvesting — monitored in relation to transport and readiness for consumption at point of sale; they claim that consistent maturity at harvest is critical as variability means longer periods of storage.
- Temperature control — fruits vary in the temperature and humidity of maturation. Accelerated ripening tends to reduce shelf life.
- Spoilage and wastage — they ensure that the vast majority of spoilage and wastage occurs before the fruits are accepted from the supplier.
- Guidance to consumers — this is by pamphlets suggesting uses and modes of storage and consumption in the home.

An example of specifications for a particular fruit — papaya from Jamaica — are: appearance, grades, sound clean, firmness, shape, and colour. Other quality parameters are maturity, texture, ripeness, and flesh and skin colour, absence of defects such as pests, chemical residues, extraneous matter, and chill damage to flavours. There are also important provisos regarding temperature control, date coding, packaging, and labelling.

Other, smaller supermarket chains have similarly agreed with suppliers specifications of varying detail based broadly on parameters of appearance, internal conditions, organoleptic criteria, labelling, packaging,

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† 100p = £1.00 = ca US$1.55.

and weights or counts. All supply sources are required to work to detailed codes of practice for hygiene and quality control.

The Corner Store as a Supplier

Nevertheless, only a section of the population purchases its tropical fruits and vegetables from supermarkets, and is thus able to buy fruits of quality with good shelf life and acceptable organoleptic properties. Those consumers who buy their tropical fruits and vegetables from corner shops have no guarantee of such quality. Indeed, some of the fruits will have long passed their 'use-by' date and be of dubious quality. For this substantial group of consumers, one requires codes of practice and specifications to be observed by original suppliers. They must instigate quality monitoring systems at all stages of distribution if they are to maintain markets in temperate climates. This is the only way they can ensure that the whole population is given a choice of quality tropical fruits, and that they will meet the imminent legislative standards in the European Community.

Requirements of Suppliers

Further, these codes of practice and specifications will refute the uneducated charges of unhealthy quality by some of the press and consumer organisations about imported tropical fruits and vegetables. The suppliers must produce codes of practice, especially hygiene ones, and issue specifications on aspects of harvesting, criteria of selection, methods of transport, expected shelf life, and recommendations on storage.

Transport will be an important factor, as distances to be covered will be great. The method of transport — chilled, controlled atmosphere, or ambient — will have considerable influence on the organoleptic quality and the shelf life of the products.

Applied technological research on such aspects as accelerated ripening in the country of sale is imperative. Not all tropical fruits will respond to the same conditions of accelerated ripening. The criteria to be used for 'sell-by' or 'eat-by' dates for fruits sold from shops that have no facilities for storage, chilled or ambient, need to be determined. Packaging of tropical fruits is another area that requires applied research. The type of packaging and its influence on ripening and ultimate quality of the products, as well as the economics of packaging tropical fruits require investigation. Sainsburys believes that films with varying rates of gaseous exchange will influence fruit maturity and control flavour.

The results of applied research by original suppliers and wholesale importers should provide small shops with simple guidelines on modes of display, coding, stock rotation, and criteria for rejection. Incentives, such as Tesco's point-of-sale guarantee of sweet taste on papayas and ripe and ready-to-eat avocados, coupled to money-back offers.

Extensive research must continue on aspects of ripening of fruit to ensure that customers can purchase fruits at their optimum. Transport in CA or MA containers would reduce the use of postharvest chemicals. Monitoring the product from growth to the ultimate consumer is essential if one is to sell a quality product at a price that the consumer will readily buy.

The market for tropical and subtropical fruit and vegetables has vast potential in Britain and Europe. This potential can be realised only if tropical suppliers can market quality products to informed consumers at prices they can afford. The prospects are infinite.

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A Multivariate Factor Analysis of Consumer Preference on Banana Attributes

Md. Yunus Jaafar and Raziah Mat Lin*

THE banana has long been accepted as an edible tropical fruit in Malaysia. However, further research is needed on banana fruit marketing. This study aimed to identify postharvest banana quality attributes that influence consumer purchasing decisions. Data collected were subjected to multivariate factor analysis.

Description of Methods

The cross-sectional study utilised a stratified random design (Yates 1981; Cochran 1977) for data collection. The study was conducted at four randomly selected major towns in Peninsular Malaysia: Kota Bharu (eastern region), George Town (northern), Kuala Lumpur (central), and Johor Bahru (southern). The sampling units (respondents) were patrons of shopping complexes. Two shopping complexes were randomly chosen from the available listing at each town. The respondents included clients, customers, shop owners, shoppers, and workers. A sample of 321 respondents was surveyed. The sample size (Snedecor and Cochran 1980; Gomez and Gomez 1984) was estimated based on the quantitative measurement from a pilot survey.

The postharvest attributes examined included fruit shape, size, cosmetic (colour) appearance, detachability, peeling quality, flesh colour, aroma, taste, and texture. Data were collected through personal interviews. The respondents were interviewed employing a Likert's scaling precoded questionnaire (Rosenthal and Rosnow 1991) compatible for computerisation on an IBM® computer. The responses were precoded in Likert's scaling (1 = not important at all, 2 = not important, 3 = indifferent, 4 = important, and 5 = very important).

The attributes characterising the consumer preference on the banana were assessed using a multivariate factor analysis (Gorsuch 1983; Dillon and Goldstein 1985). SAS package PROC FACTOR (SAS Institute 1985) was utilised in data analysis.

Multivariate Factor Analysis

As an exploratory and confirmatory statistical technique, multivariate factor analysis (FA) is a data reduction technique for investigating interdependencies among the variates (attributes in our case). The technique attains a parsimonious description of the preference on observed attributes. It describes the covariance relationship among many attributes in terms of a few underlying but unobservable random factor dimensions.

The factor model is

$$X_j = a_{j1}F_1 + a_{j2}F_2 + \ldots + a_{jm}F_m + \varepsilon_j$$

where 1, 2, ..., p (observations) and X_j are the attributes, and a_j are the weights, factor coefficients, or loadings. Each of p observed attributes is described linearly in terms of m ($m < p$) common factors, F_m, and a residual or specific unique factor, ε_j. The number of attributes should be less than the number of observations. The specific factors are uncorrelated with each other. The hypothetical unobserved common factors are orthogonal with each other. The common factors are orthogonal to the specific unique factors; and each has a multivariate normal distribution. The measurements are standardised and common factor components all have zero mean and unit variance.

The eigenvalue (λ_j), of greater than one criterion, associated with each factor dimension is of decreasing order; and this parameter determines the number of factors to extract. The first factor dimension is accounted for by the largest variance, the second factor component with second largest and so on. The eigenvalue is a proportion of variation explained by linear combination of the attributes on the dimension. Factor loadings (a_{ij}) in factor structure matrix, relate the unobservable factors to the attributes.

The significant attributes contributing to the linear factor models are indicated by the magnitude of the loadings. The greater the value of the loadings ($a_{ij} > 0.50$) the more significance of the categorical attributes. Principal factor algorithm was used to extract factors and estimate parameters. To preserve the original uncorrelated orientation between factors, and to help uncover the distinct nature of the loadings, a varimax orthogonal factor rotation procedure was employed.

Results and Discussion

The results of data analysis (Table 1a) show that only one factor dimension has eigenvalue greater than one

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($\lambda_i > 1.0$) i.e. factor 1 with eigenvalue of 2.68 accounts for 84% of the total factor variance. Table Ib contains the loadings of the extracted factor models. This table indicates that factor 1 is moderately loaded ($a_{ij} > 0.50$) on ripeness attributes of taste, peeling quality, fruit detachability, and texture, while having relatively low weights ($a_{ij} \leq 0.50$) on cosmetic appearance, flesh colour, aroma, and fruit size and shape. The ripeness attributes have significant influence on consumer's purchasing preference for the consumption of fresh banana. Similarly, the physical attributes of the fruit shape and size are loaded heavily ($a_{ij} \geq 0.80$) on factor 2 which, nevertheless, accounted for only 25% of the variance of the factor models. Factor 1 is a ripeness factor and factor 2 is characterising a physical factor. Figure 1 shows that factor 1 categorises the ripeness dimension with the attributes related to ripeness lying very close to the axis of the factor. Also, it shows that the physical attributes load very closely to factor 2. Thus, the ripeness attributes significantly categorise the preference behaviour among the consumers, based on the cross-section surveyed.

Table Ia. Eigenvalue and accounted for variance estimated by principal factor algorithm

Factor	Eigenvalue	Accounted for variance	Cumulative % of total variance
1[a]	2.68[a]	0.84[a]	0.84
2	0.80	0.25	1.10
3	0.30	0.09	1.19
4	0.20	0.06	1.25
5	− 0.08	− 0.02	1.23
6	− 0.13	− 0.04	1.19
7	− 0.17	− 0.05	1.13
8	− 0.19	− 0.06	1.07
9	− 0.22	− 0.07	1.00

[a] Factor 1 is significant with eigenvalue greater than 1 and accounted for variance more than 80%.

Table Ib. The loading of extracted factor dimensions on the rated importance of attributes influencing consumers purchasing decisions on banana

Extracted factor and loadings (a_{ij})[a]		Attribute
Factor 1	Factor 2	
0.54	− 0.01	Taste
0.54	0.18	Peeling quality
0.53	0.35	Fruit detachability
0.51	0.17	Texture
0.50	0.34	Cosmetic appearance
0.50	0.14	Flesh colour
0.41	0.12	Aroma
0.21	0.80	Fruit size
0.14	0.80	Fruit shape

[a] Loadings > 0.50; higher loading 0.51 < a < 0.79; heavy loadings > 0.80.

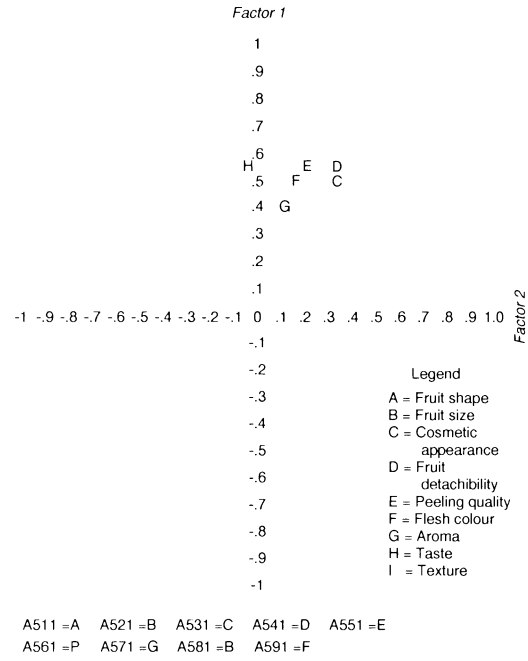

Figure 1. Plot of factor pattern for Factor 1 and Factor 2

Conclusion

The multivariate factor analysis on the cross-sectional data categorises that the banana quality attributes preferred by consumers constitute ripe fruits, sweet taste, easily separable skin, easily detachable fingers, soft texture, and yellow skin colour. These attributes are significant among consumer preferences in purchasing bananas for fresh consumption, whereas physical attributes have a weak influence on purchasing decisions.

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Part 2 — Maturity Assessment

Determination of Maturity Indices for Sri Lankan Embul Bananas

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BANANAS are the most widely consumed of all fruits grown in Sri Lanka. The Embul variety is one of the two predominant varieties grown for the domestic market. This variety is less susceptible to disease (Simmonds 1966) and is therefore more suitable to commercial production for specific export markets where a growing demand for speciality bananas has been observed.

The traditional method of assessing maturity and time of harvest via the criterion of loss of angularity of fruits leads to heavy postharvest loss. Mature-green fruits are firm and therefore better able to withstand the postharvest handling procedures required by commercial operations. However, little information is available on fruit development in these thin-skinned varieties.

Thus, this study was initiated to determine maturity indices, observe fruit development, and identify the most suitable stages of maturity at which Embul bananas may be harvested for domestic as well as overseas markets.

Correlation between age of fruit and physicochemical properties during fruit development has been established with selected commercial varieties such as Cavendish. Fruits of thick-skinned varieties are harvested according to age via tagging procedures in many commercial plantations (Sommer and Arpaia 1992).

Physicochemical observations from this study indicate that Embul variety bananas reached physiological maturity 9–10 weeks after the opening of flowers, while growth and development of fingers progressed over a 13-week period. The response of fruits to storage at 13.5°C was examined when harvested at the 9, 10, 11, 12, and 13-week stages of maturity.

Materials and Methods

Five sample bunches of Embul variety bananas were harvested at different stages of maturity from five plantations at Embilipitiya, and transported to the PHTU laboratory, CISIR, Colombo, on the same day. Healthy bunches were selected for the trials, which were repeated three times over a period of two years. Maturity of bunches was determined by a method of tagging, which commenced with the emergence of the second hand. The bunch was considered to be 1-week-old at this stage (Hurlston 1991).

Representative samples were harvested from each plantation over a period of 13 weeks. The second hand of each sample bunch was removed. Three fingers were used from the centre of each hand, to determine physicochemical properties.

Firmness of fruits with and without peel was measured using a Labsco electropenetrometer. Specific gravity of fruits was determined. The mean weight of the fruit and peel were obtained by computing the mean of 15 random observations at each stage of maturity, as were the mean curvature observations. A cross-section of the central region of each sample fruit was drawn for observations on angularity, diameter, and shape of the fruit.

A filtrate was prepared from each sample by crushing 5 g pulp with 20 mL distilled water, and used to determine total soluble solids, pH, titratable acidity, and starch content.

Samples of fruits harvested at the 9,10,11,12, and 13-week stages of maturity were selected for storage trials. Samples for the study were obtained from the second and third hands of six bunches for each stage of maturity. Bunches were dehanded and dipped in a 1% alum solution for 20 minutes. Crowns of hands were treated with a solution of 10 ppm benomyl in water, and packed in ventilated cardboard cartons before storage at 13.5°C for 21 days, followed by storage at ambient temperature for 6 days. Controls were held at ambient temperature for 6 days. Six replicates were used in each case.

The physicochemical parameters mentioned earlier also included observations on colour and flavour development after low-temperature storage.

Results and Discussion

Physicochemical properties of Embul variety banana as observed during fruit development are summarised in Figure 1. While fruit weight increased considerably between weeks 10 and 11, fruit curvature, pulp-to-peel ratio, diameter, and starch content showed considerable increases between weeks 8 and 11.

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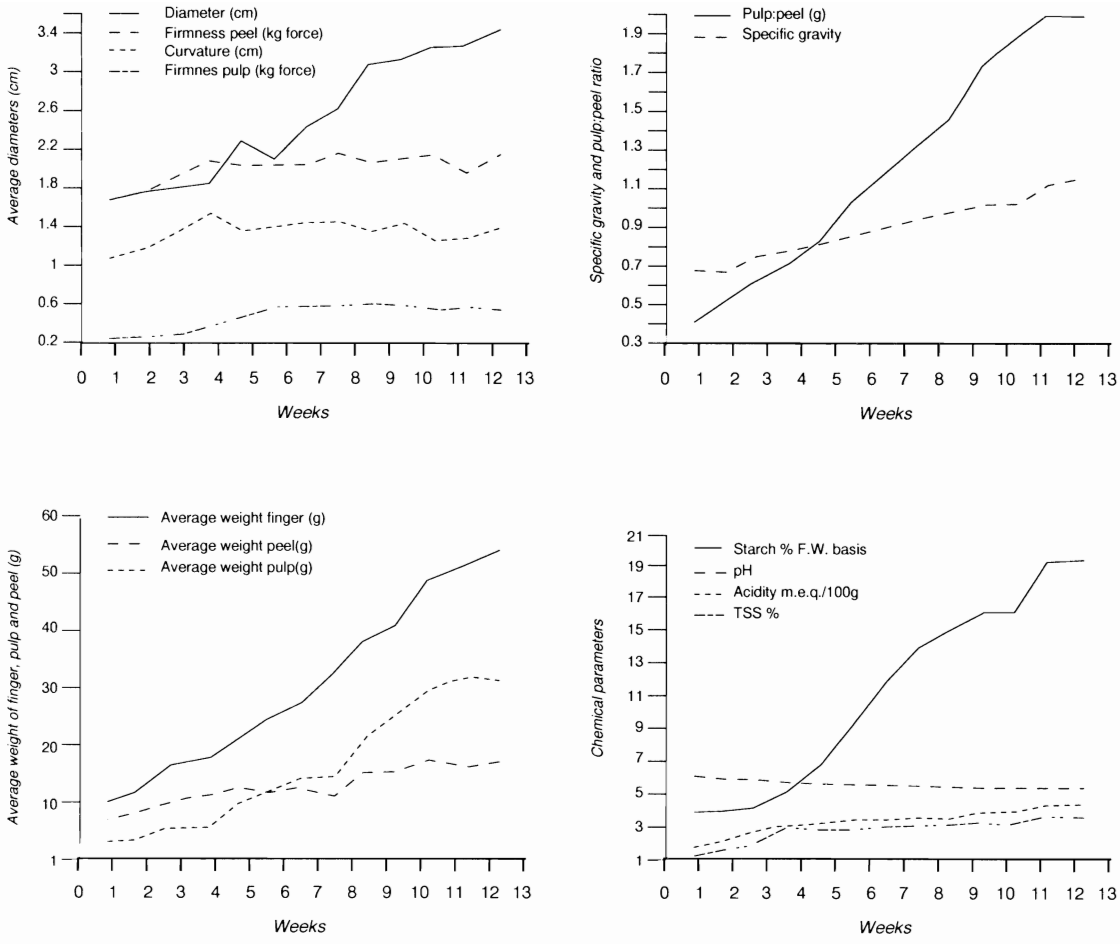

Figure 1. Observations on physicochemical properties of Embul bananas

Observations from the storage trial are presented in Table 1. Fruits subjected to low temperature storage were not observed to be different at the 5% level of significance with respect to flavour, although colour development was slower when compared with controls held at ambient temperature. The difference in total soluble solids, total acids, sugar content, total carbohydrate content, flavour, and colour development at the five stages of maturity was confirmed via Duncan's Multiple Range Test at the 1% level of significance, for both storage conditions. No difference was observed with respect to these parameters at harvest, as confirmed by an analysis of variance at the 5% level of significance.

Results from this study suggest that physiological maturity of Embul variety banana occurs between the 9 and 11-week stages of maturity. Harvest for commercial operations may be recommended at the 11-week stage for long-term, low-temperature storage, while fruits for air freight to export markets may be harvested at 12–13 weeks. The latter stage of maturity would also be acceptable for most domestic markets.

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Table 1. Observations on storage trial with Embul variety harvested at different stages of maturity.

	At harvest					After 6 days at 28°C[a]					After 21 days cold storage and 6 days at 28°C[a]				
	Stage of maturity (weeks)					Stage of maturity (weeks)					Stage of maturity (weeks)				
	9	10	11	12	13	9	10	11	12	13	9	10	11	12	13
Brix (%)	2.45	2.50	2.50	2.60	3.00	7.00c	12.0b	15.0b	20.0a	20.0a	8.0c	13.0b	18.0a	20.0a	22.0a
pH	5.83	5.74	5.77	5.41	5.53	5.03	4.66	4.50	4.48	4.43	4.6	4.52	4.42	4.38	4.33
TA (m.e.q.%)	1.90	2.10	2.20	2.60	2.80	4.60c	4.50c	4.80b	5.12b	5.8a	5.0b	5.12b	5.30a	5.32a	5.45a
Sugar (%F.W. basis)	1.50	1.59	1.57	1.63	2.04	6.11c	11.3b	14.0b	19.1a	19a	7.1c	12.1b	17.1a	19.1a	21.1a
Carbohydrate content (% glucose)	12.6	12.9	13.6	13.8	14.3	16.9b	16.4b	17.9b	21.6a	23.0a	16.8b	17.2b	18.4b	22.1a	23.8a
Flavour	–	–	–	–	–	5b	5b	8a	7a	8a	4b	5b	8a	7a	8a
Colour[b]	2	2	2	2	2	5b	6b	8a	8a	8a	3c	4c	5b	6b	7a

[a] Each entry represents mean of 9 fruits.

[b] Abdullah Hassan and Pantastico, E.R.B. 1990

Means having a common letter(s) are not significantly different by DMRT 1%.

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Development of Maturity Indices for Longan

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LONGAN is a leading export item amongst fresh fruits of Thailand. The major growing area is Chiang Mai and Lumphun provinces in the north. Fruit development takes about 21 weeks from fruit set to maturity (Wara-Aswapati et al. 1987). Maturity indices are important criteria for deciding when to harvest and to ensure the attainment of acceptable eating quality in fruit. Without a legal maturity standard, immature fruits are being sold on the commercial market. The assurance of fruit quality through a maturity standard would help alleviate this problem.

The first stage in the development of maturity indices is the evaluation of a wide range of physical and chemical parameters, with selection being based on those parameters the literature suggests have potential. Those shown to have practical value as a maturity index need to be further tested, so that variability between seasons, regions, and cultivars can be understood (Underhill and Wong 1990). This paper aims to identify a potential maturity index for Thai longans and examines the variability between different cultivars.

Selected physical and chemical parameters of five longan cultivars growing in northern Thailand, namely Daw, Biew Kiew, Haew, Srichompoo and E-Dang, were related to eating quality. Fruit were sampled at least 1 week before the start of the normal commercial harvest for each cultivar. The sample, containing as wide a range of fruit maturity as possible, was graded into five categories, using fruit size as criterion. Each fruit was weighed, sliced longitudinally, then each half peeled. One half was rated for eating quality by a taste panel using the 1 to 9 hedonic scale (Peacock and Jobin 1985). The other half was crushed and the juice sample assessed for total soluble solids using a digital refractometer and total titratable acidity by titrating against a standard 0.1 N NaOH solution using digital burette. The Brix: acid ratio value of the pulp was then calculated. The correlation between eating quality and other parameters was determined using a microcomputer analysis program.

Table 1 shows the correlation matrix of selected parameters with eating quality (EQ) for Biew Keiw longan cultivar. Fruit size and weight, and flesh weight, showed a very high correlation to eating quality. Total soluble solids (% Brix) content of the flesh also showed a high correlation, while acidity and Brix: acid ratio gave lower correlations. Similar results were obtained for other cultivars (Table 2). Total soluble solids is recommended as a maturity standard for longan. Although fruit size and weight have long been used as maturity indices for harvest by growers, high seasonal variability and differences in cultural practices reduced their usefulness as maturity standards.

A comparison of linear regression analysis of eating quality versus total soluble solids of each cultivar showed cultivar variability as differences in slope and in

Table 1. Correlation matrix of eating quality (EQ) versus selected physical and chemical parameters for Biew Kiew longan

	Fruit size	Fruit weight	Flesh weight	Seed weight	%Brix	%Acids	SA ratio
Fruit weight	0.95535	1.00000					
Flesh weight	0.94942	0.98954	1.00000				
Seed weight	0.63152	0.66896	0.56996	1.00000			
% Brix	0.69099	0.67143	0.69317	0.36643	1.00000		
% acids	−0.35166	−0.35098	−0.34674	−0.21627	−0.23040	1.00000	
SA ratio	0.56675	0.56425	0.56595	0.34194	0.56396	−0.79013	1.00000
Eating quality (EQ)	0.79154	0.77016	0.78890	0.43183	0.64661	−0.28497	0.49119

Critical value (1-tail, 0.05) = ± 0.09853
Critical Value (2-tail, 0.05) = ± 0.11725
N = 280

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calculated total soluble solids at selected eating quality (Table 3). The decrease in overall correlation coefficient between eating quality and total soluble solids of all cultivars further emphasised the cultivar differences. As eating quality of longan was not based solely on total soluble solids, others factors such as flavour and texture were also involved. In setting a threshold or minimum value for maturity standard, cultivar differences must be taken into consideration.

Table 2. Correlation coefficient of eating quality versus selected physical and chemical parameters for 5 longan cultivars

Cultivar	Fruit wt.	Fruit size	% Brix	% acids	Brix:acid ratio
Daw	0.718	0.702	0.590	−0.107	0.324
Biew Kiew	0.770	0.792	0.647	−0.285	0.491
Haew	0.814	0.827	0.634	−0.132	0.329
Srichompoo	0.872	0.889	0.672	−0.139	0.343
E-Dang	0.762	0.771	0.730	−0.194	0.517

Table 3. Linear regression analysis of eating quality versus total soluble solids (%Brix) of 5 longan cultivars tested.

Cultivar	Curve specification			% Brix at selected eating quality value		
	Intercept	Slope	r	5	5.5	6
Daw	−2.554	0.477	0.590	15.8	16.9	17.9
Biew Kiew	−8.088	0.642	0.647	20.4	21.2	21.9
Haew	−8.029	0.694	0.634	18.8	19.5	20.2
Srichompoo	−8.914	0.760	0.672	18.3	19.0	19.6
E-Dang	−5.931	0.505	0.730	21.6	22.6	23.6
All cultivars	−2.336	0.411	0.506	17.8	19.1	20.3

Acknowledgment

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Maturation and Harvesting Criteria for Avocado

Amos Blumenfeld*

Abstract

The avocado fruit does not ripen on the tree. The fruit develops and accumulates oil and other compounds until harvested, or until it drops mechanically. There are no external signs of maturity which can serve as a guide for harvest.

A correlation exists between taste and oil content, and between oil content and dry matter (DM). We can therefore estimate maturity by using dry matter measurements. Softening of fruits, another maturity-dependent characteristic of fruit ripening, can be measured only directly.

Under tropical conditions there may be several waves of fruit setting, which results in mature and immature fruits being present together at harvesting time. Relationships between taste and dry matter or oil content serve to establish the minimal DM for deciding horticultural maturity of each cultivar. Rate of DM accumulation serves for prediction of the beginning of harvest. Criteria for harvest and considerations involved in deciding when to harvest will be discussed.

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Part 3 — Disinfestation and Primary Processing

Postharvest Handling and Quarantine of Tropical Fruit in the Jiangmen Region of Guangdong, China

Chen Bing Quan* and Guan Lianghua†

THE Jiangmen region of southern China lies between 111°15' and 113°50'E and 21° to 22°50'N. It has four cities and two counties, and an area of 9400 km^2. The population is 3 million. There are two main rivers, which flow into the South China Sea. The average annual temperature is 22°C, and average annual rainfall 1800–2200 mm.

Jiangmen's agricultural economy has been developing steadily over the past 15 years. Tropical fruits such as bananas, longans, lych.es, pineapples, oranges, and watermelons are grown, and a production, handling, processing, and quarantine system has developed for supplying those commodities to adjacent Hong Kong and other markets. Recently, with rapid development of the Pearl River delta area, production of tropical fruits in Jiangmen is increasing and higher quality fruit is being supplied to the international market. There is, nevertheless, a need for further research on pest and quality control in tropical fruit.

Outline of Tropical Fruits in the Jiangmen Region

The main fruits grown in the Jiangmen region, and their production levels in 1992, are as follows: oranges, 165 500 t; bananas, 47 400 t; lychees, 6200 t; longans, 1001 t; pineapples, 3200 t; and mangoes, 474 t. Oranges and bananas are the staples, and yields of these and the other main fruits have increased markedly over the past 5 years. Yields of oranges, for example, have increased from 5.7 to 13.4 t/ha, and of bananas from 12.2 to 16 t/ha.

The main varieties of bananas grown are shown in Table 1. These varieties have been selected and bred to develop strains with good characteristics such as neat fingers and consistency of comb size.

No. 4 Taiwan Agr. Boli pineapple (*Ananus comosus* var. TA4), a variety with very good quality, pest resistance, genetic stability, and other characteristics, was put onto the domestic market after breeding tests by Jiangmen Forestry Scientific Institute. There have been no exports of this product as yet, but interest in this type of pineapple has been shown in Japan and America.

The varieties of oranges, lychees, and longans grown are nearly all native.

Table 1. Banana varieties produced in the Jiangmen region, and their provenance

Variety	Provenance
Williams	Australia
B7	Mexico
B8	Taiwan province
B9	Thailand
Tidy eyebrow	Native to Guangdong
Dun mine	Native to Guangdong
B75	Kenya
B76	Tanzania
B17	Philippines
Aromatic Hills	Native to Jiangmen
6–31	Native to Jiangmen
7–41	Native to Jiangmen

Processing and Storing

Jiangmen Jiangxing Fresh Fruit & Vegetable Company, established in 1989, has production, research, processing, and trading functions. Some US$3.28 million have been invested by the company, US$1.9 million on facilities from Japan and The Netherlands. Produce of the company is sold to Japan, USA, Canada, U.K., Sweden, The Netherlands, and Australia. The company occupies 18 000 m^2: 5000 m^2, processing factory; 1300 m^2 cold storage of 500 t capacity; and 1600 m^2 –28°C freezer storage of 1000 t capacity. The company produces 30 t of frozen lychee per day. Some 500 t of frozen lychee were exported to Japan during 1992.

Jiangfeng Food Company Limited is a similar enterprise. It has –18°C freezer storage and supplies products to both domestic and international markets.

Plant Quarantine

Plant quarantine work in China consists of domestic plant quarantine and import and export quarantine. Jiangmen City Plant Quarantine Station administers domestic plant quarantine in the Jiangmen region. All

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banana plants originate in a 'Banana Test-tube Plantlet Factory', where there is maternal plant selection and quarantine before the plants are sent out of the nursery. The targets of quarantine procedures are cucumber mosaic virus and *Fusarium oxysporum* f. sp. *cubense*.

The factory must be located in an area free from those targets. Maternal plant selection is made by Jiangmen City Plant Quarantine Station. After breeding 200 plants from a maternal plant's buds, samples are taken by the Station for biochemical and serological testing. A planting test must be carried out for 3 months to observe the symptoms of over 100 plants.

The nursery for the germplasm of the maternal plant is located in the mountains where there is no disease. All planting materials entering the nursery are inspected for disease, and diseased plants excluded. The factory and station inspect the germplasm of the maternal plants regularly. If a diseased plant is found, it is destroyed. A certificate is issued certifying that qualified test-tube plants are used.

The Xinhui Base for Experiment and Development of Test-tube Fruit Plantlets is a collaborative effort of the South China Institute of Botany, Academia Sinica, and Xinhui Institute of Plant Genetics and Breeding to advance the science and technology of plantlet production. It was established in 1986 and has expanded continuously. The factory has four workshops for plantlet production with a total area of 5600 m^2, eight screen houses, and three glasshouses of total area 1800 m^2. The factory can produce 25 million certified banana plantlets per year.

Jiangmen Animal and Plant Quarantine Service of the People's Republic of China and its five branches administer import and export plant quarantine in the region. The Service examines fruit presented for export to ensure that it meets the plant quarantine requirements of the importing country or region and contract terms. As regards imported fruits, the main targets of quarantine inspection are the following insect pests: *Ceratitis capita, Dacus* spp., *Tetradacus tsuneonis, Anastrepha fratercullus, A. ludens, A. obliqua, A. suspensa, Sternochetus frigidus, S. magiferae, S. olivieri.*

To exclude the Mediterranean fruit fly from China, all solanaceous fruit and vegetables from regions where this insect occurs are excluded entry, including those carried by incoming travellers. This regulation has been in force since 1981.

Review and the Future

Tropical fruit production in the Jiangmen region is developing rapidly. There are problems with postharvest handling, however. Cold and freezer storage are more suited to vegetables than to tropical fruits. Other storage techniques for fruit are needed.

Infection by *Macrophoma musae* disease does not damage the edible part of bananas and does in fact improve the flavour. Unfortunately, however, the black-mottled symptoms on the banana pericarp render the fruit unattractive. Jiangmen will continue to research and develop resistant strains of banana in an effort to overcome this problem.

Collaborative programs with regional and international agencies would yield mutual benefits.

Acknowledgments

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Effects of Gamma Irradiation and Hot-Water Treatment on the Shelf Life and Quality of Thai Mango cv. Rad

Ishwari P. Upadhyay, Athapol Noomhorm, and Sarath G. Ilangantileke*

MANGO is the third most important commercial fruit crop of Thailand. Like many other tropical fruits, mangoes are highly perishable mainly due to high temperatures and humidities prevailing in the tropics. The short postharvest life is the result of ripening and physiological breakdown during handling, transportation, and storage, which is further aggravated by damage from insect infestation and postharvest diseases.

A major factor limiting the international market of horticultural crops is poor quality. The domestic or export markets require a constant and predictable supply of established high quality produce. Due to the specific quality requirements, especially for export of perishable produce, it may be necessary to apply specific treatments.

Exposure of fresh fruits and vegetables to ionising radiation has been seen as a means of achieving insect disinfestation, postharvest disease control, and shelf life extension by delaying ripening and senescence. Recent research on food irradiation has focused on achieving disinfestation against fruit fly, the mango seed weevil, and the control of postharvest diseases such as anthracnose and stem-end rot with low doses (0.075–0.75 kGy) in combination with hot water and other chemicals, recognising the phytotoxic effects of irradiation at higher doses and strict plant quarantine regulation of many exporting countries. More recent South African studies claimed synergism between low dose irradiation (0.7 kGy) and hot-water dipping in the control of mango diseases, and suggested irradiation as an alternative to conventional postharvest fungicidal treatments.

Responses of mangoes to similar doses of irradiation vary between cultivars and physiological status such as stages of ripeness and maturity of the fruit at the time of treatment. This is evident in mangoes from different regions such as Australia, Mexico, the Philippines, and Thailand. Although literature is available on irradiation of Thai mango, so far no report has appeared on the effect of irradiation treatment on the shelf life of cv. Rad, one of the leading local and export cultivars of Thailand. This study was conducted to evaluate the effect of irradiation in combination with hot-water treatment on the shelf life and quality attributes of mango cv. Rad.

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Methods

Preclimacteric mature-green mangoes cv. Rad, each fruit weighing 240–250 g, were obtained from Rai Prapat & Sons Co., Ltd, Chiang Mai, Thailand. Fruit were placed in individual foam nets and packed in 4 kg paperboard cartons. Mango cartons were air freighted to Bangkok and transported by road to the Thai Irradiation Center. Selected fruits were randomly divided into two lots. One lot was treated with hot water at 55°C for 5 min. Each lot was further subdivided into 4 lots for 4 different irradiation doses (0, 0.3, 0.6, and I kGy).

Heat treatments were applied using a 100 L capacity experimental dipping tank (60 × 50 × 80 cm) equipped with a RKC PF4 temperature controller and two 2.5 kW immersion heating elements and a 0. 37 kW pump to maintain turbulence of the dip preparation. After hot-water treatment, fruit were kept in foam net and packed in cartons (50 × 30 × 9 cm), 12 fruits per carton and approximately 3.5 kg per carton. They were irradiated at the Thai Irradiation Center in a Carrier Type Gamma Irradiator Model JS-8900 designed by Nordion International Incorporation, Canada. The product was irradiated to minimum dosages of 0.3, 0.6, and 1 kGy in a batch mode (9 carriers/run).

Physical and chemical analyses were done twice a week. Thirty-six fruit from each treatment were evaluated for change in skin colour from green to yellow. Fruits were scored on a numerical scale of 1–4 where 1 corresponded to a totally green skin; 2, more green than yellow; 3, more yellow than green; and 4, full ripe. Similarly, 36 fruit from each treatment were assessed for rotting. Fruit surfaces with black spot, lesions, bruising, lenticel damage, affected by diseases, insects, or any other blemishes were scored as rotten fruits. A fruit was considered rotten when more than 5% of its surface area had decayed.

Weight loss of each replicated samples was recorded. Six mango samples were selected randomly and fruit firmness was measured with a Instron Universal Testing Machine Model 1140 fitted with an 11.1 mm spherical probe, with the probe driven at 100 mm/min. Maximum force in Newtons required to rupture fruit was taken as a measure of firmness. Quantitative measurements of skin colour development and internal pulp colour development were made using a Hunter Colour Difference Meter Model TC P III (Tokyo Denshoku Co. Ltd)

which was standardised against a white plate. Two readings per fruit were taken at the centre of each cheek by placing the samples on the top of the 20 mm diameter optical unit. Internal colour was measured by placing the beaker containing blended pulp on the top of the optical unit.

For chemical analyses, fruit used for the firmness test were peeled and mango pulp removed. Mango pulp was blended to a smooth homogenate pulp using a blender. Total soluble solid content (Brix) was determined by Abbe Refractometer. The pH of pulp was determined by a Suntex Digital pH meter. Titratable acidity was measured by titrating 20 mL filtrate against standard 0.1 N sodium hydroxide solution in the presence of phenolphthalein indicator to a faint pink end point, and acidity was calculated as percent anhydrous citric acid. Ascorbic acid was determined before and after 30 days of storage by the 2,6 Dichlorophenol Indophenol Visual Titration Method. Sensory evaluation of whole mangoes and mango pulp was done using a hedonic rating test by a panel of 10 persons on the 21st and 30th days of storage. Data from each parameter were analysed by two-way analysis of variance (Anova) at 5% significance level to test significance differences among treatments

Table 1. Effect of irradiation and hot-water treatment on weight loss, firmness, total soluble solids (TSS), pH, titratable acidity (TA), ascorbic acid (AA) and sensory score of mango cv. Rad before and after 30 days of storage at 15°C and 85% relative humidity

Treatment	Dose (kGy)	Weight loss (%)	Firmness (N)	TSS (%)	pH	TA (%)	AA (mg/100 mg)	Sensory score[a]
Before								
NHD	0.0	0.0	238.1a	12.8a	3.4a	1.4a	30.2a	
HD	0.0	0.0	236.2a	12.7a	3.4a	1.3a	29.6a	
After								
NHD	0.0	7.7c	18.6d	18.7a	5.4a	0.14de	20.4ab	7.1ab
	0.3	8.8bc	25.5cd	18.2a	4.5bc	0.21c	14.3abc	8.2a
	0.6	9.7ab	38.2abc	19.5a	4.3bc	0.33a	12.3c	6.1b
	1.0	9.1abc	40.2ab	18.8a	4.1c	0.32a	13.8bc	3.8c
HD	0.0	8.5bc	19.6d	18.0a	5.1a	0.12c	20.9a	8.4a
(55°C for	0.3	9.6ab	29.4bcd	19.0a	4.5a	0.18cd	18.5abc	6.4b
5 min)	0.6	9.9ab	40.2ab	17.8a	4.3bc	0.26b	15.9abc	7.1ab
	1.0	10.7a	49.0a	19.3a	4.2bc	0.36a	14.2abc	6.2b

Notes:
Means within the same column and storage period followed by a common letter are not significantly different at $p < 0.05$ by DMRT.
NHD = no hot dip; HD = hot dip
[a] Extremely like = 9; extremly dislike = 1

Table 2. External and internal (Hunter *L*, *a*, and *b*) colour values as affected by irradiation and hot-water combination treatment before and after 30 days of irradiation stored at 15°C and 89% relative humidity

Treatment	Dose (kGy)	External colour			Internal colour		
		L	*a*	*b*	*L*	*a*	*b*
Before							
NHD	0.0	49.5a	−11.7a	20.0a	na	na	na
HD	0.0	46.4a	−11.3a	19.6b	na	na	na
After							
NHD	0.0	61.6a	10.26a	33.5a	68.2a	9.54cd	37.5a
	0.3	61.8a	−4.0bc	31.6a	65.3a	12.0bc	36.2ab
	0.6	56.2bc	−0.2d	28.7b	60.25a	13.4ab	30.8b
	1.0	56.0bc	−0.4d	26.4bc	47.8b	13.8ab	24.5c
HD	0.0	63.2a	7.2ab	32.8a	69.2a	10.2cd	38.8a
	0.3	57.1b	5.6b	28.2b	64.9a	10.1cd	36.6ab
	0.6	56.3bc	1.2cd	27.4c	47.8b	8.6d	37.3a
	1.0	53.2a	1.6d	25.8c	48.4b	15.4a	23.9c

Notes:
Means within the same column and storage period followed by a common letter are not significantly different at $p < 0.05$ by DMRT.
NHD = no hot dip; HD = hot dip; na = not available.

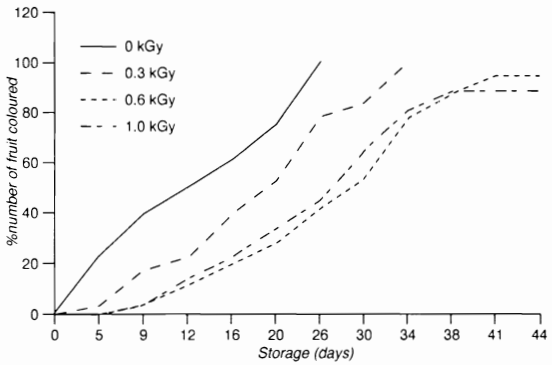

Figure 1. Effect of irradiation on ripening, assessed visually as percentage of fruit which had 75% or greater yellow skin colour.

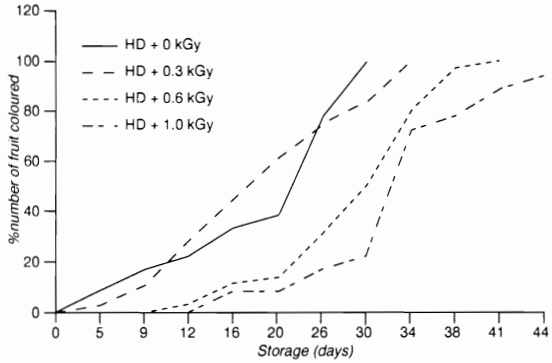

Figure 2. Effect of irradiation and hot-water treatment on ripening, assessed visually as percentage of fruit which had 75% or greater yellow skin colour.

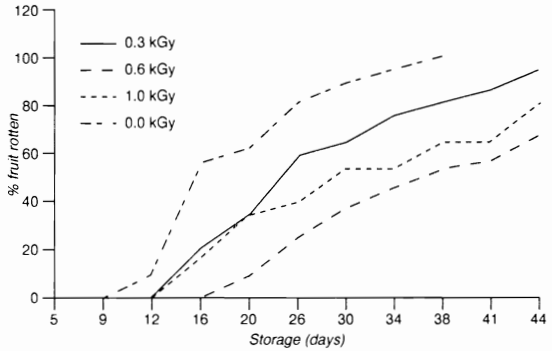

Figure 3. Effect of irradiation on rotting, assessed visually as percentage of fruit which had more than 5% of their surface area rotted.

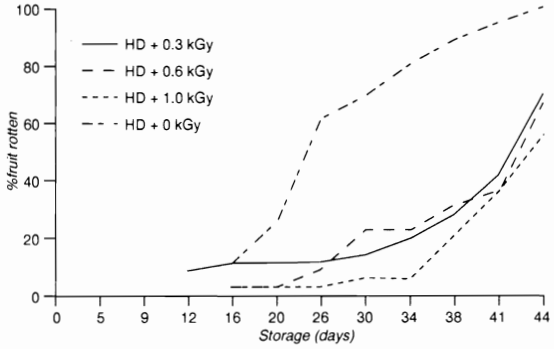

Figure 4. Effect of irradiation and hot-water treatment on rotting, assessed visually as percentage of fruit which had more than 5% of their surface area rotted.

using Statgraph 5. DMRT was used at 5% level for comparison of means.

Results

This experiment showed that irradiation significantly reduced rotting, delayed colour development, preserved quality, and extended shelf life of mangoes cv. Rad (Tables 1 and 2; Figs 1–4). Irradiation injury increased with increasing dose and storage period. Mango samples hot dipped followed by irradiation at 0.3, 0.6, and 1.0 kGy, extended the shelf life by 8, 12, and 18 days, respectively, as compared with a hot dip control, while samples irradiated at doses 0.3, 0.6, and I kGy extended the shelf life by 4, 7, and 14 days respectively, as compared with the controls. Percentage weight loss was high for hot-water treated irradiated mangoes, and increased with increasing dose. Fruit were firmer, soluble solids, pH, and vitamin C were lower, and titratable acidity was higher for treated than for untreated samples. Sensory evaluation showed no significant differences in quality attributes between treated and untreated samples up to 0.6 kGy. In terms of shelf life and quality, a hot-water treatment followed by irradiation at 0.3 kGy was found to be the best combination treatment. At this treatment, total shelf life was 38 days with 28% rotting with no irradiation injury to pulp. Results indicated that ionising radiation combined with hot-water treatment not only reduced the storage decay but also extended the shelf life.

Effect of Irradiation and Storage Temperature on the Shelf Life and Quality of Thai Lychee

Sarath G. Ilangantileke, Athapol Noomhorm, Ishwari P. Upadhyay, and M. Srinivas Rao*

THE maintenance of market quality of fresh lychee is a major problem when the fruit is transported long distances. The red skin colour is lost and diseases develop. This is evident in Thailand where fruits are predominantly grown in the far north and south of the country, and transported daily to Bangkok by truck or air. The occurrence of browning may render the fruit unsaleable.

The shelf life of lychee is 3 days or less at room temperature if left unpacked. Numerous techniques to increase shelf life have been investigated, including packing in polyethylene and polyvinylchloride bags, refrigerated storage, wax coating, hot benomyl, acid treatment, SO_2 fumigation, and storage in a CO_2 environment. Irradiation after harvest has been tried, but at present little literature is available on the effects of irradiation on the shelf life of lychee varieties grown in Thailand. An experiment was conducted to study the combined effect of irradiation and low storage temperatures on the shelf life of Thai lychee.

The experiment involved one irradiation dose and one control (1, 0 kGy), two storage temperatures (5°C and 10°C) and 3 replicates in a 2 × 2 factorial with a completely randomised design. Lychees were obtained from a commercial fruit market in Bangkok. Selected samples were packed in 29.5 × 10.5 × 19.5 cm cartons. Each carton weighed approximately 2 kg.

Lychee samples were irradiated to 1 kGy minimum dose in a static mode at the Thai Irradiation Center (TIC) in a carrier type gamma irradiator model JS-8900 designed by Nordion International Inc. using a gamma source from cobalt-60. The source strength was 277 125 curie at the time of the experiment. After irradiation, samples were stored in a cold room at one or other of two temperatures. Temperature and humidity data were measured daily by dry- and wet-bulb thermometers and ordinary alcohol-filled thermometers.

Analyses were done at 4-day intervals for 16 days. Two fruit from each carton were randomly selected, peeled, and the seeds removed. Fruit flesh was blended to a smooth pulp using a blender and the pulp was used for chemical analyses.

One carton from each replicate was assessed for percent age rotting. Hunter *L*, *a*, and *b* values were determined using a Color and Color Difference Meter Model TC P-III (Tokyo Denshoku Co., Ltd) which was standardised against a white plate (*L* 90.34, *a* 0.29, and *b* 3.26).

One fruit was randomly selected from each carton for determination of external colour. Individual whole fruits were coded and the same fruit were analysed in the apex position throughout the study. Internal colour was measured by placing the beaker containing blended pulp on the top of the optical unit and Hunter *L*, *a*, and *b* values were recorded.

Total soluble solids (TSS) content was determined by placing one drop of the juice on the prism of an Abbe refractometer and readings were recorded as °Brix (AOAC 1984). Pulp pH was measured by Suntex Digital pH meter Model Sp-5. Titratable acidity was determined by titrating against standard 0.1N sodium hydroxide in the presence of a phenolphthalein indicator to a faint pink end point and calculated as percent anhydrous citric acid.

Two-way analysis of variance (Anova) was employed to test significance differences among treatment means using Statgraph 4 (1988). All significance testing was done at $p \leq 0.05$. Least significant differences (LSD) were calculated for comparison of treatment means.

The Hunter *L*, *a*, and *b* values continually decreased with storage period in all treatments. Samples stored at 5°C, both irradiated and control, showed higher *a* values than samples stored at 10°C, indicating that irradiation combined with low storage temperature maintained the red colour of lychee. The saturation index (SI), which indicated the relative amount of colour remaining in the fruit, decreased with storage time. Hue, as represented by hue angle, increased. This corresponds to a visible image changing to a darker yellow upon storage (Table 1).

Internal colour of pulp was not significantly affected by irradiation and storage temperature. During storage, Hunter *L* and *b* values increased whereas *a* values decreased with storage time. However, the changes in *L*, *a*, and *b* values were not significant and lychee flesh colour remained white during storage.

TSS and pH content increased, whereas titratable acidity (TA) decreased continually over storage period. However, irradiation and storage temperature had no significant effect on pH, TSS, and TA content of stored

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lychee. The increase in pH and TSS, and decrease in TA, were consistent across storage days and may be attributed to natural storage effects (Table 2). Irradiation and storage temperature had significant effects on rotting of lychee. Irradiation followed by storage at 5°C reduced rotting significantly (Fig. 1).

Table 1. Effect of irradiation and storage temperature on external colour (Hunter *L*, *a*, and *b*) of lychee

Storage (days)	Dose (kGy)	Storage temperature (°C)	External colour				
			L	*a*	*b*	SI	Hue angle
0	Mean		30.31	19.56	9.79	21.88	26.59
4	0	5	29.85a*	22.98a	9.56a	24.90	17.76
	0	10	30.02a	16.44b	10.04a	19.26	28.72
	1	5	30.00a	21.73a	10.14a	23.98	25.00
	1	10	30.17a	18.33b	8.83a	20.34	25.72
8	0	5	27.24	16.64a	8.28a	18.58	24.47
	0	10	27.84a	12.90b	8.97a	15.72	34.81
	1	5	28.40a	14.59a	9.46a	17.39	32.95
	1	10	26.96a	12.23b	8.15a	14.70	33.70
12	0	5	28.51a	15.35a	8.22ab	17.41	28.17
	0	10	27.68a	8.59b	7.44b	11.36	40.90
	1	5	27.98a	13.44a	8.60a	15.96	32.63
	1	10	27.32a	11.41ab	7.84ab	13.84	34.50
16	0	5	28.51a	15.35a	8.22ab	17.42	28.18
	0	10	27.68a	8.60b	7.44b	11.38	40.94
	1	5	27.98a	13.44a	8.61a	15.96	32.63
	1	10	27.32a	11.27ab	7.84ab	13.72	34.77

* Means with the same column and storage period followed by a common letter are not significantly different at $P < 0.05$ by LSD.
Saturation index (SI) = $(a^2 + b^2)^{0.5}$, hue angle = $\tan^{-1}(b/a)$.

Table 2. Effect of irradiation and storage temperature on total soluble solids (TSS), pH, and titratable acidity (TA) of lychee

Storage (days)	Dose (kGy)	Storage temperature (°C)	TSS (%)	TA (%)	pH
0	Mean		14.1	0.29	5.2
4	0	5	14.7a*	0.20a	5.7a
	0	10	14.2a	0.19a	6.0a
	1	5	14.5a	0.29a	6.1a
	1	10	14.3a	0.26a	5.4a
8	0	5	14.5a	0.15a	6.1a
	0	10	14.2a	0.22a	6.2a
	1	5	14.7a	0.29a	6.1a
	1	10	14.5a	0.15a	5.4a
12	0	5	15.7a	0.08a	6.1a
	0	10	15.8a	0.10a	6.1a
	1	5	14.8a	0.10a	6.3a
	1	10	15.1a	0.09a	5.7a
16	0	5	15.8a	0.05a	6.4a
	0	10	15.7a	0.07a	6.6a
	1	5	15.2a	0.06a	6.3a
	1	10	15.5a	0.08a	6.3a

* Means within the same column and storage period followed by a common letter are not significantly different at $p < 0.05$ by LSD.

Irradiation of lychee at 1 kGy followed by storage at 5°C gave encouraging results in extending the shelf life by reducing the incidence of decay and loss of red shell colour. Development of browning and loss of red colour were lower both in irradiated and control samples at 5°C. Internal colour was not affected and irradiation did not show any adverse affect on soluble solids, pH, and acidity. The present study has demonstrated that irradiation up to 1 kGy dose, in combination with low temperature storage (5°C) may be used to extend storage life and to maintain the market quality by reducing loss of red shell colour and retarding decay of lychee.

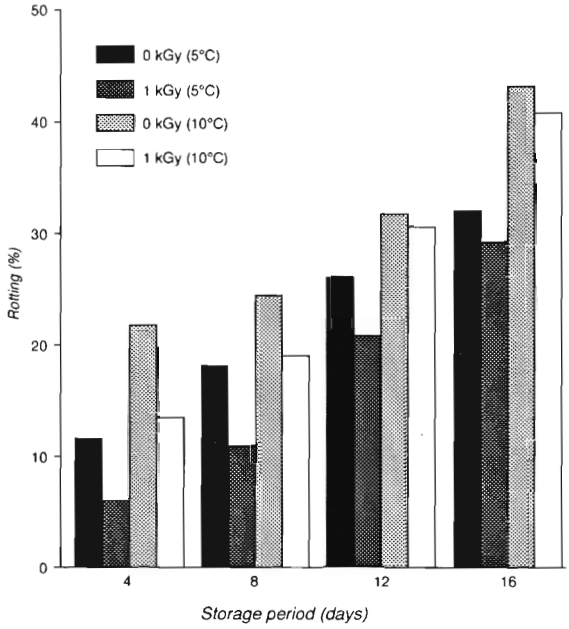

Figure 1. Effect of irradiation and storage temperature on rotting of lychees

Insect Quarantine Treatments and Fruit Ripening

Robert E. Paull* and John W. Armstrong†

POSTHARVEST treatments are required to disinfest fresh fruits, vegetables, nuts, dried fruits and vegetables, flowers, and ornamentals of economically important quarantined insects (Table 1). These insect pests are of quarantine importance because they are absent from the importing country (e.g., various tephritid fruit flies, codling moth, and mango seed weevil), or the importing country has a 'zero tolerance' for all live insects whether or not they are economically important. Failure to control the spread of insect pests can result in expensive quarantine and eradication procedures (Carey 1991), product losses due to infestation, and costly new quarantine treatment requirements (Dowell 1983).

Current research efforts are directed to the use of physical disinfestation treatments, such as heat or cold, that may be more costly and difficult to apply than chemical treatments such as fumigants. Furthermore, many commercially important commodities attacked by quarantined pests have no approved disinfestation treatments.

Insects — the Problem

The reproduction rate, short life cycle, and adaptability of pest insects, as well as their destructive potential, underscore the need for quarantine treatments and barriers. The time required for life cycle completion differs with environmental factors and species e.g., oriental fruit flies produce 3–18 generations per year (Vargas et al. 1984) depending on temperature. The damage caused by insects includes small surface blemishes, destruction of the edible flesh, fruit drop, seed destruction, and spoilage from decay organisms entering the fruit aided by insect activity.

Both fruit, cultivar, and stage of ripeness can significantly influence host status (Greany 1989). Green fruit are not frequently hosts under normal conditions. Mature-green 'Brazilian,' 'Valery', and 'Williams' bananas and 'Sharwil' avocados are not infested by fruit flies (Armstrong 1991), although hosts when ripe; and papaya with less than 25% yellow are not preferred fruit fly hosts (Couey and Hayes 1986). Pineapples with 50 percent or more 'Smooth Cayenne' parentage are not fruit fly hosts (Armstrong and Vargas 1982).

Horticultural Effects of Control Measures

Heat

Hot-water immersion, vapour-heat and forced hot-air treatments have been the methods of choice against insects (Couey, 1989). Heat treatments have the merit of effective fungicidal and insecticidal action, ease of application, and leave no chemical residues. The disadvantages are the potential for fruit damage, that must be researched on a commodity-by-commodity basis, and a relatively higher cost of application compared with fumigation. Insect responses to heat treatment and thermal death relationships have been developed for some insects of quarantine importance (Jang, 1991). Mortality due to heat is dependent upon oxygen availability, pH, previous temperatures, general energy status of the insects, and insect age and stage (Moss and Jang 1991). Hot-water immersion treatments were developed to disinfest Mediterranean fruit fly from bananas, papayas, guavas, and mangoes. Vapour-heat treatments have been developed for bell pepper, Chinese peas, cucumber, eggplant, green beans, lima beans, lychee, mango, papaya, tomato, grapefruit, and yellow wax beans. A high-temperature (or hot) forced-air quarantine treatment to disinfest Mediterranean fruit fly, melon fly, and oriental fruit fly from papaya has been developed recently.

Papaya fruit with low mesocarp calcium are more sensitive to heat treatments. Preharvest weather in the day before and the mean of 4 days before is not significantly correlated with fruit sensitivity (Table 2). However, the mean of the rainfall, evaporation, minimum and maximum temperature in the 3 days before harvest significantly correlated to fruit heat sensitivity. The 3-day mean of the minimum temperature had the greatest relationship to fruit heat sensitivity.

Heat injury is characterised by a failure to develop normal pigmentation, abnormal softening (Fig. 1) and by a marked decline in ethylene production. Respiration rate and ethylene synthesis are affected by exposure to high temperatures (Paull and Chen 1990) (Fig. 2).

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Table 1. Currently approved and possible postharvest insect control treatments for fruits, vegetables, and flowers. This lists the usefulness of various potential quarantine procedures for horticultural commodities. It does not indicate their effectiveness against specific insect pests. This table was an outcome of U.S. Dept. of Agriculture Research Service and Western Land Grant College regional project and was assembled by Dr G. Mitchell, University of California, Davis (used with permission).

Commodity		Fumigation			Cold treatments	Heat treatments	Modified atmospheres	Radiation	Other procedures, treatments, or combinations of treatments
		Methyl bromide	Phosphine	Other fumigants					
I. Fresh fruits									
Pome Fruit	Apple	T	O		T		X	X	X Certification (infestation level and handling system)
	Pear	T	O		T		X	X	
Stone fruit	Apricot	T	O		T			X	T Cold & MB
	Cherry	T	O		T			X	T Cold & MB
									X Certification (infestation level and handling system)
	Nectarine	T	O		T			X	T Cold & MB
	Peach	T	O		T			X	T Cold & MB
	Plum	T	O		T			X	T Cold & MB
Soft fruits	Strawberry	T	O			O		X	
	Bush berries							X	
	Grapes	T			T				T Cold & MB
Kiwifruit					T				
Persimmon					T				
Pomegranate					T				
Fig, fresh								X	
Date		T	T		T		T	X	
Avocado		O				X		O	T Cold & MB
									X Certification ('Sharwil')
Citrus fruits				T(HCN)		X			
	Grapefruit	X	X		T			X	X Conditioning before cold treatment
	Lemon/lime	T			X/O				
	Mandarin/tangelo	T						X	
	Orange	T			T			X	
Banana	Cavendish	O	O		O	X			X Certification
	Brazilian								
Lychee		O			X	X			
Papaya		X	O		X	T		X	T Picking maturity + hot water + cooling
Mango		X/O	O			X		X	
Cherimoya					O				
Carambola					T	O			
II. Fresh vegetables									
Tomato/pepper/eggplant		T/O	O			T(VH)			T/X Dimethoate dip
Melons/cucumber		T/O				T(VH)			
III. Dried fruit and vegetables									
(Raisins, prunes, etc.)		T	T		X	X	X	X	
IV. Tree nuts									
Almond		T	T		X	X	T	X	
Filbert		X	X						
Macadamia		X	X						
Pecan		X	X						
Pistachio		X	X			X			
Walnut		T	T		X	X	T	X	
V. Flowers		T		X (HCN)	X	X		O	

T = Treatment registered for use against certain pests; X = Possible treatment; O = Host intolerance expected based on past tests or observations. Blanks indicate no information available. HCN – hydrogen cyanide, VH – vapour heat.

Table 2. Forward stepwise regression at the most significant step, giving the parameter estimate and probability of F for each significant variable at 0.15 level of significance for entry into the model. No significant relationship was found with solar radiation. Variables up to cube factor were tested.

Variable	Preharvest period					
	1 day		3-day mean		7-day mean	
	Parameter	Probability	Parameter	Probability	Parameter	Probability
Calcium			–2.9260	0.0054		
Calcium square	0.00158	0.0688	0.022166	0.0036	0.00158	0.0688
Rain			–34.310197	0.0187		
Evaporation			0.195903	0.0011		
Evaporation cube			–0.000007	0.0002		
Low temperature			–662.365	0.0766		
Low temp. square			36.57732	0.0567		
Low temp. cube			–0.66815	0.0416		
High temp. square			–0.78734	0.0024		
High temp. cube			0.020197	0.0016		
Intercept	16.0664	0.0031	4253.28966	0.0799	16.0664	0.0031
Model probability		0.0688		0.0001		0.0688
R^2		0.1922		0.9737		0.1922

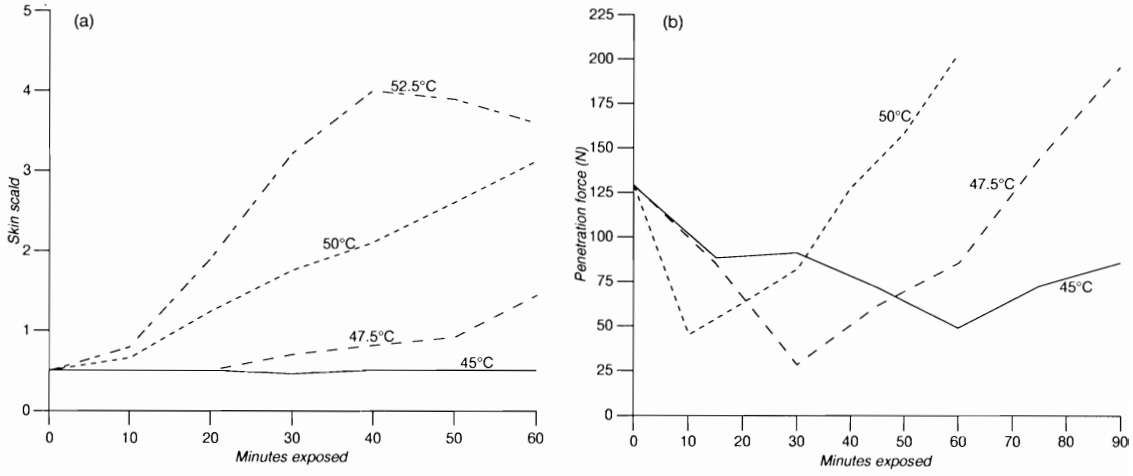

Figure 1. Effect of immersing of papaya fruit for different lengths of time in hot water at different temperatures on (a) the development of skin scald (0 = no scald, 5 = 100% scald) and (b) flesh penetration force (after Paull 1990c)

A rapid loss (75%) of ethylene forming enzyme (EFE) occurs in papaya and other fruits exposed for short periods to temperatures greater than 40°C.

Plants exposed to higher temperatures for a brief period acquire transient heat tolerance. As this thermotolerance response develops, a unique group of proteins — heat shock proteins (HSP) — is synthesised. Field induction of HSP has been shown to occur in papaya fruit (Paull and Chen 1990). The extent of protection against softening disruption is dependent upon season, stage of fruit ripeness at exposure, and pretreatment time and temperature (Paull 1990b).

Many procedures have been empirically developed to reduce the injury caused by heat treatment. Exposure of ripening papaya fruit to either 42°C for 4 hours (Table 3) or to 38–42°C for 1 hour, followed by 3 hours at 22°C (Fig. 3) results in the development of thermotolerance and the production of HSP (Paull and Chen 1990). The 8-hour approach time to 44°C used for a papaya vapour-heat treatment is designed to reduce subsequent

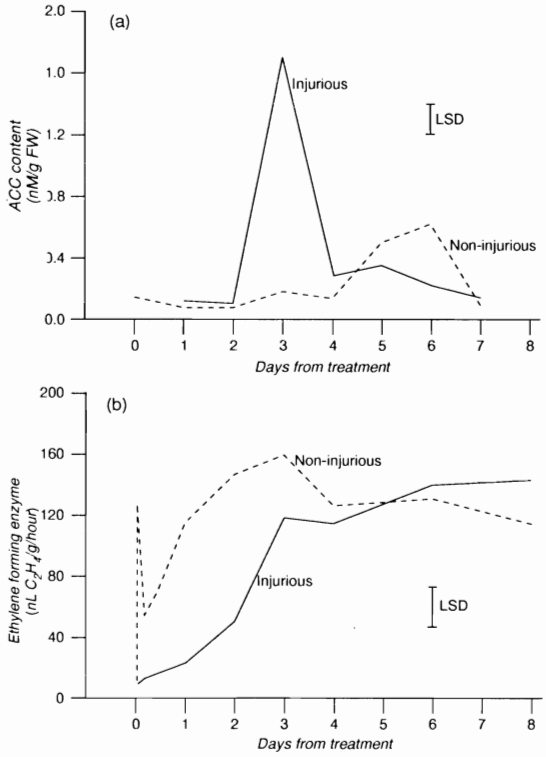

Figure 2. Effect of an injurious heat treatment (70 min at 49°C); and a non-injurious treatment (20 min at 49°C); on papaya fruit (a) ACC content and (b) net ethylene forming enzyme activity during ripening at 25°C, the difference in activity with and without additional ACC. Zero time samples taken just before treatment. Vertical lines LSD (P = 0.05).

injury when the fruit are exposed to 44°C for 8.75 hours. This approach time would be expected also to provide the conditions necessary to develop HSP and associated thermotolerance. Seasonal variation could be due to field-induced thermotolerance (Paull 1990b).

Chilling

Cold treatments have been recommended for disinfestation of fruits for many years following the observations that refrigeration was an effective quarantine treatment for Mediterranean fruit fly. The eggs and larval stages of fruit flies are killed by exposure to temperatures below 10°C. However, only temperatures below 3°C are practical because of the long exposure times involved (10 days and longer at 0°C) (Armstrong and Couey 1989).

The stage of fruit ripeness and age of leaf tissue at the time of low temperature storage significantly influences the fruit sensitivity to visible chilling injury symptom development (Paull 1990a). The preclimacteric stage is generally more sensitive to cold than the postclimacteric stage for avocado, papaya (Fig. 4), honeydew melon, tomato, and mango.

Microwaves

Microwaves, or dielectric heating, is limited by non-uniform heating and heating from the centre of the fruit outward. Microwave treatment to disinfest Mediterranean fruit fly, melon fly, and oriental fruit fly from mangoes and papayas damaged the fruits before any effect on the fruit flies was observed (Armstrong, unpublished data). Interrupted or pulsated microwave treatments may be effective against mango seed weevil with minimal fruit injury (Seo et al. 1970).

Hayes et al. (1983) showed that ultrasound just below the threshold for papaya fruit damage killed fruit flies no deeper than 1 mm inside the fruit. Since fruit fly eggs in papaya are in the first 4 mm of the fruit, ultrasound alone does not appear to be a feasible disinfestation treatment for papayas.

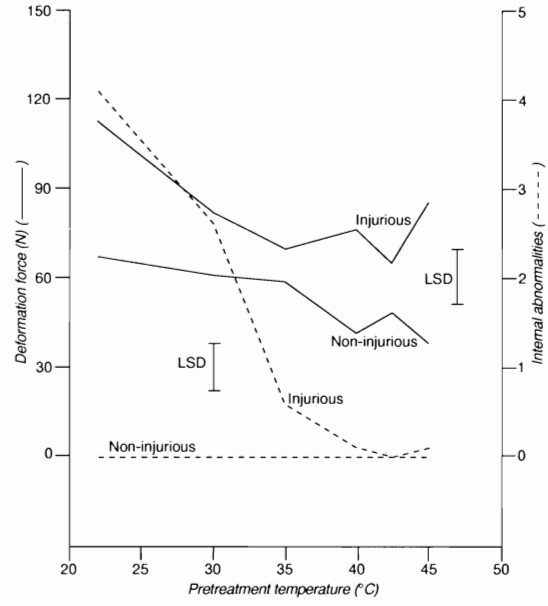

Figure 3. Effect of different pretreatment temperatures for 1 hour followed by 3 hr at 22°C on fruit failure to soften following a non-injurious 20 min at 49°C or an injurious 70 min at 49°C expressed as deformation force ~~(fruit~~ softness) (------) and internal injury (- - -) after 10 days of ripening at 25°C. Vertical bars LSD

Table 3. Effect of pretreating colour-break papaya at 42°C on fruit failure to soften after an injurious heat treatment. The fruit were treated for varying times at 42°C followed by either 20 min (control) or 70 min (injurious) at 49°C. Fruit were allowed to ripen at 25°C.

Time at 42°C (hours)	Deformation force (N)		Internal injury (scale)	
	Control	Injurious heat	Control	Injurious heat
0.5	31.4	99.0	0	4.6
1.0	23.5	84.3	0	4.8
2.0	49.0	63.7	0.3	3.2
4.0	54.9	55.9	0	0
6.0	54.9	47.1	0	0
Significance[a]	L	L	ns	L
r^2	0.363**	0.479***	---	0.664**
n	75	76	75	76
Heat treatment	***		***	
Length of treatment	ns		***	
Heat × length	***		***	
n	151		151	

[a] Coefficient of determination (r^2) for best fit model. L represents significance at $P < 0.01$ level. ns, *, **, ***, are not significant, and significant at P = 0.05, 0.01, and 0.001, respectively.

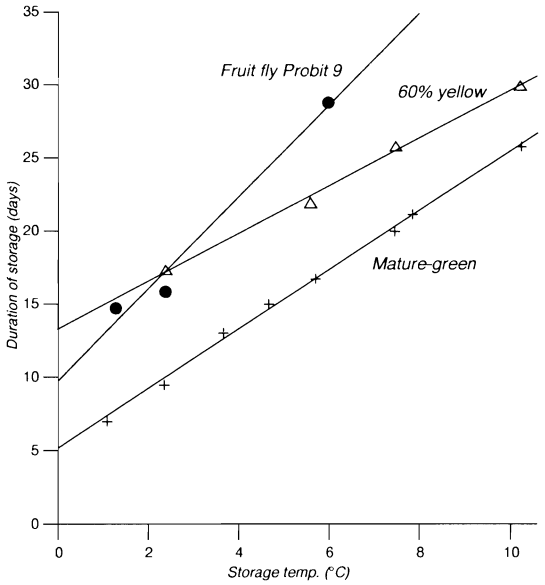

Figure 4. The time and temperature relationship of incipient chilling injury symptom development in papaya fruit and relative sensitivity of fruit flies to low temperatures, papaya chilling injury visible symptom development redrawn from Chen and Paull (1986), and Mediterranean fruit fly mortality data redrawn from Back and Pemberton (1916) and Baker (1939). Above the lines injury symptoms become more severe, while above the line fruit fly mortality reaches Probit 9.

Controlled atmospheres

Comparison of fruit tolerance data and the limited data available on the efficacy of low-O_2 atmospheres in insect control, indicates that insecticidal O_2 concentration/time/temperature combinations may have a potential use as quarantine treatments for some insects and host commodities.

Irradiation

The use of up to 1.0 KGrays for insect disinfestation in fresh horticultural commodities was approved by the U.S. Food and Drug Administration (FDA 1987). Dosages that will kill insects may also damage fruit; lower dosages that sterilise, are recommended. Unfortunately, a sterilising dose leaves live larvae and may cause regulatory problems. Treatment studies under actual or simulated harvesting, packing, treating, storing, and shipping conditions must be completed to ensure that the treatment is not in any way irreversibly detrimental to the fruits (Maxie et al. 1971). Other concerns are the economic feasibility (Maxie et al. 1971) and consumer acceptance (Schulz et al. 1989).

Irradiation has potential as a quarantine treatment against fruit flies infesting avocado, mango, citrus, tomato, lychee, banana, papaya, pome fruits, stone fruits, and strawberry (Heather 1986). Irradiation has been shown to be effective against mango weevil infesting the seeds of commercial mangoes. Cut flowers and other ornamentals with a diverse population of

insects are another group of commodities where irradiation may be successful (Wit and van de Vrie 1985a).

Low doses (250 Grays) have not been found to alter the dry matter, total and reduced ascorbic acid, carotenoids, pH, titratable acidity, total soluble solids, or total reducing sugar of papayas, and the fruit in these tests were reported to be firmer. More recent studies (R.E. Paull, unpublished data) have shown that fruit firmness varies with season and stage of fruit ripening when irradiated. Skin scald can also be a problem on papaya that are irradiated and then immediately placed into storage at 12.5°C. Irradiation of banana at 250 or 500 Grays delays ripening about 2 days at normal ripening temperatures. Irradiation at these dosages is not fungistatic. Mango palatability was preserved only if the fruit received a dose of less than 100 Grays, although different mango varieties can withstand higher doses without affecting quality.

Washing

The simple technique of washing may be used as a quarantine treatment for pest organisms found on the surface of host commodities. The addition of a detergent (insecticidal soaps) increases the effectiveness of washing by dissolving the waxy epicuticle of insect pests and causes rapid drowning (Hata et al. 1992). Additionally, the use of hot-water washing may kill surface pest organisms if the thermal death-point of the target organism is reached.

High and low pressures

High pressure and vacuum treatments can be used in conjunction with fumigants and controlled or modified atmospheres. This treatment increases penetration of the host commodity and enhances their effect on the target pest organisms. Reduced pressure has been suggested to control green peach aphid, *Myzus persicae* (Aharoni et al. 1986).

Conclusions

No single quarantine treatment or system can be expected to work equally against all insects or for all host fruits, and the response to any treatment can vary greatly. Entomologists and postharvest physiologists need to develop insect dosage–mortality information following a standardised protocol to determine the treatment levels required to insure that horticultural commodities can be shipped through domestic and international marketing channels without the risk of transporting unwanted insect pests or loss of the commodity quality attributes of appearance, texture, flavour, shelf life, and nutritive value.

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Microwaves as a Quarantine Treatment to Disinfest Commodities of Pests

Jennifer L. Sharp*

MICROWAVES (radio frequency) comprise that portion of the electromagnetic spectrum from 10 kHz to 100 GHz. Frequencies in that range have been used to heat objects by converting electromagnetic energy to heat energy. Frequencies >1 GHz are the ones most commonly used to heat foods.

Considerable research has been done using radio frequency heating to control pests of grains and nuts. Several reviews have been published (Frings 1952; Thomas 1952; Nelson 1967, 1972, 1973; Kirkpatrick 1974).

Limited research has been done using radio frequency heating to control pests of tropical and subtropical fruits. Problems have been encountered with damage to the treated fruits. Two examples of using radio frequency energy to kill insects in fruits have not been encouraging. Seo et al. (1970) used a microwave oven to kill mango weevil, *Sternochetus mangiferae* (F.), in mango seed. Mangoes were damaged by the temperatures generated. Damage was reduced, but not eliminated, by treating mangoes with repeated 10–15 second intermittent bursts of treatment instead of continuous treatment. Hayes et al. (1984) subjected papayas infested with oriental fruit fly, *Bactrocera dorsalis* (Hendel), to microwave treatment until centre temperature reached 38–45°C, followed by immersion in 48.7°C water for 8–20 minutes. The fruit were damaged. Tephritidae flies oviposit eggs singly or in masses below the peel surface, or as with papaya fruit fly, *Toxotrypana curvicaudata* Gerstacker, next to, or in seeds present in the fruit cavity. Heating must be uniform throughout the treated commodity to ensure that all stages of the pest are killed, regardless of where they may occur.

Papaya fruit fly and Caribbean fruit fly, *Anastrepha suspensa* (Loew), are fruit flies of economic importance in Florida. Neither papaya nor grapefruit may be shipped from Florida to citrus-producing areas in Texas, Arizona, and California, or to Hawaii and Japan, unless the fruits have been treated with an approved quarantine treatment. No approved treatment exists for papaya from Florida. Approved treatments for grapefruit are methyl bromide fumigation, cold temperature storage, and vapour heat (APHIS 1992). Use and production of methyl bromide may be suspended by the United States Environmental Protection Agency because that fumigant is suspected of being a stratosphere ozone depletor (Anonymous 1993). Alternate quarantine treatments are needed. One such treatment is microwave heat.

Newer microwave ovens designed for research purposes have variable power adjustment that provide a range of wattages. Precise power can be obtained that will kill insect infestations without causing damage to the treated commodity.

Herein I present results of a study that investigates microwave heating of grapefruit and its effect on fruit quality.

Materials and Methods

'Marsh' white grapefruit, *Citrus paradisi* Macf. (mean ± SE, 428.2 ± 17.0 g; range, 400.1–474.2 g) obtained from packing houses in central Florida were weighed and each equipped with three temperature sensors. The sensors were connected to a Model 1450 Fiberoptic Multisensor System (Photonetics, 18800 142nd Avenue, N.E., Woodinville, WA 98072) (Fig. 1a). The sensors are composed of fibre optic strands to precisely measure temperature in each grapefruit at different areas. The accuracy of fibre optic sensors is 0.5–1% of full scale. One sensor was placed in the centre of the fruit; one in pulp tissue one half the distance from the peel and centre pulp; and one 1 mm below the surface of the peel. Grapefruits were heated singly until the area that heated slowest reached 48°C. Heating was done using a MDS 2000 research microwave (CEM Corp.,

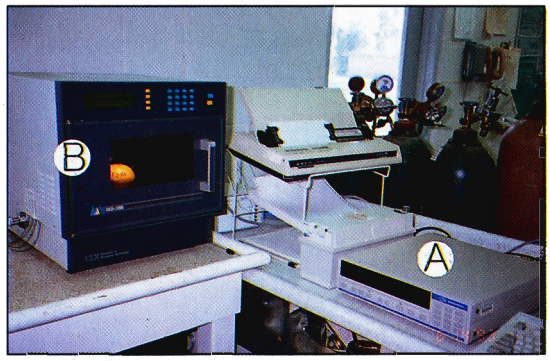

Figure 1. Microwave heating system: (a) Photonetics fiberoptic multisensor system; (b) CEM Corp. MDS 2000 microwave oven.

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3100 Smith Farm Road, P.O. Box 200, Matthews, NC 28106-0200) (Fig. 1b). The microwave power system was equipped with operator selectable output of 0–630 W (±50 W) in 1% increments. Preliminary heating was done at 2, 3, and 4% power settings. Based on the results, replicated heating tests were done at 5 (about 30 W), 10 (about 56 W), 50 (about 324 W), and 100% power (about 658 W). Fifteen grapefruits were heated individually at each power.

The quality of grapefruits was tested following microwave heating for 30 min with 5% power. A total of 23 grapefruits was heated individually. The fruit were checked visually for peel bronzing, pitting, and firmness. Pulp was examined for texture, aroma, and taste by employees. A total of 23 grapefruits not heated constituted the controls. Grapefruits were stored at 20–23°C and evaluated 5 and 11 days after the heat treatment.

Results and Discussion

Figs 2a–2g show the heating sequence at the centre, pulp, and surface of grapefruit. Areas inside grapefruit

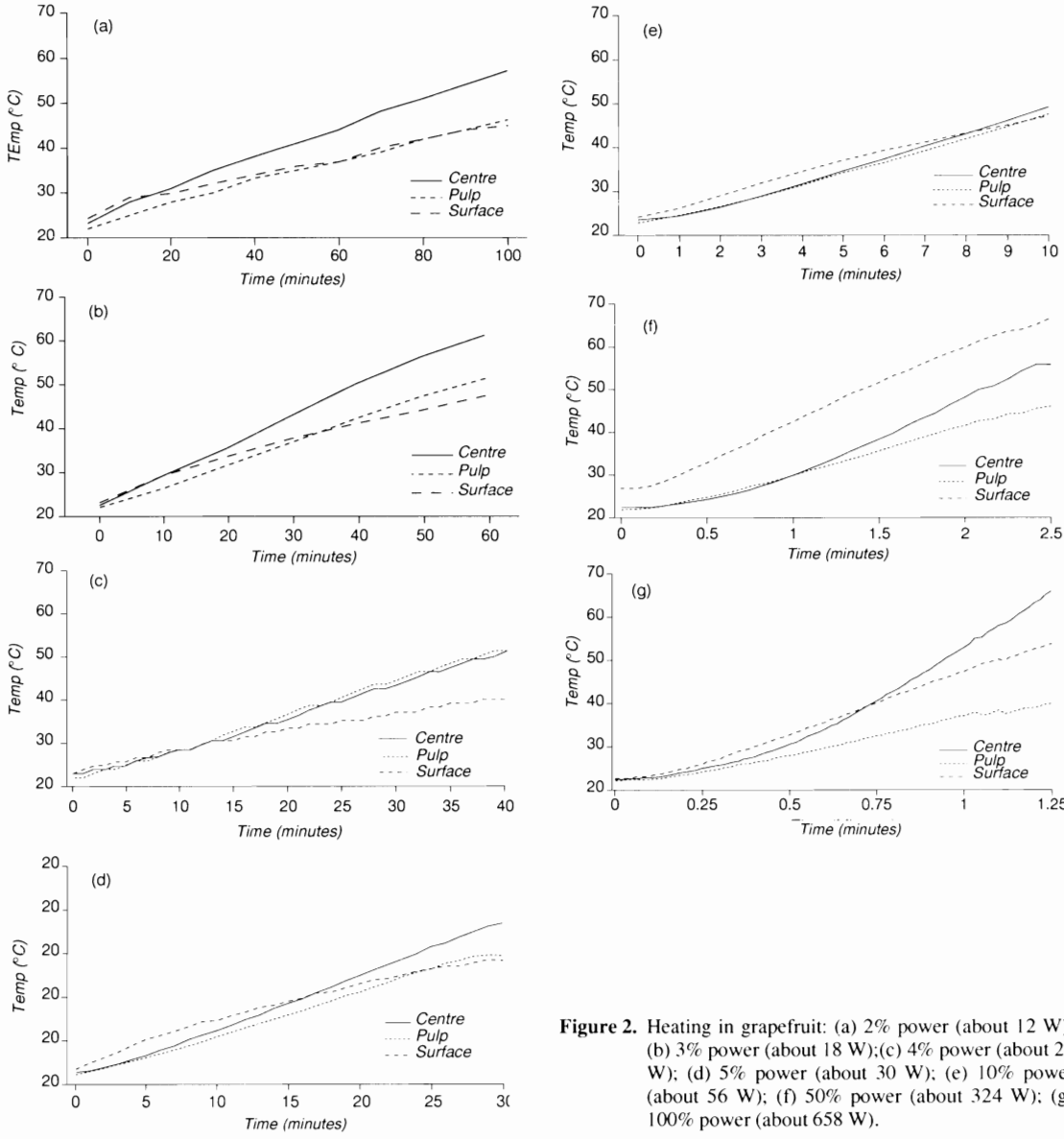

Figure 2. Heating in grapefruit: (a) 2% power (about 12 W); (b) 3% power (about 18 W);(c) 4% power (about 24 W); (d) 5% power (about 30 W); (e) 10% power (about 56 W); (f) 50% power (about 324 W); (g) 100% power (about 658 W).

heated at different rates. Tests at 5, 10, 50, and 100% power showed that centres reached 50°C in about 25, 10.5, 2, and 1 minute(s), respectively. Velocities of heating rates depend on power (wattage), type of magnetron, load and position of the commodity in the oven, and physical properties of the treated commodity (Buffler 1993). Regardless of the rate of heating, the target temperature must be reached to ensure quarantine security (99.9968% mortality) without damaging quality of the commodity. Target temperatures of 48–50°C were chosen because research has shown that fruit fly eggs and larvae are killed by exposure to heat at these temperatures (Armstrong et al. 1989; Mangan and Ingle 1992). Heating grapefruit using water (Sharp 1985), vapour (Hallman et al. 1990), and hot air (Sharp 1993) requires from one to three hours of heating to reach 48–50°C. Microwave heating has an advantage over convective forms of heating in that it is more rapid.

Compared with untreated grapefruit, heating at 5% power for 30 minutes did not produce shrivelling, scald, pitting, or bronzing of the peel. Taste and aroma were not adversely affected. Pulp texture was not changed. Grapefruit was reported to taste less bitter and appear in better condition compared with controls.

Conclusions

Based on results of the tests, controlled microwave heating should be pursued as a quarantine treatment against fruit flies infesting grapefruit. Heating at 5% power for 30 minutes produced lethal temperatures and did not damage the condition or quality of treated grapefruit.

Microwave heating would be feasible only in a small space because power requirements increase by the square of the distance from the radiating source. Fruit could be passed slowly on a conveyor. The velocity of microwave heating is inversely proportional to the mass and number of heated objects.

High energy costs compared with other disinfestation methods, uneven heating, and damage to commodities have been the primary reasons why microwave heating has not been used commercially in insect control.

Acknowledgments

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Effect of pH and Sugar Concentration on Apple Cider Quality

Yuniarti*, Suhardi†, and Soenarso†

MALANG is the main apple-producing area in Indonesia. The most common variety grown is Rome Beauty. Fruit thinning has been shown to improve the size, colour, and eating quality of Rome Beauty apples, and has reduced damage by pests and diseases (Kusumo 1986). The fruit thinnings can be used to produce cider, an alcoholic drink, rather than being treated as very low value waste fruit.

Sugar concentration and pH are the main factors determining the final alcohol content of cider. According to Cruess (1948), the optimal sugar concentration is 22%, while Amerine and Joslyn (1951) suggest 28%, and Tirtosukotjo (1987) 10–15% added sugar. Consumer preferences on the sugar content of cider also vary. Fermentation yeasts have pH preferences. Fraizer (1967) suggests an optimal range of pH of 4–4.5 for yeast activity. Under optimal conditions, fermentation will be extended and result in a higher alcohol content (Tirtosukotjo 1987), while at lower acidities, the growth of bacteria will be favoured (Prescot and Dunn 1959).

The aim of the research reported was to determine the sugar concentration and pH needed to produce a cider having a high alcohol content and meeting consumer preferences.

Rome Beauty apples collected from orchard thinnings were used. Fruit were washed, blended, and juiced. Sugar concentration was set by adding a heavy syrup till the preferred sugar concentration was reached. pH was set by adding citric acid to the solution. The mixture was then heated to 90–100°C, cooled to room temperature, then inoculated with *Saccharomyces cereviseae* yeast.

The research used a complete randomised design, comprising a factorial with 3 replications. The first factor was pH: 3.5, 4.0, and 4.5. The second factor was sugar concentration: 10, 15, 20, 25, and 30%. Each treatment consisted of 1 L of solution.

Fermentation was assumed to be complete when gas bubbles were no longer visible. The following measurements were then made: acid content; sugar content by total soluble solid measurement using a refractometer; alcohol content by the AOAC method (Anon. 1975); and taste preference using a hedonic scale score. Scores used were: 6, like very much; 5, like; 4, neither like nor dislike; 3, rather dislike; 2, dislike; 1, dislike very much.

Results

Statistical analysis of the results showed that there was no significant interaction between sugar concentration and pH and the acid, soluble solid, and alcohol content of cider. Sugar concentration had a significant influence on the characteristics of the cider produced (Table 1). Total acid content at the sugar concentrations of 20, 25, and 30% was higher and significantly different from that at sugar concentrations of 15 and 20%.

Table 1. Effect of sugar concentration to the total acid, soluble solid, and alcohol content of cider

Sugar concentration (%)	Acid content (%)*	Soluble solids (%)*	Alcohol content (%)*
10	0.2039a	4.78a	4.76a
15	0.2314a	6.00b	7.55b
20	0.2834b	7.50c	10.86d
25	0.2812b	13.15d	10.72d
30	0.2838b	20.56e	9.69c

* Numbers followed by the same letters were not significantly different according to DMRT at 5% level.

Measured soluble solids were significantly different between sugar concentrations. The highest soluble solid resulted from 30% sugar concentration.

A sugar concentration of 20% yielded the highest alcohol content but this was not significantly different from that resulting from a sugar concentration of 25%. Alcohol content from 10% sugar concentration was lower and significantly different from that yielded by a 25% sugar concentration. Strains of *S. cereviseae* tolerant to both low and high sugar concentrations were used (Amerine and Joslyn 1951). Analysis of residual sugar showed whether or not fermentation was complete (see soluble solid column in Table 1). In this experiment, 30% sugar concentration proved to be the highest concentration that could be fermented (Table 1). pH had a significant effect on acid content only (Table 2).

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Table 2. Effect of pH on the total acid, soluble solid and alcohol content of cider

pH	Acid content (%)*	Soluble solids (%)*	Alcohol content (%)*
3.5	0.3117a	10.28a	8.54a
4.0	0.2458b	10.43a	8.78a
4.5	0.2127c	10.52a	8.85a

* Numbers followed by the same letters were not significantly different according to DMRT at 5% level.

Table 3 shows that sugar concentration had a significant effect on taste preference, but pH did not. The highest score for taste resulted from a sugar concentration of 30% combined with pH of 4.0 or 4.5, but this was not significantly different from 30% sugar, pH 3.5, or from all 25% sugar concentration results.

Table 3. Preference scores for taste of combined treatments in preparing cider.

No.	Combined treatment	Scores*
1.	Sugar 10%, pH 3.5	1.6a
2.	Sugar 10%, pH 4.0	1.6a
3.	Sugar 10%, pH 4.5	2.2a
4.	Sugar 15%, pH 3.5	2.0a
5.	Sugar 15%, pH 4.0	1.6a
6.	Sugar 15%, pH 4.5	1.8a
7.	Sugar 20%, pH 3.5	1.8a
8.	Sugar 20%, pH 4.0	3.2abc
9.	Sugar 20%, pH 4.5	2.6ab
10.	Sugar 25%, pH 3.5	4.2bcd
11.	Sugar 25%, pH 4.0	4.8cd
12.	Sugar 25%, pH 4.5	5.0d
13.	Sugar 30%, pH 3.5	4.8d
14.	Sugar 30%, pH 4.0	5.4d
15.	Sugar 30%, pH 4.5	5.4d

* Numbers followed by the same letters were not significantly different according to DMRT at 5% level.

Conclusions

The highest yields of alcohol came from 20 and 25% sugar concentrations. Sugar concentrations of 25 and 30% were most preferred by consumers. Based on alcohol produced and sugar concentration preferred by the consumers, the best treatment was 25% sugar concentration combined with pH of 3.5, 4.0, or 4.5.

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Osmotic Dehydration of Membrane-coated Pineapple

Wuryani* and N. Poulter†

Osmotic dehydration is widely used in the confectionery industry for manufacturing candied fruits. However, application of the technique to membrane-coated foods, especially pineapple, has not been developed. The process is simple and may be applicable in developing countries where sophisticated equipment is often not available.

Osmosis involves the passage of a solvent from a less concentrated to a more concentrated solution through a membrane (Hope and Vitale 1972). Thus, when fruit pieces are immersed in a solution which has higher osmotic pressure than that of the fruit, a driving force for water removal arises between solution and fruit (Lerici et al. 1985). Generally, water is removed from the fruit to the extent of 30–50% of its original fresh weight, the cell wall acting as a 'semi-permeable' membrane (Ponting 1973).

However, in an attempt to achieve osmotic balance, solute molecules will pass from the osmotic solution into the fruit through the same cell membrane. This membrane is only partially selective, so there is always some leakage of solute from the osmotic solution into the fruit and from the fruit into the solution (Lerici et al. 1985). Direct osmotic dehydration is therefore a simultaneous water and solute diffusion process, although not by equal amounts, because water passes more readily than the larger solute molecules (Ponting 1973).

Further water can be evaporated from the partially dehydrated fruit by a conventional drying method, such as vacuum dehydration, yielding an intermediate moisture fruit with lower moisture content (ca. 15%).

According to Lerici et al. (1985), the osmotic solution used must have a low water activity, be harmless, and have a good taste. Concentrated sucrose solution (50–70°Brix) is the most commonly used solute.

The emphasis of the experiments reported here was to reduce the amount of sucrose passing into the fruit pieces during osmotic dehydration by coating the fruit to be dehydrated with an edible membrane. This membrane has to be permeable to water molecules but not to sugar molecules. As a result, membranes with a higher degree of rejection than that exhibited by the membranes of the fruit itself are necessary (Camirand et al. 1968). A dehydrated product with high sugar content may be undesirable, mainly due to its unacceptable taste, or for health reasons.

The work involved use of pectin and alginate as pineapple coating materials and an investigation of their ability to reduce sugar molecule penetration into the fruit during osmotic dehydration.

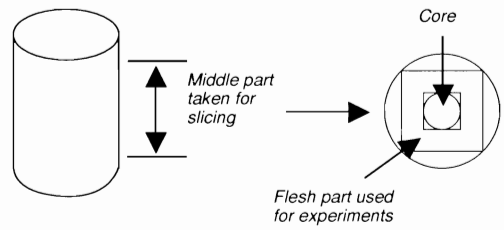
Materials and Methods

Pineapple from Kenya and the Ivory Coast was purchased from a local fruit seller in London.

Sucrose (from sugar cane), D-glucose, and citric acid were used to prepare the osmotic solution. Low-methoxy pectin and sodium alginate were coating materials. The calcium ions were provided by calcium chloride and calcium lactate. All of these compounds were reagent grade.

Fruit preparation

The pineapple was manually peeled and cut into slices (1 cm thickness). The fruit slices were cut further to form 'cubes' (1.5 × 1.5 cm).



The sampling uniformity test

The prepared pieces of pineapple obtained from 5 fruit were mixed and divided randomly into 8 parts. The 8 representative samples were analysed for moisture content and refractive index.

Fruit coating

About 40–50 g of fruit (20 cubes) were placed in a 2% solution of low-methoxy pectin for 1 minute. After

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removal from the solution they were drained for 5 minutes before dipping for 1.5 minutes in a solution of 20% calcium chloride containing 2% citric acid.

Sodium alginate (2%) was also used for treating the same amount of pineapple. Soaking was carried out for 2 minutes, followed by draining for 5 minutes. The cubes were then dipped in a 3% solution of calcium lactate for 5 minutes.

The coated fruit slices were then drained and kept in a refrigerator overnight.

Osmotic dehydration

The coated and non-coated (control) pineapple pieces were placed in conical flasks containing 70°Brix syrup prepared from glucose and sucrose (50:50). This syrup contained 0.5% citric acid. The ratio of syrup and coated fruit was 1:2.4 (w/w). The flasks were placed in a water bath at 55°C, and were gently and constantly agitated, After varying periods the flasks were removed and their contents drained for about 1 hour before analysis.

Chemical analysis

The fruit samples were analysed before, during, and at the end of the osmotic process (0.0, 1.5, 3.0, 4.5 and 6.0 hours). The factors measured were moisture content and refractive index. The water content was determined by drying under vacuum at 70°C until a constant weight was obtained. The refractive index was measured with an Abbe refractometer.

Results and Discussion

To ensure homogeneity of samples, their moisture contents and refractive indexes were measured before the experiments started (Table 1).

Table 1. The moisture content and refractive index of selected parts of 5 pineapples

No. of sample	Moisture content (%)	Refractive index (°Brix)
1	89.15	9.25
2	89.29	9.25
3	89.59	9.25
4	89.59	9.30
5	89.83	9.30
6	89.68	9.25
7	90.04	9.40
8	89.40	9.30

The experimental results (Tables 2 and 3) demonstrated that during osmotic dehydration, coated and non-coated pineapples showed interchanges of solute components. Water was lost from the fruit, and sugar molecules were absorbed into the fruit, though not in equal amounts.

Table 2. Moisture content and refractive index of low-methoxy pectin-coated and uncoated pineapple dehydrated in a 70°Brix 50% glucose–sucrose solution at 55°C

Dehydration time (hours)	Moisture content (%)*		Refractive index (°Brix)	
	control	coated	control	coated
1.5	65.19	65.73	19.60	19.60
3.0	60.37	59.37	24.00	22.50
4.5	58.78	58.59	45.00	44.75
6.0	56.11	56.32	45.50	45.00

* The untreated pineapple had 90.38% moisture content and its refractive index was 8.25°Brix.

Table 3. Moisture content and refractive index of sodium alginate-coated and uncoated pineapple dehydrated in a 70°Brix 50% glucose–sucrose solution at 55°C

Dehydration time (hours)	Moisture content (%)*		Refractive index (°Brix)	
	control	coated	control	coated
1.5	59.78	63.34	35.50	35.00
3.0	53.29	57.20	41.00	35.60
4.5	52.78	55.75	42.50	38.00
6.0	51.59	54.51	45.00	42.00

* The raw material had 82.80% water and its refractive index was 14.5°Brix.

It is interesting to note that most of the moisture and solid content exchange occurred within the first 1.5 hours of the process. After this the movement of water from the tissue to the sugar solution proceeded more slowly. The results also show that moisture content reduction of the fruit tissue started immediately, owing to removal of water close to the surface. However, it is increasingly difficult for water deeper within the tissue to diffuse to the surface. According to Hulme (1971), the latter situation is caused by the greater distance to travel, the collapse of cells closing diffusion pathways, interruption of flow by entrapped air pockets, and increasing viscosity as the concentration of solids (particularly sugar) rises. Attempts were made to overcome these problems during this experiment, as follows.

- In order to reduce the distance for water diffusion, the pineapple was cut into small 'cubes' (1.5 × 1.5 × 1 cm).
- A highly concentrated sugar solution was used (70°Brix). Hope and Vitale (1972) reported that more water will be removed in a given period if a higher starting concentration of sucrose solution is used.

- The osmotic dehydration was carried out at a relatively high temperature (55°C) because it is known that diffusion rates are temperature dependent. Also, at higher temperatures syrup solution is less viscous and more easily circulated. Speirs (1986) noted that higher temperatures and/or shorter operation times favour reductions in microbial contamination of both pineapple and syrup (particularly important if osmotic solvent is to be reused).
- Gentle and constant agitation was also applied. During dehydration, the osmotic solution becomes diluted because of sugar molecule loss, as well as through the uptake of water from the fruit. Consequently, circulating the syrup around fruit pieces is necessary to prevent localised areas of dilution. The rate of dehydration in stirred mixtures will thus be faster than in an unstirred system. Hawkes and Flink (1978) noted that samples prepared with agitation have higher levels of solute uptake than non-agitated samples.
- Citric acid was added to the system (0.5%). This accelerates the process of osmotic exchange, though not to the same extent as increased temperature. The reduction in pH also minimises microbiological activity (Speirs 1986). In this experiment, the pH of the dehydration system was 3.0, which was also required for initiating gelling and formation of the membranes.

The mechanism of calcium pectate and calcium alginate gel formation is as follows. After pineapple pieces were dipped in either low-methoxy pectin or sodium alginate solution, followed by draining, the water evaporates from a thin layer of those solutions on the fruit surface. The pectin or alginate itself remains in the form of a continuous and usually transparent film. This film can be redissolved in water, but can also be converted to a film of water-insoluble pectin or alginate. The latter process is achieved by treating the film with a calcium salt solution. Gelling behaviour and thermal depolymerisation of pectin is effected by esterification of its galacturonic acid residues. In addition, Fennema (1985) notes that reaction between calcium ions and alginate is highly influenced by D-mannuronic acid and L-guluronic acid composed in the structure molecule of alginates.

The coating treatment with both pectate and alginate gave the best results following a soaking time of 3 hours. The refractive index of pectate-coated fruit (22.50°Brix) was lower than the control (24.00°Brix). Apparently, calcium alginate has a higher degree of rejection than that exhibited by both calcium pectate and natural membranes of the fruit (control). The refractive index of alginate-coated pineapple was 35.60°Brix, 5.40 points lower than the control (41.00°Brix).

A more substantial difference in sugar uptake between coated and uncoated fruit pieces was expected. The membrane formed may be improved by the following means.

- Optimising the reaction between pectin and calcium ion. The amount of calcium present in the system affects whether a temporary or permanent film will be formed. However, calcium chloride imparts an unpleasant taste to foods when used at high levels. Although calcium lactate is preferred for taste reasons, it has a relatively low solubility (ca. 5% by weight) in water (Anon. 1983).
- Lowering the soaking temperature. Bradshaw et al. (1976) found that low-methoxy pectin gave 'not so firm' texture after heating. Moreover, according to Camirand et al. (1968), to prevent thermal degradation the processing temperature should be no more than 30°C.
- Increasing the pH. The pH of the calcium solution (20% calcium chloride containing 2% citric acid) was 1.0, therefore, when low-methoxy pectin solution reacted with this calcium solution, degradation by hydrolysis might have occurred.
- Adjusting the porosity of the thin film formed around the fruit pieces, so only the sugar molecules could pass through the membrane.

Suggested further work

Dehydration of membrane-coated fruits could become an important preservation process if membranes giving a higher rejection degree can be found. Consequently, more intensive studies are needed on other edible materials. It is necessary to determine the characteristics of the membranes formed — their thickness, porosity, continuity, and stability — before their application in osmotic dehydration. Also, it would be desirable to complete all experiments with a panel test.

Conclusion

Osmotic dehydration could be applied for reducing the water content of pineapple by up to 40%. Sodium alginate may have potential as a fruit coating. It gave a larger (5.40°Brix) difference in sugar uptake between coated and uncoated fruit than did low-methoxy pectin (1.50°Brix).

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Anti-fruit-fly Activity of Extracts of Black Pepper and Other Edible Plants

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TECHNIQUES for disinfestation of fruit flies include fumigation, radiation, heat treatment, fruit fly baits, and a combination of the these treatments, or harvesting the fruits in the unripe stage. Unripe papaya, for example, contains benzyl isothiocyanate which inhibits the growth and development of fruit fly eggs and larva (Seo et al. 1983). Insecticidal pyrethrins which have low toxicity in mammals have been isolated from pyrethrum flowers, (Windholz and Budavari 1983). Unfortunately, although pyrethrins can kill insects by destroying their nervous systems, they are unstable in light and air (William et al. 1985) and their structure must be modified before they can be used in the field. This report describes a search for non-toxic or a low toxicity insecticidal compounds that may be naturally present in edible plants. These would be used for topical application on harvested fruit, together with surface coatings or other dips.

Materials and Methods

Solvent-free methanol extracts from chilli (*Capsicum annum*), petai *(Parkia speciosa)*, galangal *(Languas galanga)*, onion *(Allium cepa)*, nutmeg *(Myristica fragrans)*, cinnamon *(Cinnamon iners)*, clove *(Eugenia aromatica)*, jering *(Pithecellobium jeringa)*, black pepper *(Piper nigrum)*, ginger *(Zingiber officinale)*, pandan *(Pandanus odorus)*, betel leaves *(Piper betle)*, cummin *(Cuminum cyminum)*, kencur *(Kaemphera rotunda)*, lemon grass *(Cymbopogon citratus)*, and coriander *(Coriandrum sativum)* were screened for activity against *Drosophila melanogaster* (vinegar fly).

Sample preparation

Samples obtained from the evening market were extracted with methanol. A general extraction procedure consisted of soaking the samples overnight in the solvent, filtering the solution, then removing the solvent using a rotary evaporator. The extraction was repeated three times, each time using a fresh solvent. The combined extracts of each solvent were kept refrigerated for anti-fruit-fly screening.

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Anti-fruit-fly screening

D. melanogaster were bred in large flasks on a medium containing 3% agar, 50% ripe bananas, 0.6% live yeast, and 600 ppm methyl paraben. Screening was carried out on *D. melanogaster* eggs and larvae, using the method of Kawazu et al. (1989). Care was taken to avoid immersion of the eggs in the medium, which will reduce their hatchability.

Results and Discussion

Table 1 shows the average percentage mortality of *D. melanogaster* resulting from the various methanol extracts. Also given are the weights of the residues obtained from the methanol extracts. At 0.1% concentration it was found that black pepper had the highest insecticidal activity, causing 97.1% death of *D. melanogaster* larvae. Extracts which had less than 50% mortality were considered not to have adequate insecticidal activity.

Table 1. Average percentage mortality of *Drosophila melanogaster* in the various organic extracts of various herbs and the weight of the residues obtained from the methanol extracts.

Samples (g residue/100 g sample)	Concentration (g/L)			
	0	0.01	0.1	1
Control (0)	5.0	5.0	5.0	5.0f
Black pepper (21.3)	5.0	71.3	76.9	97.1a
Chilli (13.1)	5.0	62.8	68.4	74.1b
Jering (8.9)	5.0	48.3	62.6	71.3b
Petai (9.2)	5.0	48.3	74.1	65.2b
Cummin (23.8)	5.0	22.5	32.5	70.0b
Cloves (19.9)	5.0	36.6	59.8	59.8bc
Galangal (4)	5.0	26.1	59.8	54.0bcd
Betel leaves (28.2)	5.0	7.5	22.5	55.0bcde
Ginger (24.8)	5.0	29.0	36.8	51.2bcde
Coriander (23.6)	5.0	25.0	25.0	32.5def
Pandan (20.3)	5.0	10.0	30.0	30.0ef
Cinnamon (24.4)	5.0	14.7	24.1	49.1f
Onions (19.7)	5.0	14.6	23.3	42.5f
Nutmeg (13.6)	5.0	23.3	31.0	39.7f
Kencur (13.2)	5.0	12.5	20.0	22.5f
Lemon grass (11.3)	5.0	13.0	15.0	30.0f

Means followed by same letter are not significantly different at 5% level

Since pepper extract was found to have the highest insecticidal activity, dried, powdered pepper seeds were sequentially extracted with petroleum ether, chloroform, dichloromethane, ethyl acetate, 25% ammoniacal chloroform, and finally methanol.

The average percentage mortality of *D. melanogaster* in the various organic extracts of black pepper and the weights of the residues obtained from the various extracts are shown in Table 2.

Table 2. Average percentage mortality of *Drosophila melanogaster* in various organic extracts of black pepper and the weight of the residues obtained from the various extracts.

Residue (g/300 g sample)	Concentration (mg/L)				
	0	0.001	0.01	0.1	1
Control (0)	5.0	5.0	5.0	5.0	5.0c
Petroleum ether (12.7)	5.0	22.5	32.5	65.0	95.0a
$C_2H_5OC_2H_5$ (7.6)	5.0	5.0	5.0	15.0	10.0c
CH_2Cl_2 (6.6)	5.0	10.0	42.5	47.5	60.0b
Chloroform (4.3)	5.0	2.5	10.0	27.5	85.0a
Ammon. $CHCl_3$ (3.2)	5.0	7.5	32.5	42.5	85.0a
Methanol (72.0)	5.0	7.5	10.0	30.0	42.5b

Means followed by same letter are not significantly different at 5% level

The lethal concentration (LC50) or effective dosage (ED50) was obtained by plotting the log scale of concentration against percent mortality (Ariens 1976). Petroleum ether, ammoniacal chloroform, and chloroform extracts had the highest insecticidal activity with LC50 values of 0.72 ppm, 0.744 ppm, and 0.688 ppm, respectively. These were followed by dichloromethane extracts and aqueous extracts with LC50 values of 1.34 ppm and 1.5 ppm

It has been shown on many occasions that piperine, one of the alkaloids found in black pepper (Michael and Salem 1987), is more toxic to house flies than is pyrethrum (Windholz and Budavari 1983). Piperine is very soluble in chloroform, petroleum ether, and hexane (Windholz and Budavari 1983) and may be the main anti-fruit-fly component in black pepper. Black pepper extract has also been shown to be effective against cowpea and flour weevils (Gomez et al. 1984), adult *D. melanogaster*, *Ceratitis capitata*, and all life stages of *Sapodoptera littoralis*. Studies by Ganesh and Chandarasekhara (1985) showed that continuous intake of 5% piperine in the diet of rats for one-third of their lifespan (8 weeks) did not significantly affect their growth, food intake, organ weights, or biochemical composition. However, the consumption of 12 g/kg body weight black pepper in rats had carcinogenic effects due to the presence of methylene-dioxybenzene-piperin and kawain alkaloids (Concon 1979).

Further work will be carried out to assess effect of piperine on economically important species of fruit flies (e.g. *Bactrocera dorsalis*), and determine the insecticidal components in chillies, petai, jering, and cummin.

Conclusions

This work confirms the potential of piperine from black pepper chloroform petroleum ether extract as an insecticidal compound effective against *D. melanogaster*.

Acknowledgments

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The Potential Use of Insecticidal Atmospheres for Mango, Avocado, and Papaya Fruits

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FUMIGANTS such as ethylene dibromide (EDB) and methyl bromide (MB) have long been used as a quarantine treatment for horticultural crops. Objection to the use of chemicals because of health risks is rising. EDB has been banned; MB is still being used but is also targeted by authorities. Several physical treatments are being investigated as alternatives. Low temperatures (0–2°C) can be used to control insects but only for crops not prone to chilling injury. Mango, avocado, and papaya are sensitive to chilling. Irradiation can control insects and has potential application for some tropical fruits, but installations are expensive, and there are consumer objections and technical difficulties. High temperatures (water or vapour) have been tested for several fruits, and hot water has been used for papaya and mango. Heat injury and short postharvest life are reported for heat-treated fruits.

Atmospheres with very low oxygen (O_2) and/or very high carbon dioxide (CO_2) are insecticidal, and have been used for commercial grain storage. The time required for 100% mortality varies greatly with species and developmental stage of insect, temperature, relative humidity (RH), and O_2 and CO_2 concentration. The lower the O_2 concentration, the higher the CO_2 level, the higher the temperature, and the lower the RH the shorter is the time for 100% mortality. At temperatures of around 20°C, O_2 concentrations of $\leq 0.5\%$ and CO_2 concentrations of $\geq 50\%$ several insect species are killed in 2–4 days (Ke and Kader 1992). There is still no information available on the control of fruit flies with insecticidal atmospheres. It is advantageous to use insecticidal atmospheres because they leave no toxic chemicals on the fruit, are environmentally safe, and are comparable in cost with chemical fumigants. The cost of treating 1 t of raisins during long-term storage was US$7.61 with MB, US$9.77 with phosphine, and US$8.77–9.66 with low O_2 atmosphere (Soderstrom and Brandl 1983). It takes longer to kill insects with insecticidal atmospheres than with fumigants. In addition, these extreme atmospheres may cause anaerobiosis and fermentation in fresh horticultural crops. The use of these atmospheres is only feasible if they do not harm the fruit. Horticultural crops vary greatly in their relative tolerance to modified and controlled atmospheres. It is important that relative tolerance to insecticidal atmospheres be determined for different fruits and vegetables, in order to evaluate their potential application.

Several experiments were conducted to test the tolerance of avocado (*Persea americana* Mill, cv. Hass), papaya (*Carica papaya* L., cv. Sunrise), and mango (*Mangifera indica* L., cv. Keitt) fruits to these extreme atmospheres (Yahia and Carrillo-Lopez 1993; Yahia and Kader 1991; Yahia et al. 1992; Yahia and Tiznado-Hernandez 1993; Yahia and Vazquez-Moreno 1993). Fruits were exposed to either a static or a dynamic modified or controlled atmosphere, containing either insecticidal low O_2, or low O_2 and high CO_2 (balance is either air or N_2 depending on the atmosphere composition). The fruits were evaluated every day, then held to ripen in air for several days and evaluated again. Fruit evaluation included quality attributes, and chemical analysis of metabolites and activity of enzymes of aerobic and anaerobic respiration. In some experiments sensory evaluation was also conducted. The sensitivity/tolerance of the fruit was evaluated subjectively on the basis of development of off-flavours (alcoholic odours) and tissue injuries.

Avocado, papaya, and mango fruits were found to tolerate these insecticidal atmospheres for 1, 2, and 5 days, respectively, at 20°C. After 1 day in very low O_2 or very low O_2 and very high CO_2 avocado fruit developed off-flavours and tissue injuries (brown discoloration, especially in the vascular tissues). Papaya fruits stored for more than 2 days in insecticidal low O_2 atmosphere developed alcoholic odours. On the other hand, mangoes stored in insecticidal low O_2 and/or high CO_2 for up to 5 days at 20°C did not develop off-flavours or tissue injury, and ripened normally.

Therefore, it is possible that insecticidal atmospheres could be used to control many insects in Keitt mangos (all those insects that can be killed within 5 days), some insects in Sunrise papaya (those insects that can be killed within 2 days), and very few insects in Hass avocados (only those insects that can be killed within a day or less). Entomological studies are needed to specify the species of insects that can be killed by these atmospheres. In addition, further studies with other varieties are also needed before this treatment can be recommended for either of these fruits. During long-term storage insecticidal atmospheres can be used for grains, nuts, and raisins. No detrimental effects were reported in

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these crops due to these atmospheres. If this treatment proves to be adequate for quarantine purposes (application for short period of time) in certain fresh fruits or vegetables (on the basis of their tolerance) it could be applied before or during transit, in a manner somewhat similar to ripening treatments. This is especially promising during marine shipments, where transit time is usually several days and controlled atmosphere containers are available. The potential of these atmospheres for insect control during storage of some less perishable products, and as a short-term quarantine treatment for various perishable fruits and vegetables is therefore very promising and merits further study.

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Preliminary Investigation of Microorganisms Antagonistic to *Colletotrichum gloeosporioides* Obtained from Rambutan

Nuanwan Farungsang, Udom Farungsang, and Somsiri Sangchote*

LONG distance transportation of rambutan (*Nephelium lappaceum* L.) has been impeded by its very short shelf life due to postharvest fruit diseases. *Colletotrichum gloeosporioides* is one of the most important pathogens on rambutan. The potential of biological control as a hygienic and effective control strategy has been investigated.

Flushing leaf, inflorescences, fruit of various stages, and dew were collected from rambutan bushes located in Chanta Buri and Chumphon provinces. Phylloplane microorganisms on the plant parts were suspended in sterile normal saline, diluted, then spread on nutrient-yeast-extract agar (NYDA).

More than 700 bacterial isolates obtained by random sampling from isolation–NYDA-plates were tested against six *C. gloeosporioides* isolates (three for Type I, the others for Type II), and about 200 antagonistic isolates selected. Significant antagonistic characteristics observed were antibiosis and vigorous growth. Yeasts may have been suppressed by vigorous competition from bacteria.

Discoloration of colonies, together with suppression of radial growth and fruiting body formation, and abnormal morphology of conidia or hyphae damaged by antagonistic bacteria, were observed on *C. gloeosporioides* developed under dual culture conditions (Figs 1 and 2). Empty swollen structures and repeated formation of empty appressoria were observed soon after

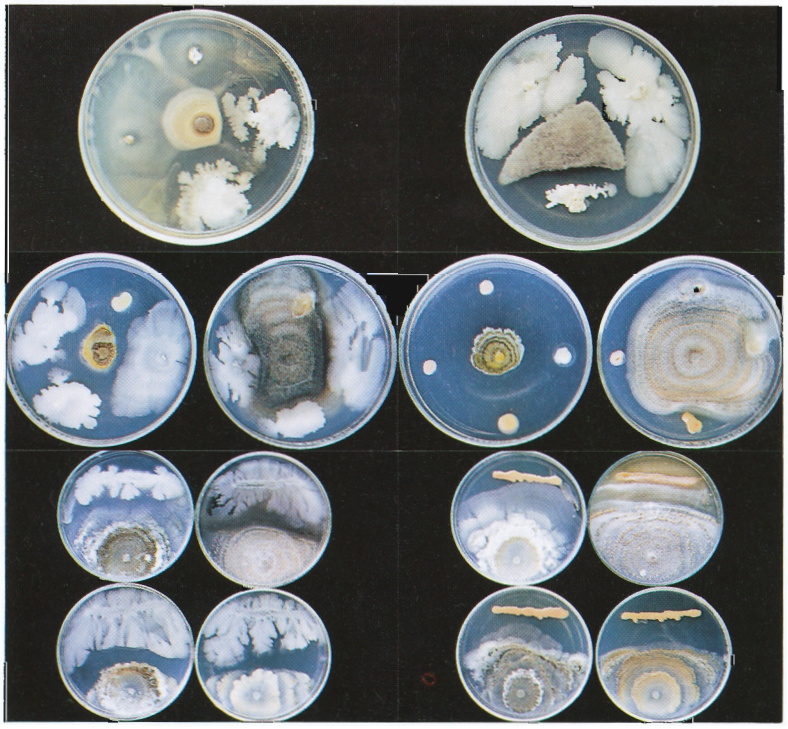

Figure 1. Dual cultures showing antagonistic characters and abnormal development of *C. gloeosporioides* Type I and Type II.

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spore germination amongst mixed populations of the fungus and antagonistic bacterial cells in a drop of sterile water held in a moist chamber at 25–27°C (Fig. 3).

Partial success of postharvest biological control of fruit rot caused by *C. gloeosporioides* Type II was shown by reduction of disease incidence from 85 to 42.5% (Table 1) when detached mature rambutans were dipped for 20 seconds in an antagonist cell suspension before being stored for 20 days at 13°C. The effect of antagonistic bacteria on *Lasiodiplodia theobromae*, *Pestalotiopsis* sp., and *Phomopsis* sp. was also tested (Table 1).

Further investigation of the aetiology and ecology of pathogen infection, as well as strategies of screening and application of antagonistic microorganisms effective for control of quiescent *C. gloeosporioides* appear warranted.

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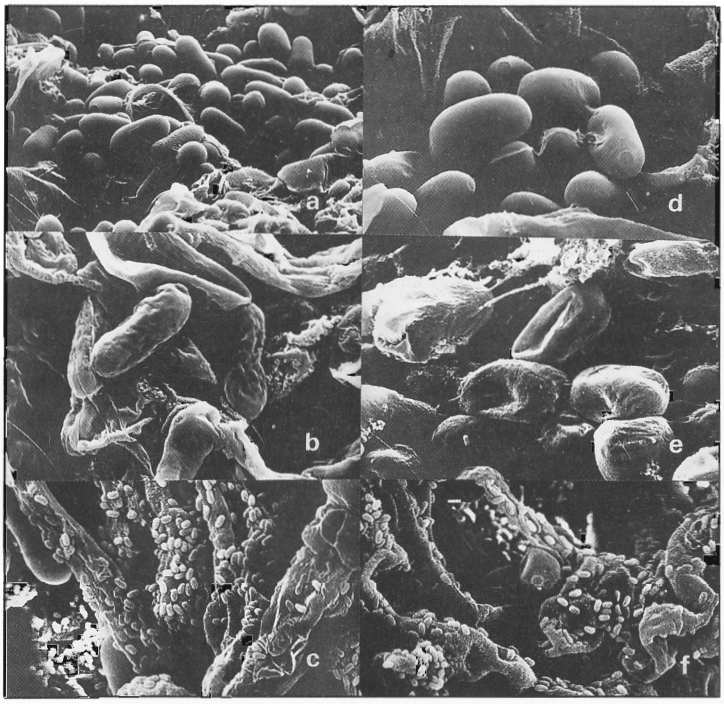

Figure 2. Scanning electron micrographs of *C. gloeosporioides* Type I (a–c) and (d–f): normal (a,d), pitted wall or wrinkled conidia (b,e) and fungal structures damaged and invaded by antagonistic bacteria cells (c,f).

Table 1. Effect of antagonistic bacteria on disease incidence caused by various postharvest fungal pathogens on rambutan

Antagonistic isolates	Percentage of fruit affected			
	C. gloeosporioides Type II	*L. theobromae*	*Pestalotiopsis* sp.	*Phomopsis* sp.
Anta 1	61.25	7.50	2.50	28.75
Anta 2	62.50	7.50	5.00	25.00
Anta 3	42.50	40.00	0.00	17.50
Anta 4	86.25	0.00	1.25	12.50
Non-suspended	86.25	10.00	0.00	5.00
Non-dipped	85.00	10.00	0.00	5.00

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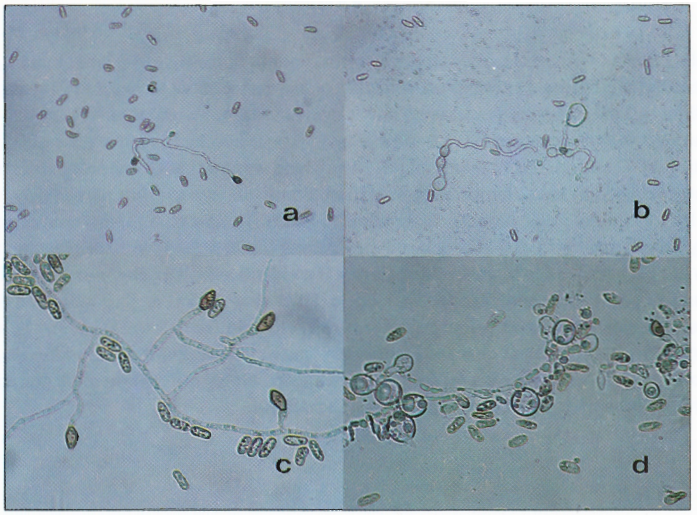

Figure 3. Development after spore germination of *C. gloeosporioides* Type II after 42 hours (a,b) and 48 hours (c,d): normal (a,c); chain of repeated formation of appressoria (b); and swollen structures (d).

Electron Beam Irradiation Combined With Hot-water Immersion Treatment for Banana Preservation

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Abstract

A study of the effects of minimal processing treatments, both individually or in combination, was carried out in order to extend the shelf life and to improve the quality of bananas without the use of refrigeration. Preclimacteric bananas at light full three-quarter grade, were either treated with hot-water immersion for 1–30 minutes at 45–55°C or irradiated with electron beams (2.0 MeV Van de Graaff accelerator), to a dose of 0.1–1.5 kGy. All fruit was stored at 21±1°C and relative humidity of 85–95%. There was no significant delay in ripening of fruit treated with hot-water immersion at the temperature specified. Some damage to fruit, particularly peel scalding at the ends of the fruit, occurred at the higher temperatures (>50°C). The 50°C, 5 minute-immersion was selected for further study. Irradiation to 0.1–0.3 kGy delayed the ripening (up to 3 days) without affecting fruit quality. Doses greater than 0.4 kGy resulted in extensive discoloration and fruit splitting. The immediate effects of irradiation included losses of peel texture and vitamin C content at doses above 0.5 kGy. Due to limited depth of penetration (50% of dose remained at 7.5mm below peel's surface), electron beam irradiation can be utilised for surface treatment only. Physico–chemical changes of ripening fruits at predetermined sampling days, and when fruits were at colour stage 5, were investigated for the 2 treatments. No significant organoleptic differences could be detected between bananas irradiated at 0.15 kGy and the control.

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Fruit Fly Problem and Disinfestation Research in Malaysia

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Abstract

Malaysia has emerged as one of the leading exporters of tropical fruits. The value of Malaysian fruit exports exceeded US $200 millions in 1992. However, one of the main pest problems faced by fruit growers is fruit fly, primarily *Bacterocera dorsalis* Hendel. Together with the Australian Centre for International Agricultural Research (ACIAR), the Malaysian Agricultural Research and Development Institute (MARDI) has developed PROMAR, a protein bait to combat the fruit fly menace in the field. Fruit fly is also a quarantine insect and, in order to meet stringent import requirements by countries such as the USA, Japan, Australia, and New Zealand, several disinfestation studies were conducted. Irradiation of papaya (*Carica papaya* L.), starfruit (*Averrhoa carambola* L.), and sapodilla (*Achras sapota* L.) has shown its potential as a quarantine treatment that causes little damage to the fruit. Dosages up to 100 Gy were able to give 100% prevention of the most resistant stage (third instar larva) from emerging into complete adult. Physical treatments such as vapour-heat treatment of Harumanis mango (*Mangifera indica* L.) was extensively tested with reduced relative humidity. On cold treatment, a combination of cling wrapping with polyethylene plastic film and storage at low temperature seems enough to kill all stages of the Oriental fruit fly in mangosteen (*Garcinia mangostana* L.). Study on methyl bromide fumigation is also being carried out especially on the starfruit and sapodilla.

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Part 4 — Storage and Ripening

Internal Quality Analysis of Watermelons by an Acoustic Technique and Its Application in Japan

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WATERMELON is now generally sold in cut sections in supermarkets and retail stores in Japan. Therefore, it has become necessary to detect and sort out hollow and overripe fruit, and means of doing this have become a major focus of attention in the production area in setting new shipping standards. Usually, watermelons have been tested for ripeness by skilled inspectors who slap the surface of the watermelon and judge the ripeness by relying on factors such as the pitch and tone of the sound produced. With this method, however, many years of experience are required before any degree of precision can be expected in classification of watermelons. As the number of skilled inspectors decreases due to ageing, there has been a strong call for the development of automatic quality measuring and sorting devices.

Various researchers have investigated non-destructive measurement of the internal quality of watermelons (Chuma 1977; Yamamoto 1984; Sasao 1985; Kawamura 1988). However, there are no practically applicable on-line measuring and sorting devices which can assess ripeness and at the same time determine whether or not a watermelon is hollow. We studied a method of classifying ripeness and detecting hollow watermelons using an acoustic technique, and this research led to the development of the MWA-9002 system for sorting watermelons.

Components and Principles

Measurement of ripeness and detection of hollow watermelons

The system, which measures ripeness and detects hollow watermelons, consists of a mechanical supply section, a height measurement section, an acoustic sound measurement section, a display section, and a wave analysing device (Fig. 1). With the acoustic technique, the watermelon is slapped with a small hammer, and ripeness and presence of hollows are detected based on changes in the sound waves transmitted from the interior of the watermelon.

Measurements of ripeness and hollowness of the melon are made by Fast Fourier Transform (FFT) analysis of the waveshape of the sound. The results from a normal and a hollow watermelon using this device are shown in Figures 2 and 3, respectively. Comparing the original wave and the auto correlation coefficient wave from a normal melon with those from a hollow melon shows that a normal melon produces a clean damped waveshape, while a hollow melon produces a disordered waveshape. Thus, to determine whether a melon is hollow, the sum of the peak waveshape for given cycle is determined, and the result is compared with a judgment value established in advance. If the watermelon is normal, the peak frequency of the power spectrum is clearly damped, but if the melon is hollow, there will be more than one peak, with the second peak tending to have a lower frequency than the first.

The quality of the melon can be determined by comparing the difference between the peak frequencies with the judgment value. Hollow spots and cracks, however, appear not in one isolated spot, but in a variety of locations. Consequently, there are cases in which these flaws cannot be detected using a sensor. As a result of our research, we realised that a minimum of three sensors is necessary for accurate measurement. There is a strong correlation between the ripeness of a watermelon and the hardness of its fruit. It has been reported that the peak frequencies gradually shift from higher frequencies to lower according to the ripeness. The transition speed varies considerably depending on the size of the melon. Therefore, we have found that it is not possible to accurately measure ripeness simply by determining the peak frequency. The relationship between the peak frequencies was studied in terms of fruit size and changes in ripeness. We found, when measuring ripeness, that it was necessary to correct for the diameter of the melon when measuring the peak frequency of power spectrum determined through wave analysis (see Fig. 4).

Capacity of the sorting system

This equipment is capable of processing 3600 watermelons per hour. The flow of the sorting process is as

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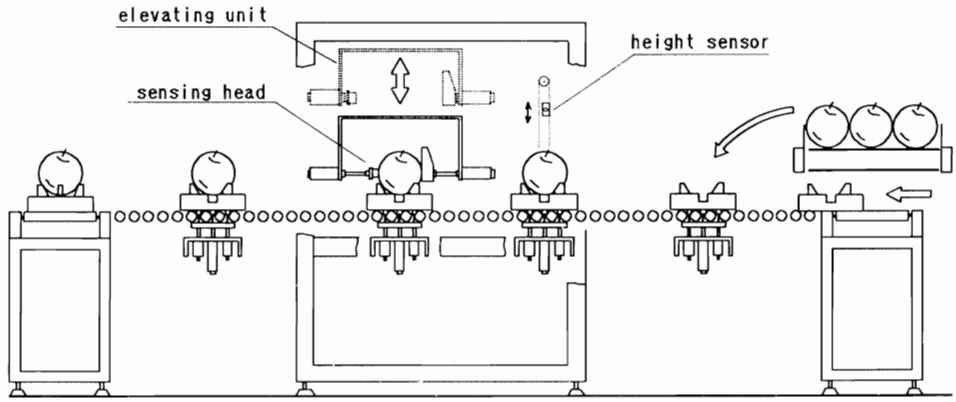

Figure 1. Ripeness and hollow detecting apparatus for watermelon.

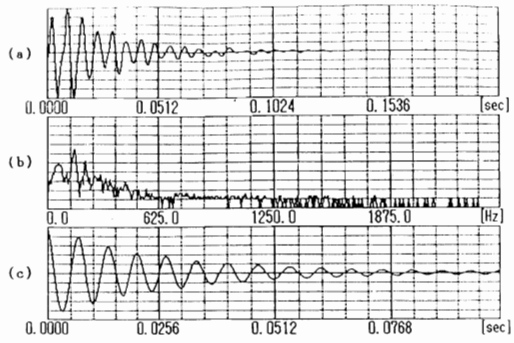

Figure 2. Result of waveshape analysis for normal fruit. The graphs show (a) the original wave, (b) the power spectrum, and (c) the auto correlation coefficient wave.

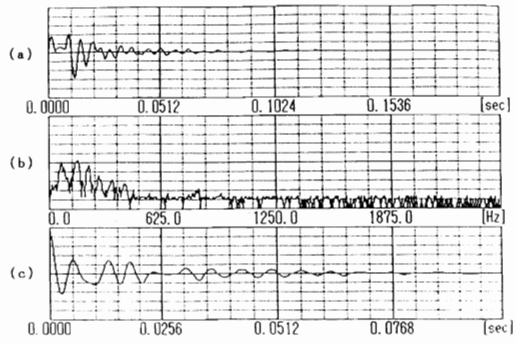

Figure 3. Result of waveshape analysis for hollow fruit. The graphs show (a) the original wave, (b) the power spectrum, and (c) the autocorrelation coefficient wave.

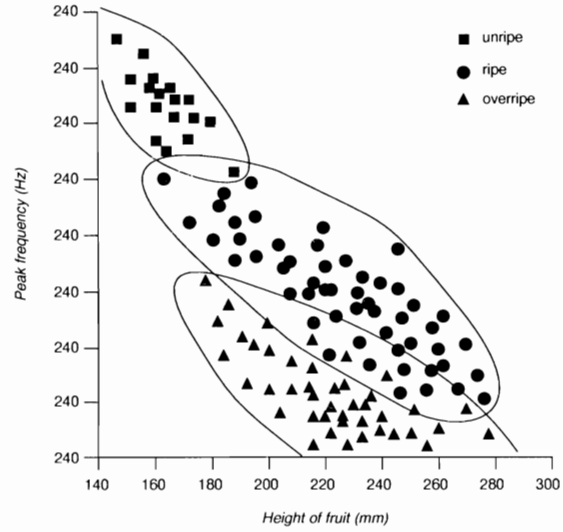

Figure 4. Relationships between the peak frequency and changes in the height of watermelon accompanied with progress of ripeness.

follows: (1) watermelons supplied to sequencing line; (2) washing to remove surface dirt; (3) visual inspection by inspector; (4) measurement of ripeness and detection of hollows; (5) grading and sizing; and (6) packing.

Conclusion

Using an acoustic technique, watermelons can be tested on-line for ripeness and hollowness. As a result, a sorting operation which had previously depended on the intuition of an inspector can be carried out based on consistent judgment criteria, enabling assured product

quality. This system has been installed in nine locations throughout Japan where watermelons are being sorted and packed automatically.

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Feasibility Studies into NIR Technique for Measurement of Internal Quality of Some Tropical Fruits

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UNTIL recently, most pineapples grown in Okinawa Prefecture have been used for processing. Crops reached a peak during the period 1965–1970, but since then the size of the crop has declined. In 1988, the crop fell to less than half of the 35 500 tons obtained during peak times. Furthermore, the 1988 GATT decision to liberalise imports of canned pineapple, beginning in 1990, dealt a severe blow to the Okinawa Prefecture pineapple industry (Kohda 1990; ODA 1990; OPG 1990). Since Okinawa Prefecture has a geographical advantage which allows companies to transport pineapples faster and with less deterioration than other suppliers, Okinawan farmers have been expanding into the market for fresh pineapple. However, when tropical fruit is hand-picked and graded based on the producer's experience and intuition, the quality is uncertain. To ensure sales of high quality pineapples, it is necessary to employ nondestructive quality detection and sorting based on the internal quality of the fruit. The possibility of sorting pineapples using Near Infrared Spectroscopy (NIR) to determine sugar content and acidity, the main quality determinants, was studied.

Materials and Methods

Materials

One-hundred-and-forty sound pineapples (*Ananas comosus* L.: cv. N 67-10) harvested in Higashi-son, Okinawa Prefecture during June–July 1992 and 40 sound mangoes (*Mangifera indica* L.: cv. Irwin) were selected and transported by air at normal temperatures to Hamamatsu, Shizuoka Prefecture and used for the experiments. Tables 1 and 2 give the main physical characteristics of the experimental fruit.

Measurement of the infrared spectrum

A Nireco model 6500 near infrared spectrophotometer was used to measure the infrared spectrum. The pineapple was placed so that the light beam was at right angles to the surface of the fruit, which was covered with a black cloth to avoid the influence of external light. A specific spectrum irradiated onto the sample and the reflected light from the centre section of the sample was sent to the detector and the absorbance measured. Four places were chosen along the equator of the fruit as the testing areas and the near infrared beam was irradiated at 2 nm intervals from 400 to 2500 nm onto the sample and the average absorbance measured. This was repeated 50 times.

Table 1. Average values and standard deviations of the shape and components of pineapples

Components	Average	S.D.
Mass (g)	1275.70	58.70
Width (mm)	114.20	3.50
Height (mm)	142.70	7.70
Sugar content (Brix)	14.08	1.39
Acidity (mg/100 mL)	3.02	0.12
Hardness of peel (kg)	3.18	0.32
Hardness of flesh (kg)	1.30	0.15

Table 2. Average values and standard deviations of the shapes and components of mangoes

Components	Average	S.D.
Mass (g)	311.90	31.60
Width (mm)	68.90	2.50
Height (mm)	105.10	3.50
Sugar content (Brix)	12.30	1.80
Acidity (mg/100 mL)	0.65	0.08
Hardness of peel (kg)	1.11	0.11
Hardness of flesh (kg)	0.42	0.06

Measurement of the sample components

Hardness of peel and flesh, and the sugar content and acidity were measured. A fruit hardness tester was used to measure the hardness of the peel in the same area as the near infrared spectrum was determined. The flesh in the area used to measure the near infrared spectrum was excised, and the juices squeezed out by hand. An Atago model PR-1 digital refractometer was used to measure, as sugar content, the soluble solid content. A Touwa-denpa model AT-100 fruit acid meter was used to measure the acidity of juice, as citric acid.

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Determination of the calibration curve

The calibration curve was determined by using the secondary differentiated spectrum to find a correlation between the value of each component and each peak in wavelength. After determination of the primary wavelengths, the highest correlations were calculated using multiple regression analysis with the variable additional method. The calibration curve was determined from four wavelengths. The following is a model equation of the calibration curve that estimates the S (%) of each component :

$$S = K0 + K1d^2\mathrm{OD}(\lambda 1) + K2d^2\mathrm{OD}(\lambda 2) + K3d^2\mathrm{OD}(\lambda 3) + K4d^2\mathrm{OD}(\lambda 4) \quad (1)$$

where $K0$, $K1$, ... are regression variables, d^2OD is the secondary differentiated spectrum absorbance, $\lambda 1$, $\lambda 2$, ... indicate each wavelength

Measurement of the distribution in internal quality of a fruit

The crown side was defined as 'up', the pineapples divided into upper, middle, and lower sections, and the core and peel separated. In order to assess the distribution in internal quality of the pineapples, sugar content and acidity were measured.

Results and Discussion

The coefficient of multiple regression (MR) for the sugar content of pineapples, as shown in Table 3, was 0.825 using 4 specific wavelengths, while the standard error of the estimated value was 0.822; for the acidity, the coefficient of multiple regression was 0.686, while the standard error was 0.107. For the hardness of the peel, the coefficient of multiple regression was 0.460 and the standard error was 0.314 and the coefficient of multiple regression was 0.568 and the standard error was 0.135 for the hardness of the flesh.

The coefficient of multiple regression for sugar content of mango fruits, as shown in Table 4, was 0.954, while the standard error of the estimated sugar content was 0.363. For the acidity, the coefficient of multiple regression was 0.856 and the standard error was 0.104. For hardness of peel, the coefficient of multiple regression was 0.949 and the standard error was 0.319. The coefficient of multiple regression was 0.920 and the standard error was 0.135 for hardness of flesh.

On the basis of these results, it can be concluded that Near Infrared Spectroscopy (NIR) of pineapples and mangoes has potential for determining the sugar content by nondestructive measurement of the inner quality, but that further studies are needed on the other components. The distribution of internal quality in terms of the portion of the fruit is shown in Table 5. It can be seen that

Table 3. Results of multiple regression analysis of some quality indices of the pineapple and the near infrared spectrum

Quality index	Specific wavelength (nm)				MR[a]	SE[b]
	λ1	λ2	λ3	λ4		
Sugar content (Brix)	900	696	1200	1138	0.825	0.822
Acidity[c] (mg/100 mL)	526	878	2338	716	0.686	0.107
Hardness of peel(kg)	668	2134	450	664	0.460	0.314
Hardness of flesh(kg)	2280	1140	614	772	0.568	0.135

[a] MR: coefficient of multiple regression.
[b] SE: standard error in estimated value.
[c] Acidity as citric acid.

Table 4. Results of multiple regression analysis of some quality indices of mango fruits and near infrared spectrum

Quality index	Specific wavelength (nm)				MR[a]	SE[b]
	λ1	λ2	λ3	λ4		
Sugar content(Brix)	1098	876	2418	2290	0.954	0.363
Acidity[c] (mg/100 mL)	620	832	1498	1668	0.856	0.104
Hardness of peel(kg)	1728	2462	1018	690	0.949	0.319
Hardness of flesh(kg)	2298	2436	1230	1740	0.920	0.135

[a] MR: coefficient of multiple regression.
[b] SE: standard error in estimated value.
[c] Acidity as citric acid.

the lower portion of the core contained the highest sugar content and the lower portion of the peel was lowest, while the centre portion had an average sugar content. The centre portion also showed average acidity.

Table 5. Distribution of sugar content and acidity according to the portion of the pineapple

Portion	Sugar content (Brix)	Acidity (mg/100 mL)
Upper portion of the peel	11.633	1.979
Upper portion of the core	12.000	1.929
Middle portion of the peel	14.300	2.097
Middle portion of the core	14.267	2.013
Lower portion of the peel	14.700	1.988
Lower portion of the core	15.800	1.974
Total average	14.078	2.019

Conclusion

The results of this analysis suggest that it may be feasible to use NIR for measuring internal quality of pineapple and mango.

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Distribution of Minerals in Alphonso Mango during Ripening

K. Hari Babu and Shanthakrishnamurthy*

MINERAL analysis has been used to predict the susceptibility of fruits to physiological disorders (Perring 1986). The influence of fruit minerals on keeping quality and postharvest physiological disorders is well known in apples, pears, and other temperate fruits, but little is known on their effects in mango. It is now recognised that the mineral nutrient status of the fruit during ripening is a major factor in postharvest storage. Although the calcium content of Alphonso mangoes with a postharvest ripening disorder known as 'spongy tissue' has been shown to be lower than in healthy fruit, there have been no studies of the the mineral composition of fruit during ripening, the object of the study reported here.

Materials and Methods

Healthy, ripening fruits were selected for mineral analysis in two consecutive years (1991 and 1992). Calcium (Ca), potassium (K), sodium (Na), and phosphorus (P) were determined using the fruit at edible ripe stage (9 days after harvest). They were estimated in peel and six different regions of pulp tissues as indicated in Table 1. The peel and pulp of the six regions were collected from 10 fruit in each replicate for three replications. Samples were cut into small pieces, mixed well, and representative samples weighed and then dried to a constant weight in a hot-air oven at 70±2°C for 48 hours. The dried samples were subjected to wet digestion and used to estimate concentrations of the four minerals. Estimation of Ca, K, and Na was by Elico Flame Photometer (Model L–22A). P was measured using a Spectronic Model 1201.

Results and Discussion

Measured concentrations of Ca, K, Na, and P in the peel and six different pulp regions of Alphonso mango fruit are give in Table 1. In general it was observed that mineral concentrations were higher in the peel than in the pulp. Within the pulp, mineral composition varied between the regions selected.

It was observed that the basal part of the pulp tissues had the highest Ca concentration, followed by middle and apical portions of the pulp. Further, the pulp closest to the peel contained more Ca than pulp close to the endocarp. A similar trend was observed by Gunjate et al. (1979), who also reported that the occurrence of spongy tissue in the apical part of the pulp nearest the endocarp was maximal at low Ca concentrations.

The highest K concentrations were recorded in pulp tissues in the middle of the fruit. This suggests that the relative concentrations of K in different parts of the pulp are the opposite to those of Ca. Both Rangwala (1975), who studied spongy tissue of Alphonso mango, and Burdon et al. (1991), who investigated softnose-affected tissue of Beverly mango, observed higher K and lower Ca concentrations associated with these disorders. This suggests that K may also have an important role in development of spongy tissue.

It was observed that pulp tissues close to the peel had a higher Na content than those close to the endocarp, but there was no definite trend in concentrations observed between the different portions of the pulp, namely basal, middle, and apical parts of the fruit.

Higher P concentrations were found in pulp tissues in the middle part of the fruit, followed by pulp tissues in apical and basal regions. Further, lower P contents were recorded in pulp near the peel than the pulp near the endocarp. Overall, it was observed that the pulp tissues close to the endocarp had higher amounts of K and P with low Ca levels, which correlates with conditions conducive to occurrence of spongy tissue reported by Subramanyam et al. (1971), Rangwala (1975), and Shanthakrishnamurthy (1981).

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Table 1. Distribution if minerals (Ca, K, Na, and P) in Alphonso mangoes during ripening

Tissue	Calcium (mg/g DW)		Potassium (mg/g DW)		Sodium (mg/g DW)		Phosphorus (mg/g DW)	
	1991	1992	1991	1992	1991	1992	1991	1992
Peel	109.0	117.3	772.0	797.0	42.4	23.1	156.8	147.9
x_1	75.0	78.1	604.0	614.0	35.8	19.6	94.6	87.4
x_2	53.8	52.1	636.0	648.0	34.7	18.6	127.2	122.2
y_1	65.7	62.7	680.0	652.0	41.1	20.1	130.8	128.3
y_2	53.2	41.4	691.0	684.0	38.1	19.2	150.9	141.2
z_1	52.7	56.4	576.0	603.0	38.4	19.8	116.1	108.2
z_2	38.8	39.3	620.0	631.0	39.7	18.6	140.8	116.4
Mean	64.0	63.9	654.0	616.0	38.6	19.8	131.0	121.7
SEM±	1.20	0.99	4.87	4.10	0.48	0.35	1.35	1.05
CD at 5%	4.57	3.77	18.54	15.61	1.82	1.33	5.18	3.99

x_1 and x_2 are outer (near peel) and inner (near endocarp) pulp tissue from the basal part of the fruit.
y_1 and y_2 are outer (near peel) and inner (near endocarp) pulp tissue from the middle part of the fruit.
z_1 and z_2 are outer (near peel) and inner (near endocarp) pulp tissue from the apical part of the fruit.

Effect of Calcium on Physicochemical Changes in Alphonso Mango during Ripening and Storage

K. Hari Babu and Shanthakrishnamurthy*

ALPHONSO is one of the most popular mango varieties grown in India. The marketing potential for mangoes is limited due to their high perishability. Under tropical ambient conditions fruits ripen rapidly after harvest at the green-mature stage, become soft in texture and are predisposed to injury. Appropriate technology to extend the shelf life and reduce postharvest losses of mangoes is therefore required. The possibilities for low temperature storage are limited by the high capital cost and susceptibility of mangoes to chilling injury at temperatures below 15°C (Shanthakrishnamurthy and Joshi 1989). Modified atmosphere storage of mangoes is also limited by high incidence of rot, fermented odours, and internal breakdown of fruit (Gautam and Lizada 1984). Calcium (Ca) is known to be an essential plant nutrient involved in a number of physiological processes concerning membrane structure and function, and enzyme activitys (Jones and Lunt 1967). Ca compounds have shown promise in the quality retention of fruit and vegetables through maintaining firmness, reducing respiratory rate and ethylene evolution (Pooviah 1986), and decreasing storage rots (Conway and Sams 1984). The present study was undertaken to investigate the effect of pre- and postharvest Ca treatments on various physicochemical changes and shelf life of Alphonso mangoes during ripening and storage.

Materials and Methods

Pre-harvest calcium chloride ($CaCl_2$) sprays were applied to Alphonso mango trees in the orchard of I.I.H.R., Hessaragatta, Bangalore during 1992. $CaCl_2$ solutions containing 5000 and 10 000 ppm calcium concentrations were sprayed at 5 intervals on 5 trees per treatment. The first spray was applied 15 days after fruit set followed by second and third sprays of fortnightly intervals. Forty-five days after fruit set two more sprays were applied at monthly intervals. Teepol at 0.1% was used as a surfactant. The trees were sprayed until dripping. Fruit were harvested 110 days after fruit set. Lots of 20 fruits in 3 replications were prepared and used for postharvest dip treatments in $CaCl_2$. These were made by infiltrating under vacuum (250 mm Hg) for 5 minutes. Pre- and postharvest Ca-treated fruit were stored at ambient temperature (28 ± 2°C) and relative humidity (40–60%) and various physicochemical parameters estimated during ripening and storage. An Instron 4201 meter was used to measure firmness; total soluble solids (°Brix) were estimated with an Erma hand refractrometer; and chemical constituents (acidity, reducing and total sugars, starch, and carotenoids) were estimated following the procedures suggested by Ranganna (1986).

Results and Discussion

It was observed that untreated fruit had maximum physiological loss of weight — PLW (18.13%) as compared with both pre- and postharvest Ca-treated fruit, 19 days after harvest (Table 1). Among all the treatments, the fruit infiltrated with 4% $CaCl_2$ showed minimum PLW (12.61%). Minimum PLW has been reported in fruit sprayed with pre-harvest $CaCl_2$ in Amrapali (Singh et al. 1987) and in Julie mangoes (Mootto 1991).

At harvest, the mean fruit firmness with (16.81 kg/cm^2) and without (10.34 kg/cm^2) peel was much lower in control fruit with (1.97 kg/cm^2) and without (0.59 kg/cm^2) peel at 15 days after harvest, whereas fruits infiltrated with 4% $CaCl_2$ showed maximum firmness both in fruits with (3.98 kg/cm^2) and without peel (1.81 kg/cm^2) even at 19 days after harvest. This was probably due to added calcium in the peel and pulp helping to maintain the structure and function of cell walls. Similar results on retention of firmness by calcium treatment were also reported in apples by Poovaiah (1986). Formation of calcium pectate by added Ca, a substance not readily available to pectic acid degrading enzymes, was reported by Bangerth (1979).

The initial mean titratable acidity of fruit pulp was 3.92%. This fell to a minimum of 0.17% 15 days after harvest in control fruits. Among the treated fruit, maximum acidity (1.81%) was recorded in fruit infiltrated with 4% $CaCl_2$ while minimum acidity (0.76%) was recorded at 15 days after harvest in fruit treated with 10 000 ppm Ca as a preharvest spray. Higher acidity following $CaCl_2$ treatment either as a preharvest spray or postharvest dipping in Amrapali mangoes was reported by Singh et al. (1987). Tirmazi and Wills (1981), however, observed no difference in acidity levels of 'Kensington Pride' mangoes following postharvest dipping with $CaCl_2$.

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Table 1. Effect of pre- and postharvest calcium treatments on physicochemical changes in Alphonso mango during ripening and storage

Treatments	Physiological loss of wt. (%)				Firmness with peel (16.81[a]) (kg/cm^2)				Firmness without peel (10.34[a]) (kg/cm^2)			
	Days after harvest				Days after harvest				Days after harvest			
	6	9	12	19	6	10	15	19	6	10	15	19
T_1[b]	5.75	10.66	13.81	18.13	7.38	4.38	1.97	–	6.07	2.05	0.59	–
T_2	4.21	8.76	11.77	15.43	9.33	5.77	3.59	2.11	6.70	2.80	0.87	0.34
T_3	4.05	8.39	11.24	14.46	11.62	5.94	4.29	2.17	7.17	3.42	1.19	0.57
T_4	2.91	7.30	10.49	13.55	13.34	7.85	5.24	3.30	7.88	4.44	2.02	1.14
T_5	2.85	6.79	9.43	12.88	14.81	8.57	5.77	3.66	8.49	5.59	2.29	1.44
T_6	2.72	6.43	9.23	12.61	15.57	9.57	6.31	3.98	8.96	6.59	2.62	1.81

[a] Initial values

[b] T_1 is control. T_2 and T_3 are preharvest sprays with 5000 and 10 000 ppm Ca and T_4, T_5 and T_6 are vacuum infiltrations with 2.0, 3.0, and 4.0% $CaCl_2$ solutions respectively.

Table 2. Effect of pre- and postharvest calcium treatments on physicochemical changes in Alphonso mango during ripening and storage

Treatments	Total titratable acidity (3.92[a]) (%)				Total soluble solids (9.33[a]) (°Brix)				Reducing sugars (1.16[a]) (%)			
	Days after harvest				Days after harvest				Days after harvest			
	6	10	15	19	6	10	15	19	6	10	15	19
T_1[b]	2.15	0.79	0.17	--	16.71	18.57	16.73	--	2.29	3.75	3.13	–
T_2	2.45	1.26	0.85	0.25	15.42	17.47	19.09	17.63	2.06	3.37	4.51	3.96
T_3	2.65	1.72	0.76	0.34	14.48	17.93	20.54	18.83	1.83	3.47	4.79	4.21
T_4	3.16	2.16	1.44	0.73	12.62	14.80	17.57	16.55	1.72	3.24	3.72	3.20
T_5	3.31	2.52	1.63	0.89	11.49	15.35	17.87	16.97	1.56	3.04	3.79	3.54
T_6	3.54	2.93	1.83	1.02	11.08	15.05	18.21	17.63	1.32	2.82	4.09	3.69

[a] Initial values

[b] T_1 is control. T_2 and T_3 are preharvest sprays with 5000 and 10 000 ppm Ca and T_4, T_5 and T_6 are vacuum infiltrations with 2.0, 3.0, and 4.0% $CaCl_2$ solutions respectively.

Table 3. Effect of pre- and posthavest calcium treatments on physicochemical changes in Alphonso mango during ripening and storage

Treatment	Total sugars (2.11[a]) (%)				Starch (14.01[a]) (%)			Total carotenoids (1411[a]) (µg/100g)				Shelf life (days)
	Days after harvest				Days after harvest			Days after harvest				
	6	10	15	19	6	10	15	6	10	15	19	
T_1[b]	10.29	14.74	13.64	–	4.50	0.79	0.04	8404	16449	17785	–	12
T_2	8.63	13.24	15.24	14.08	5.76	1.10	0.08	6509	14641	18364	18480	14
T_3	8.43	13.64	16.33	15.35	6.46	1.43	0.15	6230	15930	19212	19222	15
T_4	5.55	11.23	14.03	13.25	6.53	2.00	0.74	4648	12666	17785	17435	17
T_5	4.99	10.63	14.42	13.71	7.72	2.38	0.85	3766	11052	16723	16980	19
T_6	4.53	8.71	14.69	13.90	8.38	2.62	0.91	3533	9671	16430	16632	20

[a] Initial values

[b] T_1 is control. T_2 and T_3 are preharvest sprays with 5000 and 10 000 ppm Ca and T_4, T_5 and T_6 are vacuum infiltrations with 2.0, 3.0, and 4.0% $CaCl_2$ solutions respectively.

Maximum TSS content (20.54 °Brix) was recorded in fruit sprayed with 10 000 ppm Ca, while the minimum TSS (16.73 °Brix) was recorded in control fruit 15 days after harvest. It was observed that the rate of increase in TSS content was more rapid in control fruit than in fruit infiltrated with $CaCl_2$ This indicated that calcium treatments delayed ripening. These results agree with those of Kumar and Chauhan (1989) in Kinnow mandarin, where TSS content increased more rapidly in control than Ca-treated fruit.

Reducing and total sugar content increased during postharvest storage in both control and Ca-treated fruit (Table 2). Maximum reducing (4.79%) and total (16.33%) sugar contents were recorded 15 days after harvest in fruit treated with pre-harvest sprays of 10 000 ppm $CaC1_2$, whereas minimum reducing (3.13%) and total (13.64%) sugars were recorded in control fruit. This increase in sugar content may be the result of the conversion of starch to sugar.

The initial mean starch content of 14.01% in untreated fruit fell to 0.04% after 15 days of storage. The degradation of starch was more rapid in control fruit than in those infiltrated with $CaCl_2$ (Table 3). The rate of degradation was further retarded by increasing the concentration of $CaCl_2$ used for infiltration.

Higher total carotenoid contents (19 212 µg/100 g in 10 000 ppm and 18 364 µg/100 g in 5000 ppm Ca) were recorded in fruit treated with preharvest Ca sprays as compared with control fruit (17 785 µg/100 g) at 15 days after harvest. However, the fruit treated with postharvest $CaCl_2$ infiltration showed lower carotenoid contents than both control and preharvest Ca-treated fruit (Table 3). Also the rate of increase in carotenoid content was higher in control fruit than in fruit infiltrated with $CaCl_2$. Similar results on reduced carotenoid content in Ca-treated Dashehari mangoes have been reported (Anonymous 1991).

The shelf life of untreated fruits was 12 days, as compared to 14–15 days in fruit treated with Ca as a preharvest spray. Fruits infiltrated with 4% $CaCl_2$ recorded the maximum shelf life — 20 days — followed by 2 and 3% $CaCl_2$ treatments with 17 and 19 days, respectively. Increased shelf life of 10 days in Julie mangoes following postharvest $CaCl_2$ dips was reported by Mootto (1991).

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A Low-cost Cool Chamber: an Innovative Technology for Developing Countries

Susanta K. Roy and R.K. Pal*

STORAGE of fresh tropical fruits after harvest is a pressing problem in developing countries such as India. A large quantity of fruit goes to waste in developing countries because of lack of adequate storage facilities. India is the second largest producer of fruit in the world with annual production estimated at 28 Mt, roughly 8% of world production. Nearly 80% of fruit production in India is of tropical fruits, the most important being mango (31%) and banana (26%). It is estimated that 30–40% of fruit produced is lost owing to inadequate postharvest handling and processing facilities. This results in a monetary loss of about US$1000m.

Current cool storage relies on mechanical refrigeration, which is energy intensive, expensive, and difficult to install. An Expert Consultation on Food Loss Prevention in Perishable Crops held at FAO, Rome, in May 1980, recommended use of simple, low-cost cooling systems based on evaporative cooling for storage of fruits and vegetables (Anon. 1982). In view of the current energy crisis and lack of sufficient cool storage space in most of the developing world, an attempt was made to develop a low cost evaporatively cooled system suitable for storage of tropical fruits.

Materials and Methods

Small, zero-energy cool chamber

A zero-energy cool chamber (1 m × 0.5 m × 0.5 m) was developed at IARI, New Delhi using locally available materials: bricks. sand, bamboo, dry grass, jute cloth, etc. This is a chamber designed for on-farm use which operates on the principle of evaporative cooling. The chamber is an above-ground, double-walled structure made of bricks. The cavity of the double wall is filled with river sand. The lid is made from dry grass or straw on a bamboo frame. A rise in relative humidity and a fall in temperature of 10–15°C below ambient could be achieved by watering the chamber twice a day (Roy and Khurdiya 1986).

Large cool chamber

A large cool chamber (2.5 m × 2.5 m × 2.5 m) has been constructed, also with double brick, sand-filled cavity walls. The bottom of the chamber is provided with four ducts, one from each wall, meeting at the centre. The floor of the chamber is made of wooden planks with holes at the periphery providing for entry of fresh outside air. The top of the chamber is made of metal sheeting with an exhaust fan at the centre. A chimney is also provided. The wall is watered from the top, through perforated pipes inserted into the cavity. The ducts at the base are submerged in wet sand (Roy 1984). Observations on the temperature and relative humidity were recorded daily using standard instruments.

Storage of tropical fruits

As part of these experiments mangoes, bananas, guavas, and limes were stored at New Delhi, while sapota was stored in Bangalore and annona in Faizabad (U.P.) in the small zero-energy cool chamber. Periodic observations on physiological loss in weight (PLW) were made. The shelf life of fruits was determined on the basis of 10% loss of fruits during storage.

Results and Discussion

The small, zero-energy cool chamber was found to have maintained a relatively low temperature compared with ambient temperature with approximately uniform difference between the maximum and minimum temperatures throughout the year. The large chamber yielded similar results (Fig. 2), but the small, zero-energy cool chamber was found to be more effective in reducing temperature. In contrast, there were wide fluctuations in ambient maximum and minimum temperatures (Fig. 1). Figure 3 shows that the maximum relative humidity in the small, zero-energy cool chamber was maintained above 90% for most of the year, whereas ambient humidity fluctuates wildly. The larger chamber maintained relative humidity above 80% (Fig. 4). This divergence could be due to the difference in surface to volume ratio. The results of the storage study of some of the important tropical fruits in the small, zero-energy cool chamber at different agroclimatic locations of India are presented in Table 1 and Figure 5.

It is evident from Table 1 that the shelf life of tropical fruits held in the cool chamber was increased by 2 to 14 days, as compared to storage at room temperature. The physiological loss in weight (PLW) was also found to be

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lower in cool chamber-stored fruit, reductions ranging from 2% in bananas to 19% in limes. Percentage increase in shelf life ranged from 15 to 127%, depending on the commodity (Fig. 5). These results are similar to those obtained in earlier studies on storage of other fruits and vegetables in evaporatively cooled chambers (Pal and Roy 1988; Anon. 1991; Roy and Pal 1989, 1991; Roy et al. 1992; Waskar and Roy 1992).

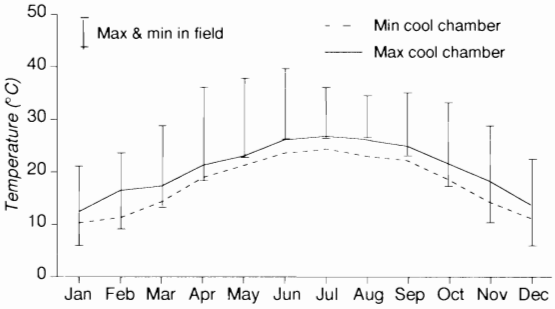

Figure 1. Fall in temperature due to evaporative cooling in small, zero-energy cool chamber

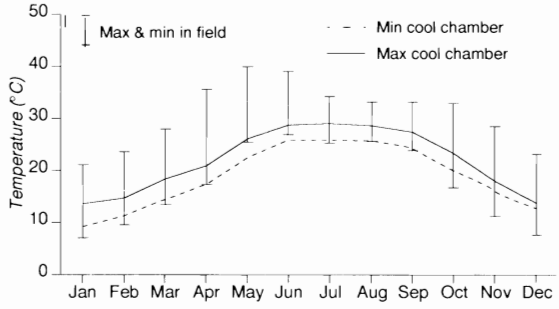

Figure 2. Fall in temperature due to evaporative cooling in large cool chamber

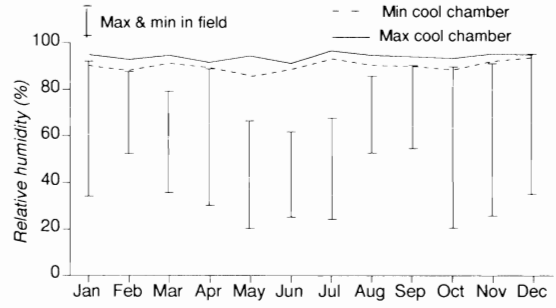

Figure 3. Relative humidity in small, zero-energy cool chamber

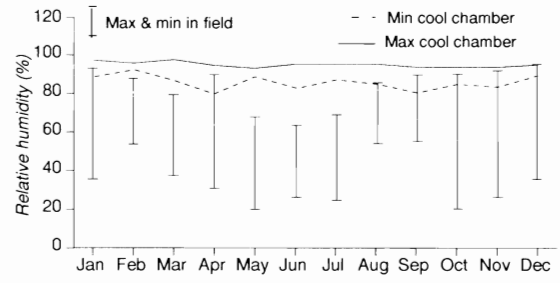

Figure 4. Relative humidity in large cool chamber

Table 1. Efficacy of a zero–energy cool chamber for storage of tropical fruits.

Crop	Cool chamber		Room temperature	
	Shelf life (days)	PLW[a] (%)	Shelf life (days)	PLW (%)
Mango (*Mangifera indica* L.) Var. Baneshan	9	5.04	6	14.99
Banana – mature green (*Musa acuminata*) Var. Dwarf Cavendish	20	2.50	14	4.80
Guava – mature green (*Psidium guajava*) Var. Allahabad Safeda	15	4.00	10	13.63
Sapota (*Achras zapota* L.) Var. Kalipatti	14	9.46	10	20.87
Lime (*Citrus aurantifolia*) Var. Kagzi	25	6.00	11	25.00
Aonla (*Emblica officinalis* Gaertn.) Var. Chakaiya	18	1.72	9	8.70

[a] PLW = Physiological loss in weight

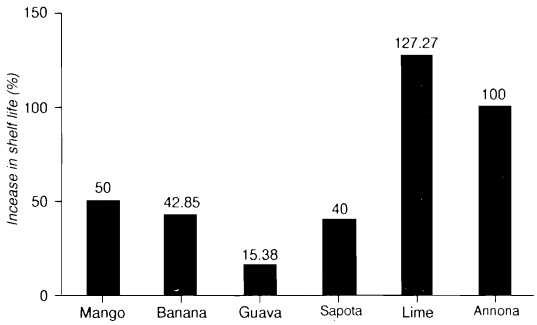

Figure 5. Percent increase, compared with storage at room temperature, in shelf life of fruits stored in a cool chamber.

Conclusions

Cool chambers developed at the Indian Agricultural Research Institute, New Delhi, based on the principle of evaporative cooling, were ideal for short-term storage of fruits and vegetables. Moreover, the chambers are easy to build using locally available resources. Besides storing fruits and vegetables these chambers may also be used for growing mushrooms, storing bio-fertilizers and short- term storage of milk.

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Effect of Low Temperatures on Storage Life and Quality of Carambola (*Averrhoa carambola* L.) cv. B_{17}

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THE carambola or starfruit (*Averrhoa carambola* L.) is a popular dessert fruit in Malaysia. In recent years it has gained popularity as an export commodity, with B_{17} the main commercial cultivar. B_{17} fetches a higher price in local markets. There is potential for this cultivar to be developed as an export commodity since the flavour and taste of its fruit are highly acceptable to consumers.

Since carambola fruit are non-climacteric (Oslund and Devenport 1981; Lam and Wan 1983) they have to be harvested at a time that will maintain the sweetness of the fruit. Studies by Siti Halijah and Md. Yunus (1992) indicated that the fruit can be harvested at 11–13 weeks after fruit set.

There have been a number of studies on low temperature storage of carambola (Oslund and Devenport 1981; Lam 1983; Lam and Wan 1983; Wan and Lam 1984; Kenny and Hull 1986; Campbell et al. 1987), but none involving the B_{17} cultivar. The main objective of the study reported here was to determine the storage potential of the B_{17} cultivar. The effects of low temperatures on the quality and storage life of the fruits were also investigated.

Materials and Methods

The carambola were obtained from a commercial farm in Raub, Pahang, 180 km north of Kuala Lumpur. Bagging was carried out when the fruit were about 5–6 cm long (about a month after fruit set) to prevent fruit fly attack. Bagging also helped to give the fruit an attractive glossy appearance.

The fruits were harvested at 10, 11, 12, and 13 weeks after fruit set and brought back to the Food Technology Research Center where the storage studies were conducted. At each harvesting date, fruit with predominant colour grade were selected and randomly alloted to 4 replicates with 10 fruits per replicate. Each replicate of fruit was then placed into a corrugated fibre-board box lined with perforated polyethylene bag. The boxes were stored at 5, 10, 15, and 20°C and removals were carried out every fortnight until the fruit were senescent or diseased. At each removal, half the fruit were also placed at ambient temperature (28°C) for a week to determine quality of fruits after storage at low temperature. A randomised complete block design with harvest and storage temperature combinations forming the blocks (Cochran and Cox 1957) was employed in data collection.

The changes in skin colour, firmness, and development of disease were recorded. For skin colour, the changes were recorded using a scoring system where 1 = green, 2 = light green, 3 = yellowish green, 4 = more yellow than green, 5 = more orange than yellow, and 6 = full orange.

Firmness of the fruit was determined by puncture test using an Instron 1140 machine. The puncture test was carried out using the 7 mm diameter Magness Taylor probe which was driven into the horizontal surface of the fruit until punctured. The machine was operated using a cross-head speed of 50 mm/min and a chart speed of 500 mm/min.

Changes in disease development were also recorded, using a scoring system where 0 = no disease, 1 = < 25% of fruit affected, 2 = 25–50% of fruit affected, and 3 = > 50% of fruit affected.

The fruits were analysed for pH, percentage of total soluble solids (TSS), total titratable acidity (TTA), and total sugars (TS).

The pH was determined by blending whole fruit at room temperature; readings were taken using an Orion digital pH meter model SA520. TSS of the expressed juice of the whole fruits was measured using an Atago digital refractometer (0–32° Brix). TTA was determined by titrating a known weight of blended fruit sample to pH 8.1 with 0.1N NaOH and the results expressed as percentage of oxalic acid (Lam 1983). Total sugars were analysed by the method of Lane and Eynon (AOAC 1975).

Analysis of variance and Duncan's Multiple Range Test were performed on data (Gomez and Gomez 1984; Steel and Torrie 1980). Correlation analyses were also performed on the data to determine the relationship between the varieties. The SAS procedures were utilised for data analysis using a mainframe computer (SAS Institute 1985).

Results

The results indicated that there were significant changes in the physical attributes of B_{17} carambola during stor-

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age. These changes were greatly influenced by fruit maturity, the storage period, and temperature during storage. Table 1 shows the relationship between these changes. There was a highly significant correlation between fruit maturity and colour development of the fruit. There were differences in the colour of the fruit since harvesting was done at different maturities and various colour indices. As the fruit matures, its colour changes from green to full orange (Siti Halijah and Md Yunus 1992). However, during storage at the various temperatures significant colour changes also developed (Table 2). When the fruit were stored at 5°C the changes were slow. For fruits that were harvested at 10 and 11 weeks after fruit set the change in colour developed after 2 weeks storage, following which there was no further change in colour. For fruits harvested at 12 and 13 weeks after fruit set, the change in colour from yellowish green (colour score 3) to more yellow than green (colour score 4) occurred after 6 weeks storage.

Rapid colour change was observed when the storage temperature was increased. At 15°C and 20°C the colour score changed to about colour score 5 (more orange than yellow) within 2 weeks storage.

Prolonged storage at the various temperatures also affected the firmness of the fruit (Table 3). This relationship was observed to be negatively correlated (Table 1.) There was a decrease in the force needed to puncture the fruit during storage. The fruit lost their firmness mainly due to softening of the tissues as the fruit ripened. Softening of the tissue occurred at all storage temperatures but the rate was lower at 5°C compared with those stored at 10, 15, and 20°C. However, when the fruit were harvested at 13 weeks after the fruit set, they seemed to be more elastic, especially when stored at 5°C. There was no significant difference in the firmness of the fruit stored at this temperature. After storage for 8 weeks there was no significant change in the firmness of the fruits.

The storage life of the fruit was strongly influenced by the development of diseases. The maturity, storage period, and storage temperatures played important roles in the development of diseases on the fruits (Table 4). More diseases developed as the storage period was extended. Diseases also developed faster on younger fruit, especially those harvested at 10 and 11 weeks after fruit set. Fruit harvested at these stages, when stored at 5°C and 10°C had significant disease development at 4 weeks storage period. For fruit harvested at a later stage (12 and 13 weeks after fruit set) significant disease development was observed only after 6 weeks storage. At higher temperatures (15 and 20°C) all the fruits were diseased after 2 weeks storage.

Table 5 shows the correlation matrix of the chemical characteristics of the B_{17} carambola during storage at the various temperatures. This relationship indicated that fruit maturity, storage period, and storage temperature significantly affect the chemical changes during storage.

Table 1. Correlation matrix of physical characteristics of B_{17} carambola during storage at various temperatures

Pearson correlation coefficients/prob.>/R/under Ho:RHO = 0/n

Storage period	−0.2834				
	0.0001**				
	2280				
Temp.	0.000	0.000			
	1.000	1.000			
	2280	2280			
Colour	0.3402	0.0479	0.2939		
	0.0001**	0.0583*	0.0001**		
	1560	1560	1560		
Diseases	−0.2632	0.3341	0.2011	0.4959	
	0.0001**	0.0001**	0.0001**	0.3415	
	1560	1560	1560	1560	
Firmness	0.0491	−0.3838	−0.3237	−0.0638	−0.0793
	0.4565	0.0001**	0.0001**	0.3415	0.2371
	232	232	232	224	224
	Maturity	Storage period	Temp.	Colour	Diseases

Table 2. Changes in colour score of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C) 5	10	15	20
10	0	2.0a	2.0a	2.0a	2.0a
	2	2.0a	2.1a	4.8b	4.6b
	4	2.6b	2.7b	4.8b	–
	6	2.8b	2.7b	–	–
	8	2.6b	4.0c	–	–
11	0	3.0a	3.0a	3.0a	3.0a
	2	3.2a	3.7b	4.8b	5.0b
	4	3.3a	4.0b	4.8b	–
	6	3.4a	5.0c	–	–
	8	3.4a	–	–	–
12	0	3.5a	3.5a	3.5a	3.5a
	2	3.5a	3.5a	4.7b	5.0b
	4	3.3a	3.9b	–	–
	6	4.0b	4.1b	–	–
	8	4.1b	–	–	–
13	0	3.6a	3.6a	3.6	3.6
	2	3.8ab	3.8a	–	–
	4	3.6a	4.9b	–	–
	6	4.0b	–	–	–
	8	–	–	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

As the fruit matured, there was a decrease in the TTA followed by an increase in pH, TS, and TSS (Siti Halijah and Mohd Yunus 1992). During storage, however, there was an increase in pH followed by a reduction in TTA, TSS, and TS (Table 5).

The pH increased significantly, especially in fruits harvested at 10 and 11 weeks after fruit set (Table 6). When the fruit were stored at 5 and 10°C the increase in

pH was very gradual. Significant changes in pH occurred after 2 weeks storage with no changes after that. For fruit harvested at 12 and 13 weeks after fruit set, significant changes occurred only between 4 and 6 weeks storage.

Table 3. Changes in firmness (kg force) of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	5.51a	5.51a	5.51a	5.51a
	2	4.49b	4.29b	2.65b	2.29b
	4	4.18b	3.71c	2.03b	–
	6	3.30c	3.36c	–	–
	8	3.35c	2.77d	–	–
11	0	4.66a	4.66a	4.66a	4.66a
	2	4.67a	4.12b	2.24b	1.98a
	4	4.00b	3.58c	2.05b	–
	6	4.04b	2.56d	–	–
	8	3.36c	2.20d	–	–
12	0	4.50a	4.50a	4.50a	4.50a
	2	4.48a	3.68b	2.96b	0.99b
	4	3.84b	3.60b	–	–
	6	3.63bc	2.80c	–	–
	8	3.18c	1.76d	–	–
13	0	4.51a	4.51a	4.51a	4.51a
	2	4.89a	4.28ab	2.40b	1.63b
	4	4.21a	3.79b	–	–
	6	4.94a	3.88ab	–	–
	8	5.27a	4.05ab	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

Table 4. Development of diseases on B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	0.00a	0.00a	0.00a	0.00a
	2	0.00a	0.00a	0.73b	0.70b
	4	0.30b	0.60b	2.43c	–
	6	0.53c	1.13c	–	–
	8	1.07d	2.37d	–	–
11	0	0.00a	0.00a	0.00a	0.00a
	2	0.00a	0.03a	1.77b	1.53b
	4	0.37b	1.26b	2.40c	–
	6	0.80c	1.97c	–	–
	8	0.50b	–	–	–
12	0	0.00a	0.00a	0.00a	0.00a
	2	0.00a	0.17a	1.67b	0.90b
	4	0.17a	0.17a	–	–
	6	0.40b	0.90b	–	–
	8	0.50b	–	–	–
13	0	0.00a	0.00a	0.00a	0.00
	2	0.06a	0.03a	0.83b	–
	4	0.00a	0.00a	–	–
	6	0.27b	–	–	–
	8	–	–	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

Table 5. Correlation matrix of chemical characteristics of B_{17} carambola during storage at various temperatures

Pearson correlation coefficients/prob.>/R/under Ho:RHO = 0/n

Storage period	0.000					
	1.000					
	320					
Temp.	0.000	0.000				
	1.000	1.000				
	320	320				
TTA	–0.6693	–0.1161	–0.0289			
	0.0001**	0.0777	0.6615			
	232	232	232			
TSS	0.4984	–0.4443	0.0860	–0.3563		
	0.0001**	0.0001**	0.1920	0.0001**		
	232	232	232	232		
pH	0.2039	0.3253	–0.1296	0.1310		
	0.0018**	0.0001**	0.0487*	0.0017*	0.0462*	
	232	232	232	232	232	
TS	0.3693	–0.2757	–0.1928	–0.2020	0.5093	0.0179
	0.0001**	0.0001**	0.0032*	0.0020**	0.0001**	0.7861
	232	232	232	232	232	232
	Maturity	Storage period	Temp.	TTA	TSS	pH

Table 6. Changes in pH of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	3.80a	3.80a	3.80a	3.80a
	2	4.20ac	4.60b	4.58b	4.68b
	4	4.68bc	4.38b	4.62b	–
	6	4.55bc	4.48b	–	–
	8	5.05b	4.53b	–	–
11	0	4.05a	4.05a	4.05a	4.05a
	2	4.45b	4.40b	4.58b	4.05a
	4	4.65b	4.53b	4.37b	–
	6	4.50b	4.40b	–	–
	8	4.53b	4.50b	–	–
12	0	4.55ab	4.55b	4.55a	4.55a
	2	4.58ab	4.93a	4.48a	4.35a
	4	4.65a	4.70ab	–	–
	6	4.40b	4.63ab	–	–
	8	4.45ab	4.65ab	–	–
13	0	4.53a	4.53ab	4.53a	4.53a
	2	4.40ab	4.50ab	4.65a	4.40a
	4	4.38ab	4.53ab	–	–
	6	4.43ab	4.73a	–	–
	8	4.28b	4.42b	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

In general, there was a reduction in the TTA produced during the storage period (Table 7) but the changes were not significant.

The TSS significantly declined as the storage period was extended (Table 8). Significant changes occurred after 2 weeks storage at 5 and 10°C. At these storage

temperatures it was observed that the decline in TSS was also gradual when compared with those stored at 15 and 20°C.

Similar trends were observed in the decline of the TS content during storage (Table 9). In younger fruits significant reduction was observed only after 6–8 weeks storage at 5 and 10°C. In more mature fruit (13 weeks after fruit set) the total sugar declined after 2 weeks storage and became stable after that. An increase in temperature also caused rapid reduction in TSS.

Table 7. Changes in total titratable acidity (%) of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	0.20a	0.20a	0.20a	0.20a
	2	0.17a	0.19ab	0.18a	0.18a
	4	0.17a	0.18ab	0.15b	–
	6	0.18a	0.18ab	–	–
	8	0.20a	0.17b	–	–
11	0	0.16a	0.16a	0.16a	0.16a
	2	0.18a	0.18a	0.18a	0.18a
	4	0.17a	0.17a	0.15a	–
	6	0.17a	0.16a	–	–
	8	0.15a	0.16a	–	–
12	0	0.15a	0.15a	0.15a	0.15a
	2	0.16a	0.15a	0.13a	0.13a
	4	0.17a	0.15a	–	–
	6	0.15a	0.14a	–	–
	8	0.15a	0.13a	–	–
13	0	0.13a	0.13ab	0.13a	0.13a
	2	0.15a	0.14ab	0.12a	0.14a
	4	0.12a	0.15a	–	–
	6	0.14a	0.11b	–	–
	8	0.12a	0.12ab	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

Quality of carambola quickly deteriorated when held at ambient temperature (28°C). This was demonstrated by the development of diseases (Table 10 and 11). Fruit that had been stored for 2–4 weeks at 5 and 10°C were attacked by diseases within 3–5 days storage at ambient.

At this temperature the senescing fruit seemed to lose resistance to disease. At the same time, the appearance of the fruit was also less attractive. The colour became dull and the fruit began to lose its firmness, mainly due to water loss through the process of respiration and transpiration.

Discussion

Both the storage life and quality of carambola cv. B_{17} were affected by fruit maturity, storage period, and storage temperatures. At 5 and 10°C the storage period could be extended to about 4 weeks if the fruit were harvested at 12 and 13 weeks after fruit set. Younger fruit (harvested at 10 and 11 weeks after fruit set) had a shorter storage life of about 2 weeks. The storage life was strongly influenced by the development of diseases

Table 8. Changes in total soluble solids (°Brix) of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	7.10a	7.10a	7.10a	7.10a
	2	7.83a	7.15a	7.98b	7.78a
	4	7.45a	7.68a	7.60a	–
	6	7.35a	7.55a	–	–
	8	7.45a	7.00a	–	–
11	0	10.50a	10.50a	10.50a	10.50a
	2	9.30b	9.35b	10.00	7.68b
	4	8.95b	9.28b	9.50a	–
	6	8.58b	8.88b	–	–
	8	8.55b	8.68b	–	–
12	0	11.03a	11.03a	11.28a	11.28a
	2	10.50ab	10.15ab	9.00b	8.88b
	4	9.83bc	9.80b	–	–
	6	9.50bc	8.33c	–	–
	8	8.88c	7.50c	–	–
13	0	12.25a	12.25a	12.25a	12.25a
	2	10.28b	10.45b	9.58b	8.38b
	4	9.20b	9.55b	–	–
	6	9.23b	8.23c	–	–
	8	9.35b	7.40c	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

Table 9. Changes in total sugar (%) of B_{17} carambola during storage at various temperatures

Maturity (weeks)	Storage period (weeks)	Temperature (°C)			
		5	10	15	20
10	0	7.17a	7.17a	7.17a	7.17a
	2	6.86a	6.86a	5.92b	5.29b
	4	6.19a	6.79a	5.10c	–
	6	6.36a	6.34b	–	–
	8	6.25a	6.06b	–	–
11	0	7.38a	7.38ab	7.38a	7.38a
	2	7.64a	7.90a	7.31a	6.32a
	4	7.67a	7.38ab	7.10a	–
	6	7.75a	7.02ab	–	–
	8	6.31b	6.70b	–	–
12	0	7.65a	7.65ab	7.65a	7.65a
	2	7.90a	8.10a	7.97a	6.60a
	4	7.69a	8.49a	–	–
	6	7.33a	7.08b	–	–
	8	7.13a	6.81b	–	–
13	0	9.22a	9.22a	9.22a	9.22a
	2	7.94b	8.47b	4.21b	4.49b
	4	7.99b	7.90bc	–	–
	6	7.37b	7.41c	–	–
	8	7.59b	6.25d	–	–

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

(Table 4). The shorter storage life of the younger fruit may be due to chilling injury, an environmental effect on younger fruit conducive to the growth of microorganisms, or that the fruit had lower resistance to diseases than the mature fruit (Lam 1983). At higher storage temperatures (15 and 20°C) the fruit could be stored for only about a week before they decayed due to rapid development of diseases.

Table 10. Development of diseases on B_{17} carambola placed at ambient temperature after 2 weeks storage at 5°C and 10°C

Maturity (weeks)	Days at ambient	Temperature (°C)	
		5	10
10	0	0.00a	0.00a
	3	0.10a	0.00a
	5	0.43b	0.40b
	7	0.66c	0.70c
11	0	0.00	0.03
	3	0.00	1.30b
	5	0.00	2.03c
	7	0.43	2.63d
12	0	0.00a	0.17a
	3	0.00a	0.37a
	5	0.12ab	0.37a
	7	0.23b	0.97b
13	0	0.06a	0.03a
	3	0.07a	0.04a
	5	0.63b	0.77b
	7	0.73b	0.96b

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.

Table 11. Development of diseases on B_{17} carambola placed at ambient temperature after 4 weeks storage at 5 and 10°C

Maturity (weeks)	Days at ambient	Temperature (°C)	
		5	10
12	0	0.17a	0.17a
	3	0.37ab	0.63b
	5	0.53bc	1.03c
	7	0.73c	1.50d
13	0	0.00a	0.00a
	3	0.40b	0.46b
	5	0.85c	1.00c
	7	1.10d	1.00c

Mean separation within column, at each maturity by DMRT at 5% level. Means with the same letter are not significantly different.
Note: No data available for fruits harvested at 10 and 11 weeks after fruit set because all fruits already decayed or diseased.

Lower storage temperatures also help to preserve the quality of the fruit. This is because carambola stored at low temperatures have lower metabolic and respiration rates than those stored at higher temperatures (Lam and Wan 1987). The low metabolic rate helps to slow down the ripening process. This was exhibited in the slow or gradual change in colour and firmness of the fruit when stored at 5°C as the ripening process was retarded. At this temperature, the colour index at harvest could be maintained, while it was impossible to stop the ripening process at higher temperatures. The rate of ripening was faster when the temperatures were increased, as indicated by a decrease in the firmness of the fruits (Table 3). At higher temperatures, softening of the tissues may also be accelerated due to senescence. This process was particularly rapid when the fruit were held at ambient temperature.

Changes in the chemical quality were also affected by fruit maturity and storage temperatures. All these changes were also affected by the metabolic rate of the fruit. At low temperatures, both the metabolic and respiratory rates were reduced. Thus, the change in pH, TSS, and TS was very gradual due to the low metabolic rate of the fruit.

During storage, the pH in the younger fruit continued to increase gradually, indicating that the ripening process was still in progress especially during the first 2 weeks (Table 6). No significant increase in pH was observed after that, indicating that the ripening process was retarded due to reduction in fruit metabolism. However, during the first 2 weeks storage the pH rapidly increased to values approaching those of ripe fruit.

In general, there was significant reduction in both the percentage TSS (Table 8) and TS (Table 9) which clearly indicated that these components were being utilised in the metabolic processes of the fruit. The rate of reduction was more rapid when the temperature was increased, correlating with higher rates of respiration.

Conclusion

Carambola cv. B_{17} can be stored at low temperatures. Mature fruits can be stored longer since they are more resistant to disease development. Fruits harvested at 12 and 13 weeks after fruit set can be stored for 4 weeks at 5 and 10°C. Since carambola are non-climacteric fruit (Oslund and Devenport 1981; Lam and Wan 1983) harvesting at this maturity stage gives better quality fruits in terms of flavour, colour development, and taste (Siti Halijah and M. Yunus 1992).

Fruits harvested at 10 and 11 weeks after fruit set can be stored for 2 weeks at low temperatures (5 and 10°C). At higher temperatures (15 and 20°C), the fruit can be stored for about 1 week before they decay, mainly due to diseases. However, it is not advisable to harvest the fruit at these shorter times after fruit set, since they have a shorter storage life and their colour and flavour do not develop fully.

Diseases also developed rapidly on fruits that had been stored at 5 and 10°C when held at ambient temperature. At this temperature the fruits should be marketed 3–5 days after removal from cold storage.

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Incidence of Chilling Injury in *Salacca zalacca*

M. S. Mahendra and John Janes*

THE susceptibility of tropical and subtropical fruits to chilling injury has been widely reported in the literature (Lyons 1973; Couey 1982; Brown 1986; Wills et al. 1989; Kays 1991). At temperatures of 0–13°C the tissues of many horticultural crops of both temperate and tropical origin weaken because of the failure to maintain normal metabolic activities (Wang 1992).

In bananas cv. Lady Fingers it has been reported that chilling injury is only a slight problem when they are stored at 12.5°C (Mahendra et al. 1992). Low temperature storage is widely used to extend fruit shelf life. For fruit with a marked seasonal production or in fruits that are transported over considerable distances resulting in a long period between harvesting and consumption, there is a need to extend the shelf life of the product. The sensitivity of tropical fruit to chilling limits the use of reduced temperature as a means of preserving fresh fruit for consumption at some later time.

While there have been detailed reports of the low-temperature susceptibility of many tropical fruits, there appears to have been limited work on the incidence of chilling injury in salak (*Salacca zalacca*). The plant which produces the edible fruit, salak, belongs to the lepidocaryoid palms (Beccari 1918, in Mogea 1978) which include sago and raphia palms. The fruit has a scaly pericarp containing three creamy, edible, fleshy 'fruits' of varying size. The edible parts are not fruits botanically, but fleshy arils that surround the brown, stony seeds. The arils are outgrowths of the funiculus (stalk) of each ovule (I.A. Staff, pers. comm. 1993).

Salak has a marked seasonality of production in Bali, the major fruit season being December–February following a minor fruiting in June–July. The fluctuating supply of fruit and the distance it has to travel to markets on other islands dictates a need to extend its shelf life.

The aim of the experiment reported here was to evaluate the effects of storage temperatures between 3 and 32°C on harvested salak fruit, with special attention being given to the occurrence of chilling injuries.

Materials and Methods

Fruit were obtained from a local farmer in Bali. They were picked at maturity about 6 months after flowering. All fruit were examined individually on arrival at the laboratory and only those in good condition were allocated randomly to each treatment in the experiment. The experiment was conducted in a randomised block design (RBD) which consisted of five treatments with 4 replications. The five treatments consisted of storage in air temperatures of 3–5°C, 7–10°C, 15°C, 22–24°C, and at ambient temperatures (29–32°C). Each treatment unit consisted of 10 fruit. An analysis of variance of data from the randomised block experiment was carried out. A square root transformation of data expressed as percentages was applied before analysis (Gomez and Gomez 1976). Further to analysis of variance, where significance was shown, differences between treatments were established using Duncan's Multiple Range Test.

Observations were made on the first visible symptom and on the rate of development of chilling injury using the following score: 0 = none; 1 = slight injury; 2 = moderate injury; and 3 = severe injury (Mahendra et al. 1992). Fruit shelf life was visually assessed daily. Fruit was considered unsaleable and discarded from the experiment when the sample reached 10% damage. The criteria for damage were: mouldy, soft texture, wrinkled, and skin discoloration. Fruit firmness was measured objectively with a fruit pressure tester (Effegi Model FT. 011, Alphonsine, Italy) fitted with a 0.8 cm plunger. The pressure (kg force) required to puncture the fruit was recorded. The mean value of an individual fruit was calculated from three readings taken at three points around the fruit. The fruit weight loss was assessed by subtracting final fruit weight after storage from the initial weight.

Results and Discussion

The most common symptoms of chilling injury observed in the fruit of *Salacca zalacca* were skin pitting and external discoloration. The more severe symptoms were necrotic areas, wilting, and a smoky to dark or brownish black peel colour. Fruit flesh tended to turn brown and became soft textured.

The development of chilling injury in the fruit over time at low temperatures is shown in Figure 1. It was observed that fruit stored at 3–5°C and 7–10°C exhibited chilling injury symptoms after 2 and 3 days (score 1), respectively. The symptoms became moderate (score 2) after 15 days and severe (score 3) after 32 and 33 days of storage at each of the two lowest temperature regimes (3–5° and 7–10°C). Chilling injury of the

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fruit pulp was indicated by flesh that had turned brown and soft. No symptoms of chilling injury were observed on fruit stored at 15°C or above. These results indicate that the fruit of *Salacca zalacca* are as susceptible to chilling injury as other tropical and subtropical fruit.

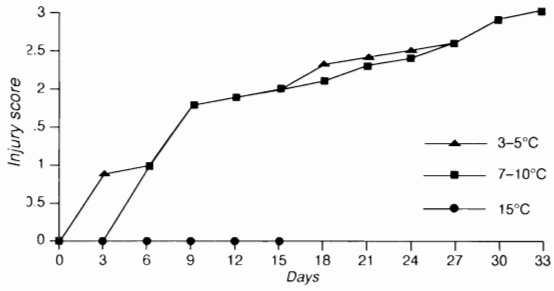

Figure 1. The pattern of development of chilling injury in fruit of *Salacca zalacca*.

The longest storage life was shown by fruit stored at 3–5°C (25 days), followed by fruit stored at 7–10°C (23 days) (Fig. 2.). However, both these groups suffered from moderate to severe chilling injury. While the storage life of the fruit was extended 15 and 14 days, respectively, in the two lowest temperature conditions compared with fruit stored under ambient temperatures, this advantage was offset by moderate to severe chilling injury. Cooling the fruit to 15°C achieved a gain in storage life of only 2.5 days with no chilling injury evident. This result represents only marginal improvement in storage life which would be of limited value to local and regional marketing of the fruit and of little assistance to the exported product.

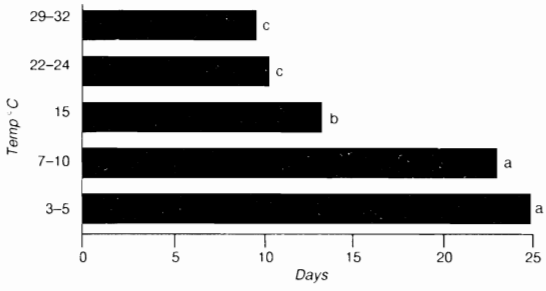

Figure 2. Storage/shelf life of fruit of *Salacca zalacca* stored under different temperature regimes. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

The fruit firmness was measured after 0, 7, 14, 21, and 28 days at each of the temperature regimes (Fig. 3). No significant difference ($P > 0.05$) in the value of fruit pulp firmness was observed on day 0, with the values for the determination ranging from 6.1–6.8 kg force. Fruit firmness deteriorated with an increase in storage temperature. It was observed that fruit stored at ambient temperature (29–32°C) had the lowest value measured after both 7 (5.8 kg force) and 14 days (3.0 kg force). Fruit stored at 3–5 and 7–10°C showed an increase in fruit firmness measured after 7 days (8.55 and 8.0 kg), which then decreased gradually after 14 days (6.6 and 8.0 kg), 21 days (6.5 and 6.8 kg), and 28 days (6.4 and 6.3 kg), respectively. A rapid decrease in fruit firmness during storage was observed on fruit stored at 15 and 22–24°C measured after 7 days (8.0 and 7.2 kg) and 14 days (8.0 and 5.8 kg), respectively.

Fruit weight loss was measured over the period of 1–4 weeks at each of the temperature treatments. It was observed that percentage of fruit weight loss increased significantly with increase in storage time (Fig. 4). The lowest value was observed on fruit stored at 3–5 and 7–10°C measured after either 1 (9.8 and 8.9%) or 2 weeks (14.2 and 14.5%), while a significantly higher percentage of weight loss was observed on fruits stored at 15, 22–24, and 29–32°C measured after 1 (16.9, 15.3, and 13.7% and 2 weeks (22.9, 23.6, and 22.4%), respectively. The fruit stored at the two lowest temperatures lost a considerable amount of water at 3 weeks (18.1 and 18.9%), and 4 weeks (21.0 and 22.9%), respectively. These results indicate that considerable fruit weight loss occurred over the storage period and methods to control this loss may be worth investigating.

Conclusion

Cooling was shown to extend the storage life of the fruit of *Salacca zalacca* by up to 15 days but the low temperature treatments imposed, namely 3–5°C and 7–10°C caused moderate to severe chilling injury. Methods that may reduce the incidence of chilling injury in the fruit need to be researched if the benefits of increased storage life by refrigeration of the salak fruit are to be realised.

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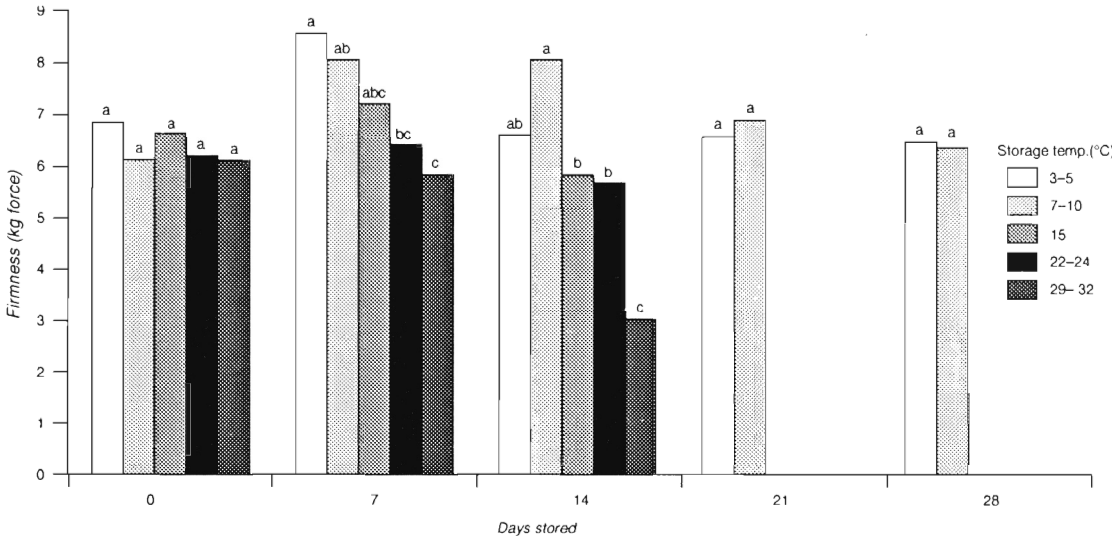

Figure 3. The effect of storage temperature on the firmness of fruit over the period of storage. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

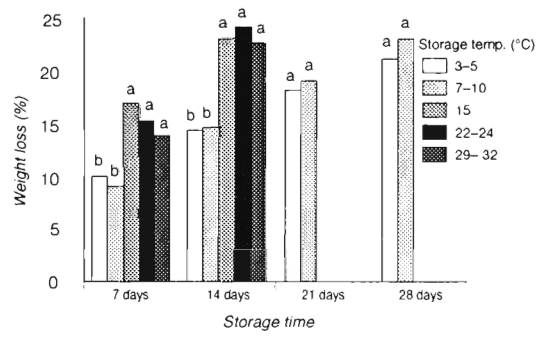

Figure 4. Percentage weight loss of the fruit of *Salacca zalacca* stored at the different temperatures over the period of storage. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

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Internal Carbon Dioxide and Ethylene of Avocado Fruit (*Persea americana* Mill.) Measured by an Equilibration Technique

Ubol Bonruengsri*, David Simons*, and Daryl Joyce†

RIPENING of avocado fruit does not occur as long as the fruit remains attached to the tree (Schroeder 1953; Tingwa and Young 1975). Changes in the internal atmosphere of avocado fruit after harvest are associated with ripening (Burg and Burg 1962a; Ben-Yehoshua et al. 1963). The means used for obtaining the internal atmosphere of avocado fruit include vacuum extraction (Burg and Burg 1962a,b; van Eeden et al. 1990) and sampling from a cavity bored in the fruit mesocarp (Ben-Yehoshua et al. 1963).

The purpose of the present study was to measure the internal concentrations of carbon dioxide (CO_2) and ethylene of mature avocado fruit during preharvest and postharvest periods. A non-injurious equilibration technique was used to obtain samples of atmosphere in equilibrium with the internal atmosphere of the fruit.

Materials and Methods

Five uniform fruit were tagged on each of 2 'Hass' avocado trees. Glass tubes (1.8-2.0 mL internal volume), each with a septum secured beneath a screw cap, were attached with Blu-tack® [Bostik (Australia) Pty Ltd] to the widest circumference of these fruit (Fig. 1). Two 0.2 mL gas samples were withdrawn for each fruit for analysis of CO_2 and ethylene. A Shimadzu GC-8A gas chromatograph (TCD detector) operated at oven and detector temperatures of 20 and 30°C, respectively, was used to measure CO_2. A Shimadzu GC-8A gas chromatograph (FID detector) operated at oven and detector temperatures of 80 and 120°C, respectively, was used for ethylene measurement. The lower limit of detection was approximately 0.004 µL ethylene/L in a 10 mL air sample (V. Robertson, pers. comm.).

After sampling on the tree for 15 days the 10 fruit were harvested and randomly allocated to two sample lots. The samples of unwrapped and wrapped (PWGS cling-wrap plastic film) fruit were then held at 20°C and 50-60% relative humidity. CO_2 and ethylene concentrations in the attached tubes were generally measured daily. Fruit colour changes were monitored using a colour rating scale of 0 (green), 1 (25% darkening), 2 (50% darkening), 3 (75% darkening), and 4 (100% darkening).

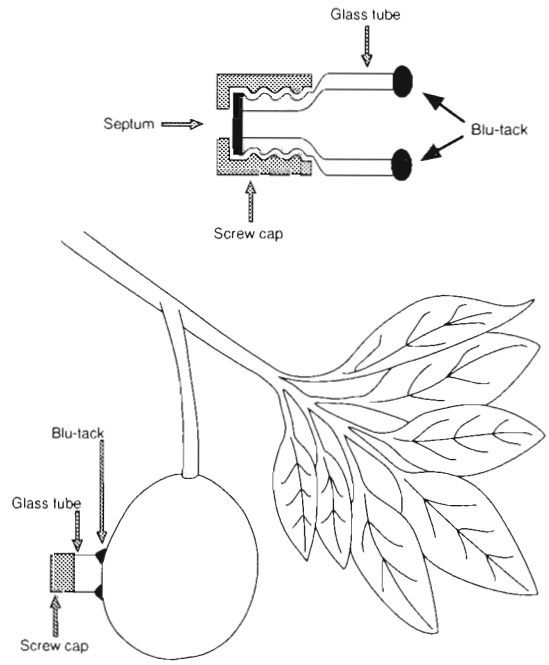

Figure 1. Gas equilibration system used for obtaining samples of the internal atmosphere of 'Hass' avocado fruit.

Results and Discussion

No measurable internal ethylene was detected during the preharvest period (Fig. 2). Thus, preharvest equilibrium ethylene concentrations were in the order of 0.004 µL/L or less. Ethylene was first detected 7 and 15 days after harvest in unwrapped and wrapped fruit, respectively (Fig. 2).

Burg and Burg (1962a) found by vacuum extraction that the internal concentration of ethylene in 'Cho-

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quette' avocados at the time of harvest ranged from <0.01 to 0.06 μL/L. The lowest concentration of ethylene which could be measured in their study was 0.01 μL/L. Very low ethylene concentrations in 'Hass' avocados 4 days after harvest were determined in gas samples obtained by partial vacuum extraction (van Eeden et al. 1990). The absence of detectable ethylene before the climacteric peak could indicate a difference between the equilibration and vacuum extraction techniques. Vacuum extraction may remove dissolved or bound ethylene from the tissue, not just from the intercellular space.

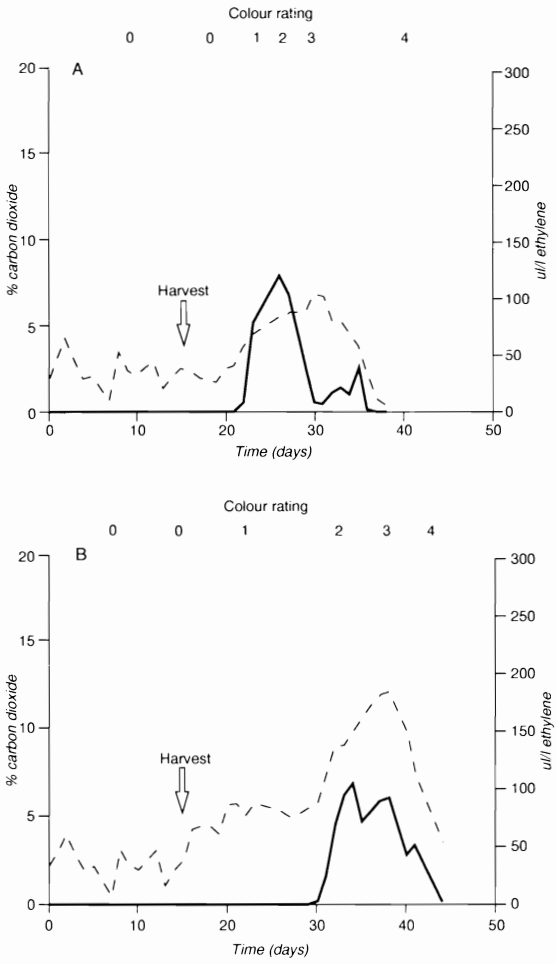

Figure 2. The average internal concentrations of CO_2 (dashed line) and ethylene (solid line) and colour rating of unwrapped (A) and wrapped (B) avocado fruit. Data represent 5 fruit. Arrow indicates the time of harvest.

Concentrations of CO_2 fluctuated around 1–4% before harvest (Fig. 2). After harvest, CO_2 concentrations in wrapped fruit were consistently higher than in unwrapped fruit (Fig. 2). The peak CO_2 concentrations for unwrapped and wrapped fruit were recorded 15 and 23 days after harvest, respectively (Fig. 2). Peak ethylene concentrations in unwrapped and wrapped fruit occurred 11 (at colour rating 1–2) and 19 (at colour rating 2–3) days after harvest, respectively (Fig. 2).

Film wrapping with PGWS film after harvest increased the internal CO_2 concentration from 1–4% to 5–7% during the preclimacteric period and delayed peak CO_2 and ethylene levels (Fig. 2). Wrapping also delayed fruit colouring (Fig. 2). Similarly, Joyce and Shorter (1992) reported that wrapping in LDPE cling film extended the green life of 'Hass' avocado fruit, with an associated decrease in the rate of water loss and an increase in CO_2 concentrations beneath the wrap.

Attaching vials to the surface of avocado fruit with Blu-tack to obtain equilibrium atmosphere samples was used successfully during both pre- and postharvest periods. The technique is simple and non-destructive, and appears to be a valid means for measuring internal CO_2 and ethylene concentrations for avocado. Film wrapping after harvest increased the internal CO_2 concentration and delayed peak CO_2 and ethylene levels in association with delayed fruit ripening.

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Effects of Plantation and Postharvest Management Factors on Shelf Life of 'Williams' Banana

J.A. Seberry and D.R. Harris*

ALTHOUGH New South Wales (NSW) growers consistently supply about 25% of the 3.8 million cartons of bananas sold annually on the market in Sydney, Australia, NSW bananas consigned there have gained a reputation for poor quality. There is a marked preference in retail demand throughout the year for north Queensland (NQ) bananas, which constitute the remaining 75% supplied to the market. Despite a lack of documented evidence, bananas grown in NSW are often regarded as inferior to those from Queensland, because they are perceived by retailers and wholesalers to have a shorter shelf life (SL) (Moody 1993). This is reflected by the prices paid for NSW bananas which are often $4–7 per 13 kg carton lower than for comparable fruit from NQ. The lower prices paid for their bananas are estimated to be costing NSW growers between $3 million and $6 million annually. Because of concern about these problems, the NSW Banana Industry Committee (BIC) and the Horticultural Research & Development Corporation (HRDC) agreed to fund research on banana SL by NSW Agriculture.

There are significant climatic differences between the NQ and NSW banana production areas. Most of the fruit from NQ is grown in wet tropical conditions on the 100 km coastal strip between Innisfail (17°30'S) and Cardwell (18°15'S). Annual rainfall is 2100–3800 mm, but most plantations are irrigated and capable of a more regulated supply of fruit than those in southern areas. However, NQ is subject to summer cyclones and temperature fluctuations, with occasional chilling conditions. Production areas in NSW are located on the coast between Tweed Heads (28°S) and Macksville (31°S), with annual average rainfall of 1500–2200 mm and subtropical temperatures. Plantings are mostly on hillsides and slopes to avoid frost and provide cold air drainage. The bunch-to-bunch cycle in NSW plantations is 14–16 months, compared with about 12 months in NQ.

It has been suggested that SL of fruit might be related to a range of plantation factors, such as soil type, plant nutrition, pest and disease control (particularly leaf diseases), soil moisture levels, bunch pruning, and physiological age of the fruit at harvest, as well as ripening and storage practices in the market.

Sample cartons of 10–12 commercial lines of green bananas (cv. 'Williams') from NSW districts and NQ have been purchased each month from Sydney Market since the project commenced in October 1991. The bananas have been transported to Gosford, ripened with ethylene under simulated commercial conditions for 4–5 days at 16–18°C to CSIRO standard colour index 3 or 4 (Anon. 1971), and then stored at 20°C for SL assessments.

On removal from the ripening room, the bananas were rated each day by a panel of 8–10 people for quality of skin colour and general appearance, until the fruit was considered to be commercially unacceptable because it was overripe or rotting, as described by Peacock (1980). Changes in peel colour, pulp firmness, and development of postharvest rots were monitored as the fruit ripened. Fruit weight and finger length/diameter were recorded, and pulp and peel samples were oven-dried to determine dry matter content. Samples of the dried fruit were also analysed for mineral nutrients in an attempt to determine whether there is any correlation between composition and fruit SL.

Seasonal differences in SL between NSW and NQ bananas

Between October 1991 and June 1993, 158 grower lines from NSW and 56 from NQ were evaluated. The comparative SL of fruit sourced from NSW districts and Queensland varied according to season (Figs 1 and 2). The mean SL of Queensland fruit was longer than that of NSW fruit in the spring months of October and November in both 1991 and 1992. Much of the NSW fruit marketed in these periods showed brown discoloration under the peel after ripening, and had a dull yellow colour, a typical indication of chilling injury which probably occurred in the plantation. However, in both years by mid-summer fruit from both sources had similar SL and colour. By February and March (autumn), SL of NSW fruit was superior. From late autumn through to early spring, there were differences in keeping quality between fruit from NSW and Queensland, but these did not appear to be consistent from year to year.

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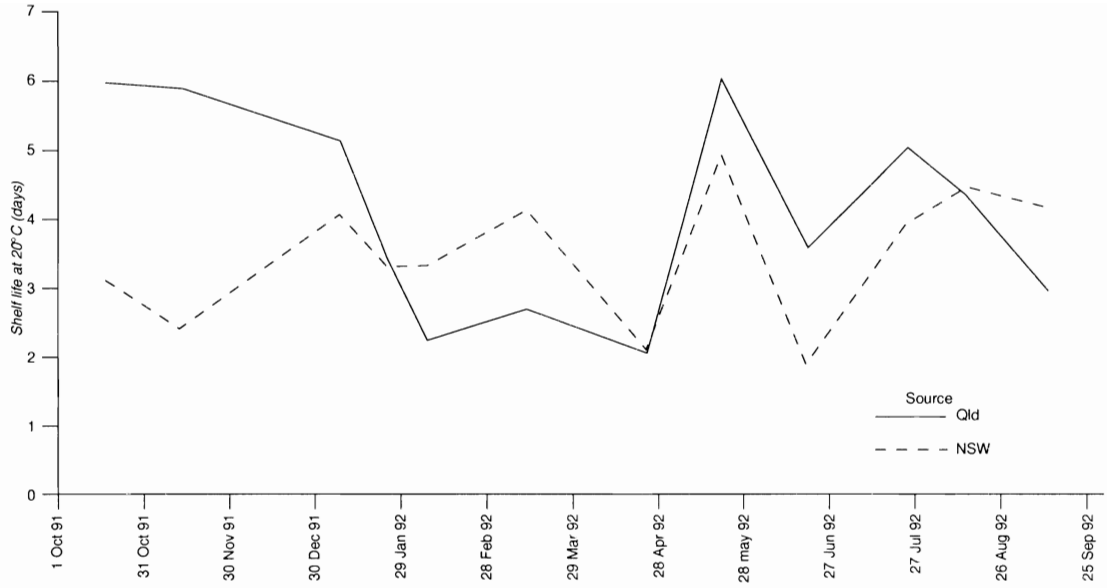

Figure 1. Seasonal fluctuations in shelf life at 20 °C, after ripening, of bananas from New South Wales and north Queensland sampled between October 1991 and September 1992.

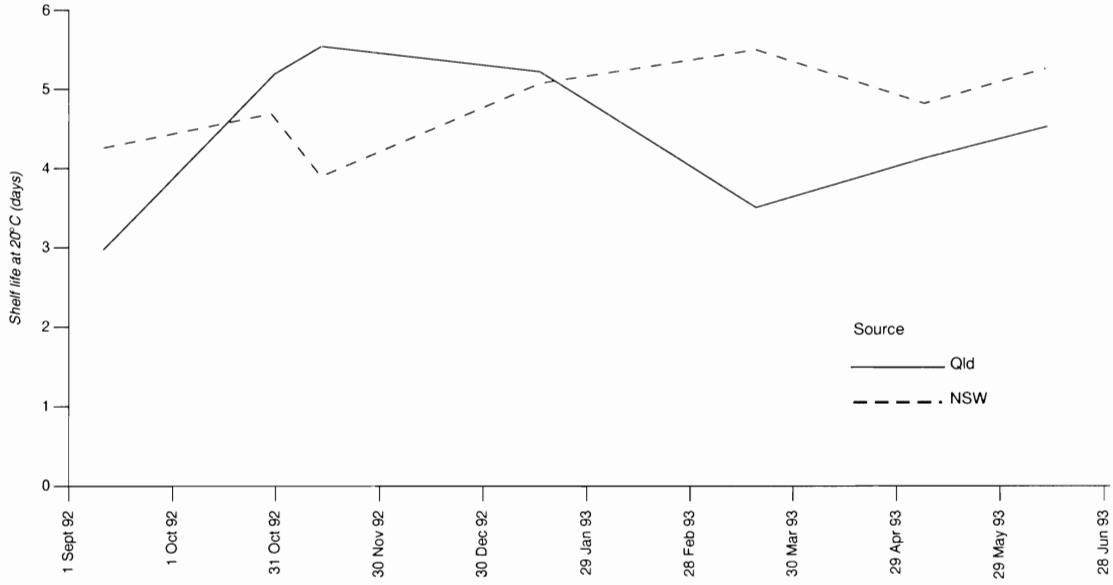

Figure 2. Seasonal fluctuations in shelf life at 20°C, after ripening, of bananas from New South Wales and north Queensland, sampled between September 1992 and June 1993.

Chemical composition of banana fruit in relation to SL

Over the past two years we also analysed 71 lines of the fruit obtained for SL assessments, using inductively coupled plasma (ICP) techniques and Kjeldahl extractions to determine 6 major and 5 minor nutrient elements. Samples consisted of two fruits from a single hand of green bananas from each grower line, separated into peel and pulp, weighed, and oven-dried to constant

Table 1. Mean concentrations of N, P, K, Ca, Mg, B, and Mn in banana peel dry matter in relation to fruit shelf life (SL)

Month of sampling	State of origin	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Mn (ppm)	SL (days)
Apr 1992	NSW	1.2	0.16	6.7	0.19	0.17	22	120	2.1
	QLD	1.5	0.19	6.8	0.22	0.21	22	94	2.1
May 1992	NSW	1.3	0.17	6.5	0.16	0.19	20	61	5.0
	QLD	1.5	0.16	5.9	0.16	0.18	22	167	6.1
Sep 1992	NSW	1.3	0.18	6.9	0.17	0.11	24	133	3.6
	QLD	1.4	0.15	6.1	0.16	0.12	23	169	2.6
Oct 1992	NSW	1.4	0.20	7.5	0.20	0.14	23	87	4.5
	QLD	1.6	0.17	6.1	0.20	0.19	23	73	5.1

weight, before being stored in a freezer. This material provided dried samples of peel and pulp from hands with a wide range of SL scores. Results of analysis of samples, taken in April, May, September, and October 1992, to determine nutrient concentrations in peel dry matter in relation to fruit SL, are shown in Table 1. There were no consistent correlations between any of the peel and pulp mineral elements and the mean SL scores for these lines of fruit.

Precooling and refrigerated transport

Until recently, unrefrigerated rail vans were the most common method of transport for NSW bananas to Sydney, with refrigerated road transport being used by Queensland producers. In summer, NSW fruit could often be subjected to high temperatures at the railhead and during transport for 3–4 days. A series of trials has been commenced to compare the effects on SL of rail or road transport at ambient temperatures in summer with precooling and refrigeration. To date we have been unable to demonstrate that the latter have any beneficial effect on SL.

Discussion

There is a general perception among merchants and retailers in Sydney that NSW bananas have a shorter SL than Queensland fruit, especially on either side of the NSW peak season between January and April when supplies of NSW fruit are greatest. The major supplies of fruit to the southern Australian markets from NQ are between May and December. The survey described here confirmed that NSW bananas harvested in the spring months are generally of poorer quality than comparable fruit from NQ. The NSW fruit marketed in this period comes from bunches which have hung in the plantation over winter.

Our results provide evidence that the cool winter conditions in many NSW plantations, and the occurrence of chilling injury, are not only affecting the appearance and colour of fruit adversely, but may be also directly or indirectly reducing SL. It is possible that poor leaf health is reducing spring fruit SL. The effects of severe leaf disease, especially sigatoka leaf spot, on fruit filling and premature ripening are well known. It has also been suggested that bunch pruning during stress periods will improve the quality of the remaining fruit, but this has not been tested. However, we were unable to show any relationship between gross fruit composition and SL.

Acknowledgments

This research project and presentation have been undertaken with the financial support of the NSW Banana Industry Committee and the Horticultural Research and Development Corporation of Australia which is gratefully acknowledged. The tissue analyses of banana samples were carried out by the Chemistry Branch of NSW Agriculture at the Biological & Chemical Research Institute, Rydalmere. The authors are indebted to Dr Geoff Johns for his advice on the project and Mr Ken Ward for his competent assistance with the experiments.

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Optimisation of Indigenous Ripening Systems for Bananas in the Philippines

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BANANA is the prime fruit commodity in the Philippines. Producers and entrepreneurs, 80% of whom are smallholders, usually harvest the fruit green and ripen it with calcium carbide (CaC_2), or with leaves of gliricidia (*Gliricidia sepium* Steud.) or rain tree (*Samanea saman* Merr.). Ethylene is used only by the large, export-orientated firms.

Very little research has been done to examine and improve the indigenous ripening systems in bananas. Earlier studies by the authors in 'Saba' bananas (*Musa*, BBB Group) showed that the conventional rate of CaC_2 application of 25 g/100 fruit produced during a 24-hour treatment at least 10 times more acetylene (10,000 µL/L) than required for inducing ripening. It was also found that gliricidia leaves at 5% of fruit weight (w/w) applied for 1 day effectively enhanced ripening. This is much lower than the traditional rate of 10–30% of fruit weight (w/w) applied for 2–4 days. Moreover, fruit disorders such as CaC_2 injury, soft-green disorder, ripe flesh hardening and poor flavour development, are not uncommon in fruit ripened by traditional methods.

This study optimised the treatment with CaC_2 and leaves of gliricidia or rain tree on 'Saba' banana, the most important commercial cultivar. CaC_2 treatment was also optimised on 'Latundan' banana (*Musa*, AAB Group), the leading table cultivar. Freshly harvested fruits of 'Saba' (full three-quarters stage) and 'Latundan' (full stage) were used. CaC_2 at 0–25 g/100 fruit was applied for 1 day in a 20-L bucket covered with four layers of newsprint. The CaC_2 was wrapped in newsprint and placed at the bottom of the container. Gliricidia at 5–10% of fruit weight (w/w) was applied for 1–2 days in a 0.05-mm thick, 35 cm × 25 cm polyethylene (PE) bag with 16 diffusion holes. Immature, fully expanded leaves were used since they produced higher ethylene levels than mature ones. Ten fruit were treated in each PE bag. The effect of gliricidia was also compared to that of ethephon (2-chloroethyl phosphonic acid) at 1000 µL/L applied as a 5-minute dip. Rain tree treatment was the same in rate and procedure as that of gliricidia but mature leaves were used. Since the leaves produced high CO_2 levels, a CO_2 scrubber — calcium oxide (CaO) or ordinary lime at 10% of leaf weight (w/w) and wrapped in newsprint — was incorporated during treatment. Ethylene, CO_2, and O_2 levels during gliricidia and rain tree treatment were measured by gas chromatography. After treatment, the fruit were kept in air. The experiments were done on a non-commercial scale under ambient conditions (26–31°C, 68–85% relative humidity). A completely randomised design with 3 replicates (10 fruit/replicate) was used. Two trials were done for each experiment and results were consistent.

CaC_2 at 5 g or more per 100 fruit enhanced ripening of 'Saba' and 'Latundan' fruits (Table 1). However, 'Saba' required a higher level (15 g CaC_2) than 'Latundan' (5 g CaC_2) to ripen in 2 days from harvest, similar to that effected by the conventional rate of 25 g CaC_2.

Table 1. Ripening period and weight loss at the ripe stage of 'Saba' and 'Latundan' bananas treated with 0–25 g CaC_2/100 fruit for 1 day.

CaC_2 level (g/100 fruit)	Ripening period[a] (days from harvest)	Weight loss (%)
A. 'Saba' (*Musa*, BBB Group)		
0	11.0a	11.1a
5	3.2b	4.2b
10	2.5c	4.4b
15	2.4cd	4.2b
20	2.1d	5.7b
25	2.1d	5.4b
B. 'Latundan' (*Musa*, AAB Group)		
0	7.5a	11.1a
5	2.3b	5.5b
10	2.0b	4.3b
15	2.0b	4.4b
20	2.0b	4.2b
25	2.0b	4.4b

[a] Number of days to reach peel colour stage 4–5 for 'Saba' and 6 for 'Latundan', the ripeness stage when the fruits are usually utilised (inclusive of treatment period). Peel colour index (CI): 1–green; 2–first trace of yellow; 3–more green than yellow; 4–more yellow than green; 5–yellow with green tips and/or angles; 6–full yellow.

Means having a common letter within columns per cultivar are not significantly different by DMRT 5%.

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At the ripe stage, total soluble solids, titratable acidity, and sensory quality did not vary between CaC_2-treated and untreated fruit but weight loss of the former was about 50% lower than that of the latter (Table 1). CaC_2 injury was not observed.

Gliricidia leaves at 5% of fruit weight (w/w) applied for 1 day ripened 'Saba' fruit in 3–4 days from harvest (Fig. 1a), confirming earlier results. Treatment with 10% leaves did not result in faster ripening than with 5% leaves. Two-day treatment slowed down peel yellowing (Fig. 1a) due possibly to high CO_2 and low O_2 (Table 2). Untreated fruit ripened in 7–10 days from harvest. Relative to ethephon, gliricidia was less effective in advancing ripening, but only by 1 day. The same trend in respiration and ethylene production was observed, except that ethephon-dipped fruit evolved high amounts of ethylene immediately after treatment and thereafter. Their internal ethylene content concomitantly increased to 3–4 µL/L, which can initiate ripening if treated for 8 hours. In contrast, during gliricidia treatment, ethylene slowly accumulated and on the 6th hour, was about 0.3 µL/L which is the minimum concentration for a 24-hour treatment to initiate ripening. The 6-hour lag period can render the treatment ineffective. However, the accumulated ethylene on the 12th hour, about 1.0 µL/L, was sufficient to enhance ripening as it requires only 12 hours treatment time.

Rain tree treatment had a similar effect as gliricidia in enhancing 'Saba' fruit ripening (Fig. 1b). However, when the leaves were applied for 2 days, about 30–40% of the fruit became soft but green. This was observed immediately after treatment and 1 day later. The green-soft fruit eventually turned yellow during holding in air but they became unacceptably soft.

Higher ethylene and CO_2, and lower O_2 levels prevailed during rain tree treatment as compared with those during gliricidia treatment (Table 2). These conditions, particularly those during the second day of treatment, possibly induced green-soft development. Reducing CO_2 levels with CaO slightly increased ethylene accumulation (Table 2) and improved the ripening-enhancing effect of rain tree only when applied for 2 days. The fruit turned yellow more rapidly than those

Table 2. Ethylene, CO_2, and O_2 levels in PE bags during treatment of 'Saba' bananas with 5% gliricidia or rain tree leaves (w/w) for 1–2 days.

	Days from treatment	Ethylene (µL/L)	CO_2 (%)	O_2 (%)
A. *Gliricidia*				
	1	5.2b	7.6b	10.2a
	2	8.5a	13.0a	7.2b
B. Rain tree				
without CaO	1	6.6b	10.7b	7.7
	2	9.1a	14.5a	6.2
with CaO	1	7.6b	2.4c	7.3
	2	9.9a	11.7b	6.8

Means having a common letter within columns per leaf type are not significantly different by DMRT 5%.

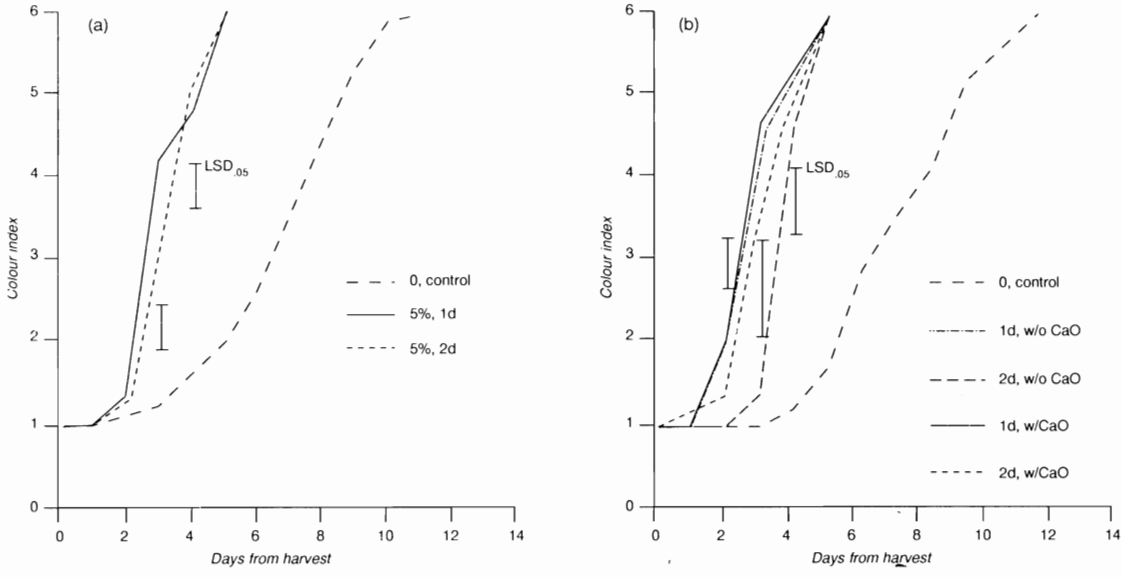

Figure 1. Peel colour development of 'Saba' bananas treated with 5% (w/w) gliricidia (a) or rain tree leaves (b) for 1–2 days.

treated without CaO (Fig. 1b). The green-soft disorder was also inhibited, affecting less than 5% of the 2 day-treated fruit.

The results indicate that the traditional quantities of CaC_2, gliricidia, or rain tree used for ripening bananas are excessive. Using traditional rates, the fruit are exposed for prolonged periods to conditions such as low O_2 and high CO_2 which can antagonise the effect of the ripening agent and induce the development of fruit disorders. Optimisation studies have been on a non-commercial scale. The identified optimum rates of CaC_2, gliricidia, and rain tree application need to be validated under normal commercial treatment where large volumes of fruit of mixed maturities are involved. Only then can a technically and economically efficient indigenous resource-based ripening system in bananas be established.

Fundamental Studies on Respiration Rates and Storage Properties of Some Tropical Fruits Grown on Okinawa

Takayoshi Akinaga and Yoshihiro Kohda*

IT is a essential to know the rate of respiration governing the storage life of fresh fruits so that the precooling facilities can be designed for maximum efficiency. The rate of respiration is a good index of the quality of fresh produce, and can be measured nondestructively. There is a large body of scientific literature on the rates of respiration in fruit, vegetables, and cut flowers (see, e.g., Lutz and Hardenburg 1968). However, the measurement methods, maturity of samples, and time after harvest have not been reported in detail.

Respiration rates of fruit are usually measured by infrared CO_2 gas analyser, a high-cost item (e.g. Yen 2 000 000 per unit). There is also a chemical method, however, using a CO_2-absorbent agent (Matsumoto 1936), which does not require a high-price measuring instrument. This paper reports chemical measurements of rates of respiration of some Okinawan-grown subtropical and tropical fruits at various temperatures.

Materials and Methods

Measurement of respiration rate by titration

Twenty-five mL of 2N KOH were placed in an evaporating dish on the bottom of a fixed-volume plastic vessel. Test fruits were placed in the vessel, which was then tightly sealed. The plastic vessel, test fruits, and the chemical were kept in the dark at a constant, pre-set temperature in a constant temperature and humidity chamber. The CO_2 generated in the vessel was absorbed by the KOH. After a fixed time (2–4 hours), the evaporating dish was removed and the KOH immediately poured into a 250 mL graduated flask containing 10 mL of 25% $BaCl_2$. Distilled water was added to constant volume and the contents of the flask allowed to settle after shaking well. $BaCO_3$ settled as a white precipitate. Fifty mL of the supernatant liquid were taken and neutralised with 0.2N HCl, using phenolphthalein as an indicator. As a control, 25 mL of KOH held in a plastic vessel under the same conditions as the test fruit was titrated.

The following equations describe the chemical reactions involved (Nakagawa 1981).

$$CO_2 + 2KOH = K_2CO_3 + H_2O$$

$$2HCl + 2KOH = 2KCl + 2H_2O$$

Therefore 1 mL of 0.2N HCl was equivalent to 4.4 mg of CO_2, and CO_2 generated

$$= 4.4 \times a \times (1/t) \times (1/w) \times f \times (250/50)$$
$$= 22\ af/tw \text{ (mg/kg/hr)}$$

where a = (volume of 0.2N HCl in control) – (volume of 0.2N HCl on sample) (mL)
w = sample mass in (kg)
t = measuring time in (hours)
f = factor of 0.2N HCl

Materials

Green-ripe banana cv. Ogasawara were harvested in 1992 in the courtyard of the College of Agriculture. Sound fingers were selected. Respiration rates of bananas were measured at fruit temperatures of 0–35°C, at 5°C intervals. Fully ripe pineapples cv. N67-10 were harvested on 8 December 1992 in Nago. Respiration rates of pineapples were measured every 5°C from 0–30°C. Fully ripe mangoes cv. Irwin were harvested on 20 July 1992 in Ginoza. Respiration rates of mango fruits were measured every 5°C from 5–35°C. Full ripe papaya fruits cv. Solo-Sunrise were harvested on 18 November 1992 in Higashi. Respiration rates of papaya fruits were measured every 5°C from 5–35°C.

Arrhenius plot

Respiration rates and inverse absolute temperatures were plotted on semilogarithmic graph paper as Arrhenius plots (Kitagawa 1986). It was found that they lay approximately on two straight lines. There was a large change at the lower temperature end of the line, which suggested a chilling temperature.

Storage tests

Storage tests were carried out to estimate the suitable storage temperatures of tropical fruits produced on Okinawa. Bananas, pineapples, mangoes, and papayas were stored from 7–14 days in constant temperature and

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humidity chambers, and were periodically inspected for qualities such as fruit hardness, peel colour, weight loss, moisture content, total soluble solids, and acidity.

Results and Discussion

Figure 1 shows the typical Arrhenius plots of respiration rates of bananas and temperatures. The critical chilling injury temperature was estimated from this plot at about 15°C. The recommended storage temperature for bananas given in the USDA handbook (Lutz and Hardenburg 1968) is 13–14°C. Thus, the storage temperatures for the test were set at 15°C and 25°C at 85% RH.

Figure 2 shows the plots of pineapples. The critical temperature for pineapples was estimated at about 10°C. The USDA-recommended storage temperature for fully ripe pineapples is 7–10°C (Lutz and Hardenburg 1968). Storage tests of pineapple were therefore carried out at 5,10, and 25°C and 80% RH.

Figure 3 shows the plots of fully ripe mangoes. The critical temperature of fully ripe Irwin mangoes was about 7°C. as compared with the USDA-recommended

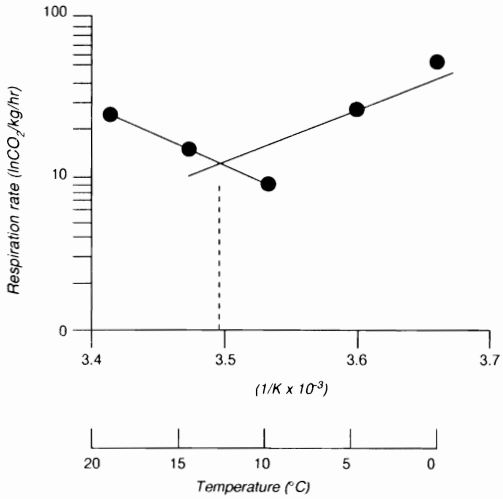

Figure 1. Arrhenius plots of respiration rates of bananas and temperatures

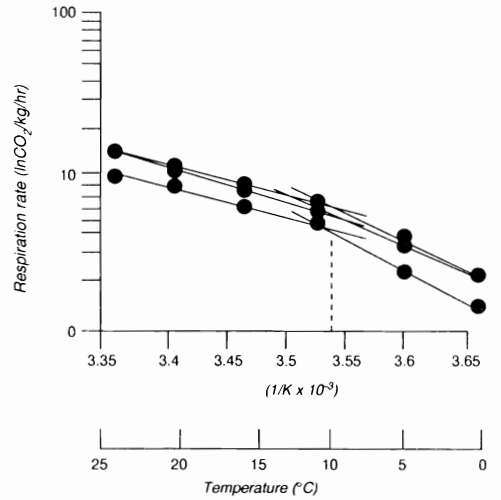

Figure 3. Arrhenius plots of respiration rates of mangoes and temperatures

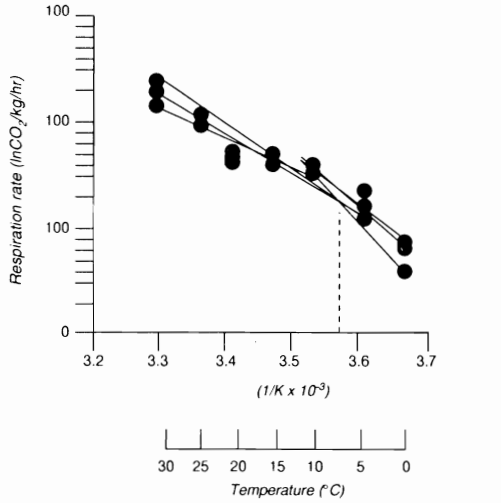

Figure 2. Arrhenius plots of respiration rates of pineapples and temperatures

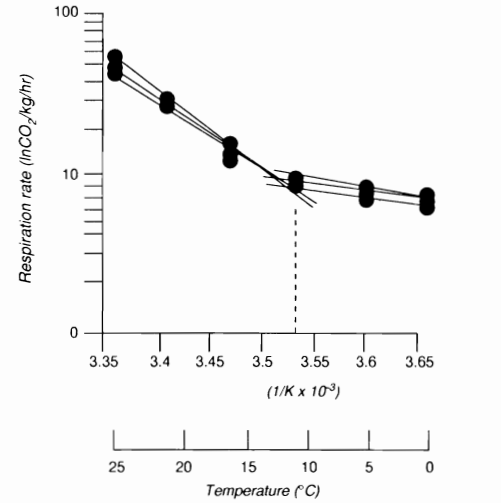

Figure 4. Arrhenius plots of respiration rates of papayas and temperatures

10°C. Storage tests of mangoes were carried out at 5, 12, and 25°C at 85% RH.

The plots for papayas (Fig. 4) show a critical temperature of about 10°C. From the USDA handbook, since papayas are subject to chilling injury, they should be held at a temperature close to, but not below 7°C. Storage tests of papayas were carried out at 5, 10, and 25°C at 85% RH.

From the results of storage tests, the recommended storage temperatures for bananas, pineapples, mangoes, and papayas were estimated at 15, 10, 12, and 12°C, respectively.

Conclusion

Arrhenius plots of respiration rates and fruit temperatures were an effective method for predicting the temperature below which fruit chilling injury will occur. Respiration rates of the tropical fruits were easily measured by the titration method, at lower cost than use of an infrared gas analyser.

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Reducing Decay and Extending Shelf Life of Bell-peppers and Mangoes by Modified Atmosphere Packaging

V. Rodov, S. Ben-Yehoshua, S. Fishman, S. Gotlieb, T. Fierman, and D.Q. Fang*

PREVIOUS research has shown that seal-packaging fruits in plastic films reduces weight loss and preserves the firmness and freshness of stored produce (Ben-Yehoshua et al. 1983). However, this method also has problems with some fruits. With peppers (*Capsicum annum* L.), in spite of positive results reported for individual seal packaging, high relative humidity may increase the risk of fungal decay, especially late in the season. With mangoes, the altered in-package atmosphere inhibits normal ripening of the fruit (Ben-Yehoshua et al. 1990; Sornsrivichai et al. 1992). In this paper, we present some modified atmosphere packaging (MAP) approaches enabling the reduction of the undesirable effects of sealing.

Materials and Methods

Bell-peppers of Maor and Maccabi cultivars were packed in plastic trays sealed in low density polyethylene (LDPE) of 20, 40, and 80 μm thickness, four fruit per tray. Sodium chloride (NaCl) was added to bell-pepper packages within the pouches of spunbonded polyolefin (Tyvek, Du Pont Co.). Mangoes of Tommy Atkins and Keitt cultivars were individually sealed in shrinkable Cryovac polyolefin films of 15 or 19 μm, either non-perforated (MD film) or perforated: MPY (8 holes of 1.7 mm diameter per square inch) or SM60M (8 holes of 0.4 mm diam. per sq. inch). Part of the fruit was sealed in the same films within foam polystyrene trays. Rotronic I-108 probes were used for monitoring the in-package relative humidity (RH).

Results and Discussion

Modified humidity packaging of bell-pepper

Relative humidity in the sealed tray-packages holding 4 fruit reached 99–100%, and condensation occurred on the film. Hygroscopic material (NaCl) was used to control the RH in the packages (Shirazi and Cameron 1992). The humidity level was stabilised by the amount of NaCl added, varying from 96–98% with 5 g NaCl to 86–90% with 15 g. Water condensation inside the packages was prevented or significantly reduced, depending on the amount of NaCl added. Lowering relative humidity in the package markedly reduced the decay of bell-peppers (Fig. 1). Nevertheless, fruit in the packages with modified humidity still had significantly lower weight loss and retained better firmness and quality than the non-sealed control (Fig. 1).

It should be added that decay in the tray packages was higher than that observed on individually sealed fruit. This difference may relate to the absence of water droplets and the lower RH (97%) in the individually sealed packages (Ben-Yehoshua et al. 1983).

Effect of film perforation on mango quality

According to predictions based on a mathematical model of the package, perforation of the film markedly changes the package atmosphere while only slightly influencing the relative humidity. In our experiments, using perforated polyolefin films for mango packaging enabled normal ripening of the fruit and reduced weight loss and decay as compared with a non-sealed control (Fig. 2). The best results after 2–3 weeks of storage at 14°C and one additional week at 17°C were achieved when film with 0.4 mm perforations was combined with increased free volume inside the package by sealing the fruit within polystyrene trays.

Prolonged storage of sealed Keitt mango

The delayed ripening of fruit sealed in non-perforated film was advantageous during prolonged storage of Keitt mango. After 3 weeks of storage and 1 week of shelf life the sealed fruit displayed inferior quality to the control because ripening was inhibited. However, with longer storage (4–6 weeks plus 1 week shelf life) the difference in physicochemical parameters (TSS, acidity, firmness) between sealed and non-sealed fruit became less, and sealed fruit received higher taste scores because overripening was prevented. The effect of sealing on fruit colour was less significant for typically green Keitt mango than for yellow varieties. However, sealing did not reduce decay of mangoes stored for long periods. The combination of sealing with decay-control measures such as hot water or fungicide dips may be useful in these cases.

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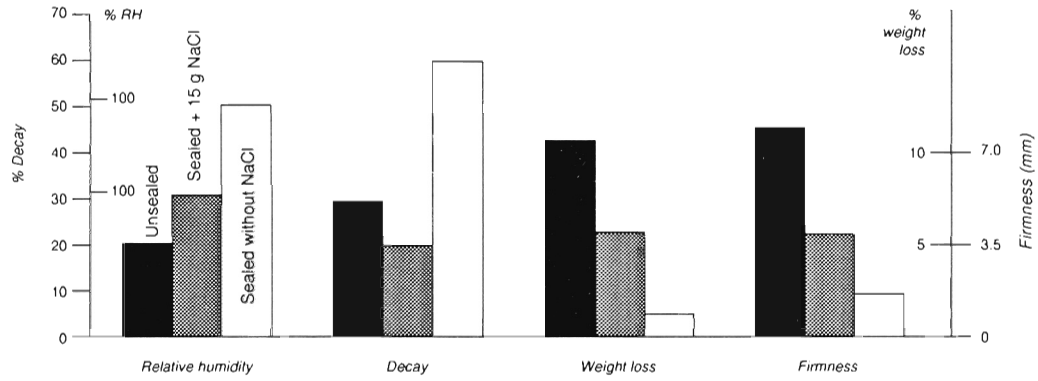

Figure 1. Effects of hygroscopic material on keeping qualities of bell-pepper stored for 3 weeks at 8°C and 1 week at 17°C. Firmness measured as residual deformation (mm) after 19.8 N pressure.

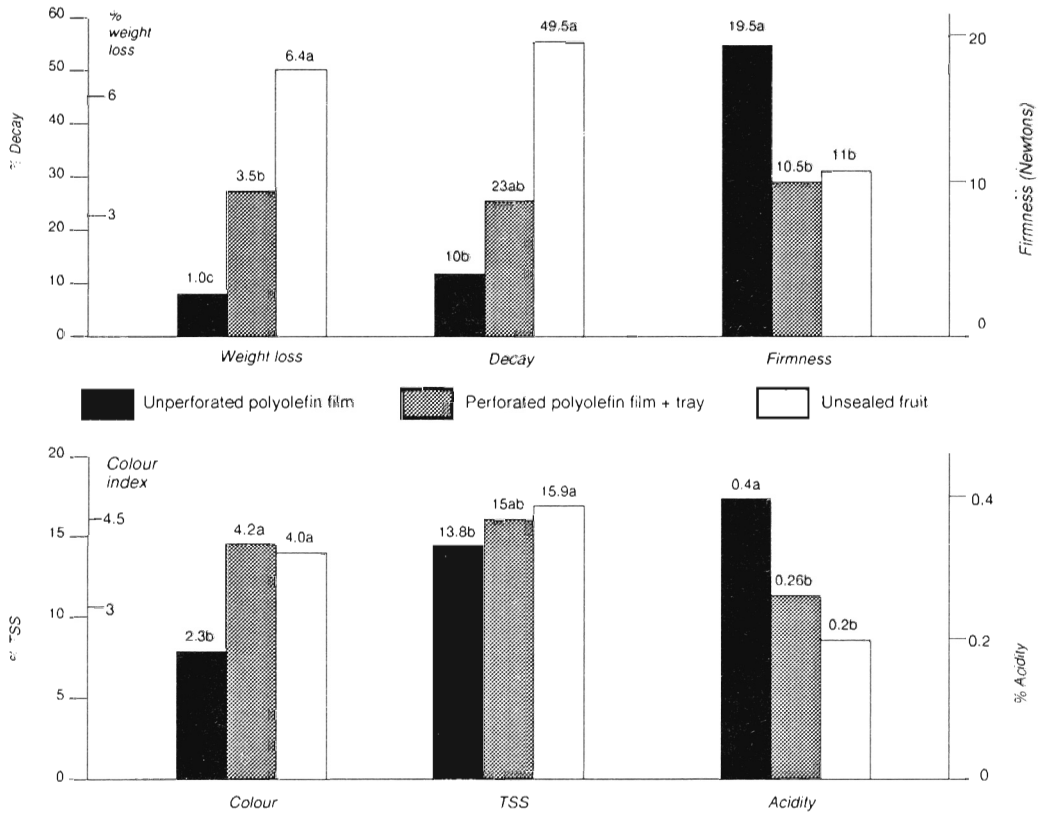

Figure 2. Effect of seal-packaging on keeping qualities of Tommy Atkins mango stored for 3 weeks at 14°C and 1 week at 17°C.

Conclusion

These results show that application of additional factors such as hygroscopic materials or perforation may prevent the harmful effects of tray-sealing in plastic film while retaining its advantages. Mathematical modelling may help to predict the optimal packaging parameters.

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Modified Atmosphere Storage of Bananas at Chilling Temperatures

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THE green life of Cavendish bananas can be extended using a modified atmosphere (MA) in which oxygen is reduced and CO_2 concentration increased (Scott et al. 1971; Scott and Gandenagara 1974). This was achieved by sealing the fruit in polyethylene bags which allowed the development of a stabilised MA in 3–4 days. Shorter stabilisation times were obtained in bags evacuated before sealing (Badran and Lima 1969). This technique has been adopted commercially and is known as the 'banavac' system. In addition to extending storage life, MA storage has been reported to reduce the incidence of chilling injury for avocado (Scott 1978) and tomato (Hobson 1987). The green life for bananas could be extended by lowering the temperature below 13.5°C if the incidence of chilling injury could be minimised by MA. This paper reports experiments in which bananas were held in a MA below the critical 13.5°C.

Material and Methods

Cavendish bananas harvested approximately 2 weeks earlier in Equador and sea transported at 14°C were used for the study. Hands were separated into clusters which contained 5 fingers. Individual clusters were enclosed in 41 × 28 cm, 0.05 cm gauge, low density polyethylene bags (PEB). Excess gas in the bag was evacuated until the film adhered to the fruit surface and the bag was then sealed. Another set of clusters was enclosed in similar size perforated PEB. Immediately after sealing, 12 bags from each were transferred to 8, 11, and 14°C.

Oxygen and CO_2 concentrations in the PEB system were measured three times per week. Gas concentrations were measured using a gas chromatograph with alumina column and thermal conductivity detector. Four bags of each treatment were removed from the store at 10-day intervals for peel colour measurements. Bags were unsealed and peel colour of fruits was monitored using a Minolta colour meter (CR 200 Japan). L* value of the colour meter was used to measure the chilling injury of the fruits.

A centimetre thickness of transverse section of fruit was used to measure firmness of pulp using a Macmesin electronic force gauge with a 6 mm plunger. A 10 g sample of pulp from the middle of the finger was homogenised using a known amount of distilled water and filtered through cotton wool. A few drops of the filtrate were used to measure total soluble solids (Brix) using an Abbe type refractometer at 20°C. A 10 mL aliquot of filtrate was titrated against 0. 1N NaOH to measure the titratable acidity and the acidity was expressed as malic acid. Three fingers from each cluster were treated with 1000 ppm ethylene to induce ripening at 17°C. Peel colour, firmness, TSS, and TA of the ripe fruit were measured as described earlier. Organoleptic evaluations were conducted to test the quality of ripe fruit.

Results

Oxygen levels within the MA at each temperature are given in Figure 1. At 14°C, the O_2 concentration remained stable (10–12%) throughout the storage period. The initial higher levels of O_2 at both 11 and 8°C declined, and became significantly lower than at 14°C and 6 days storage. However, the O_2 level in the bags stored at 11°C gradually increased up to the level of bags stored at 14°C. The oxygen content of the MA in the bags stored at 8°C remained significantly lower than at 11 and 14°C throughout the storage period. The CO_2 content of the MA (results not shown) behaved in a manner converse to that of O_2.

Peel colour measured as L* of green and ripe fruit at each sampling time is presented in Table 1. After 10 days storage, L* was significantly lower in MA stored fruit at 8°C. There were no differences in green fruit stored in either sealed or perforated bags after 10 days of storage. No difference in L* of green fruit was detected after 20 days of storage. A higher L* was observed in fruit stored in perforated bags after 30 days of storage, compared with those stored in sealed bags, due to ripening of some fruit in the perforated bags.

A one-way analysis of the results showed that firmness, TSS, and TA of both green and ripe fruit stored in sealed bags were not significantly affected by storage temperature (results not shown). No significant differences in sensory parameters (flesh colour, aroma, flavour, and texture) were detected by the taste panel assessment of ripe fruit (results not shown).

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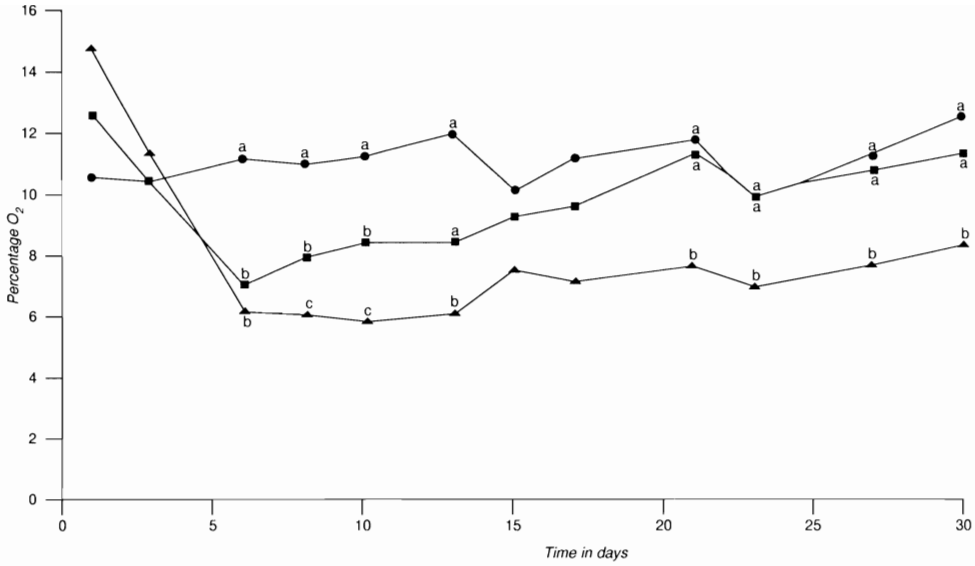

Figure 1. Percentage O_2 content developed in polyethylene bags stored at 14, 11, and 8°C: (●) 14°C, (■) 11°C, and (▲) 8°C. Treatment means having a common letter in a day are not significantly different by DMRT 5%.

Table 1. Peel colour of green and ripe bananas expressed as L* after storage for 10, 20, and 30 days in modified atmosphere and perforated polyethylene bag. Treatment means having a common letter(s) in a column of green or ripe fruit are not significantly different by DMRT 5%.

Treatment	Storage time in days		
	10	20	30
Green fruit			
Sealed 14°C	60.11a	58.79	56.69bc
Sealed 11°C	58.02ab	55.19	54.17d
Sealed 8°C	53.16c	54.72	54.73cd
Perforated 14°C	57.47ab	58.69	61.09a
Perforated 11°C	57.31ab	56.04	55.33bcd
Perforated 8°C	55.42bc	55.54	57.31b
Ripe fruit			
Sealed 14°C	64.33a	72.34a	71.48a
Sealed 11°C	59.07bc	65.46b	66.17b
Sealed 8°C	56.82c	54.99d	56.65c
Perforated 14°C	61.65ab	69.84a	70.84a
Perforated 11°C	58.50bc	63.45bc	63.45b
Perforated 8°C	58.50bc	60.51c	58.03c

Discussion

The consistently lower O_2 levels in the MA at 8°C could have been due to chilling-induced respiration or changes in permeability of the film at low temperature. A chilling-induced rise in respiration has been observed in sweet potatoes (Lewis and Morris 1956) and cucumbers (Eaks and Morris 1956). Temperature is also known to affect the gas permeability of plastic films at lower temperatures (Hayankawa et al. 1975). Further research is required to measure the contribution of each factor with respect to the gas composition of the MA.

Lower values of L* in low-temperature stored fruit compared with those stored at 14°C are indicative of chilling damage having occurred in fruit stored at the former. Chilling injury damage developed at 11 and 8°C, and the MA in the bags failed to prevent the damage. The chilling damage observed in green fruit was more pronounced after ripening. In addition to the colour meter assessments, ripe fruit stored at chilling temperatures appeared dull and less attractive.

With the exception peel colour, other physicochemical parameters remained unaffected by chilling temperatures. No difference in eating quality between chilled and unchilled fruit was detected by the taste panel in bananas at these temperatures. These results confirm those of Aziz et al. (1976).

Conclusion

The MA achieved using evacuated PEB was not effective in alleviating chilling injury in bananas stored at 11 or 8°C for a minimum of 10 days. The MA may be effective for periods less than 10 days. Although the green life was equally extended at either 11or 8°C under MA conditions, chilling damage limits the opportunity to use these temperatures.

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Storage of Fresh Pineapples

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As with many other fruits the pineapple is very sensitive to storage temperature. Storage at 7–8°C and 10°C has been recommended for ripe and unripe fruit, respectively (Anon. 1989). Akamine et al. (1975) indicated that the maximum storage period at 7°C was 4 weeks. Pineapples which are stored at less than 7°C for longer than 7 days will develop chilling injury, usually manifested as internal browning. Fruit which were stored at 4°C and 8°C for 10–20 days, followed by storage at 20°C developed internal browning. Also, fruit stored at 10°C for 50 days developed this symptom (Wills et al. 1985). Rohrbach and Paull (1982) reported that storage of pineapple at 8°C for 1 week was long enough to cause the development of internal browning. Paull and Rohrbach (1985) found that storage of pineapple at 3, 8, and 12°C for 2–3 weeks can induce internal browning within 2 days when fruit were transferred to 18–30°C. In a storage experiment with the cultivar Mauritius, fruit were stored at 7–9°C for up to 19 days without developing internal browning (Thompson 1987). Internal browning was detected in this cultivar when it was stored at 8°C and 12°C for 3 and 2 weeks, respectively. On storage at 5°C for 3 weeks the fruit suffered chilling injury but did not develop internal browning (Hassan and Atan 1983).

Akamine and Goo (1971) found that the storage life of Smooth Cayenne pineapple was significantly extended under 2% O_2 at 7.2°C compared with air. Dull et al. (1967) found that the respiration rate of pineapple decreased as the concentration of O_2 decreased. CO_2 levels up to 10% had no detectable effect on the respiration rate of pineapple at the commercial maturity stage. Kader et al (1985) recommended 5% O_2 and 10% CO_2 at 10–15°C for pineapple storage. Paull and Rohrbach (1985) found that storage at 3% O_2 and 5% CO_2, or 3% O_2 and 0% CO_2 did not suppress internal browning symptoms in Smooth Cayenne stored at 8°C. If fruit were exposed to 3% O_2 in the first week of storage at 22°C followed by 8°C, the occurrence was reduced. Storage of pineapple under hypobaric conditions was reported to extend the storage life by up to 30–40 days (Staby 1976). Storage of Mauritius pineapple under modified atmosphere, using polyethylene film bags, for 2 weeks at 10°C resulted in black heart development. The final O_2 and CO_2 contents in the bags were 10% and 7%, respectively (Hassan et al. 1985).

Smooth Cayenne pineapples from Mexico were harvested at two maturities and stored at gas compositions of 2% O_2 + 0% CO_2, 2% O_2 + 10% CO_2, and 1% O_2 + 0% CO_2, and temperatures of 4, 8, and 12°C. After storage, fruit were transferred to 22°C for 3 and 6 days. Pineapples stored under 1% O_2 or 2% O_2 and 10% CO_2 showed a delay in the development of internal browning. The shell colour of pineapple changed at a slower rate when fruits were stored under controlled atmospheres rather than air. The half mature pineapples could be stored longer than mature fruit by approximately 3 days at 22°C. The change in shell colour of the fruit was retarded at 4°C but the subsequent development of the colour was incomplete at 22°C. Fruit also suffered from chilling injury during subsequent storage. The shell colour of the mature fruit changed to slightly orange–yellow at 8°C and 12°C after 3 weeks storage. The development of internal browning occurred with fruits stored at 12°C without being subjected to subsequently higher temperatures. The results indicate that pineapples should be stored for less than 3 weeks in all the conditions tested in these experiments.

Materials and Methods

Fresh Smooth Cayenne pineapples were shipped from Mexico by air. Fruit were originally graded from the field into mature and half mature.

Controlled atmosphere storage

Weighed fruits were placed in 25-litre sealed plastic boxes fitted with inlet and outlet tubes in temperature controlled rooms. The humidity inside the box was created by placing 300 mL of water in each box with the fruit stored above, but not touching the water. Each gas mixture from a premixed cylinder was passed continously through the fruit boxes at a flow rate of 400 mL/minute. The gas compositions used were: 2% O_2 + 0% CO_2, 2% O_2 + 10% CO_2, 1% O_2 + 0% CO_2 and an air control. Storage was at 8°C for 2 weeks followed by 1 week under normal air.

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Storage temperature

Pineapples were stored at 4, 8, and 12°C for 3 weeks.

Assessment

After storage fruits were transferred to 22°C for 3 and 6 days before evaluation of fruit quality. The mature fruit were evaluated after 3 days while the half mature fruit were evaluated after 6 days using scales described by Rohrbach and Paull (1985). The scale of shell colour was 0–5, where 0 = green and 5 = yellow, orange–yellow, and coppery red. The scale of pulp translucency was 0–4, where 0 = no translucency and 4 = maximum translucency. The internal browning scale was 0–6, where 0 = none and 6 = complete browning. Browning was scored separately for each fruit both on the basis of incidence and severity. Brix and acidity were measured using the juice from the centre slices of the fruit. Brix was measured using an Atago digital refractometer. Acidity, as percentage of citric acid, was determined by titration with 0.125N NaOH using bromothymol blue as indicator.

Results

Controlled atmosphere storage

After 2 weeks storage the shell colour of the fruit was very similar to the initial colour, the change of colour started in the third week of storage. This continued more rapidly when the fruit were removed to 22°C (Table 1).

Table 1. Effect of controlled atmosphere storage at 8°C on the shell colour of pineapple (0 = green; 5 = yellow orange)

Controlled atmosphere	Original colour	Days at 22°C following CA storage		
		0	3	6
2% O_2 + 0% CO_2				
Mature	1.75	3.5	5.0	–
Half mature	0.5	1.5	–	3.5
2% O_2 + 10% CO_2				
Mature	2.25	3.0	3.0	–
Half mature	0.75	0.75	–	4.5
1% O_2 + 0% CO_2				
Mature	2.25	3.75	4.5	–
Half mature	1.25	2.25	–	4.5
Air				
Mature	2.0	4.0	5.0	–
Half mature	1.0	2.5	–	5.0

Internal browning was not detected in the flesh when pineapples were stored at 8°C for 3 weeks in all treatments. The symptom developed when fruit were subsequently stored at 22°C. The mature fruit did not develop internal browning within 3 days at 22°C following storage in a mixture of 2% O_2 + 10% CO_2 or 1% O_2 + 0% CO_2 but the half mature developed internal browning within 6 days. The half mature fruit developed severe internal browning symptoms at 22°C following storage, which might be due to a too long storage period for the stage of maturity. The results showed that both the mature and the half mature fruit can develop this disorder (Table 2). From this experiment it was noted that, at low oxygen concentration, the additive effect of high carbon dioxide could delay the development of internal browning for a short period.

The pulp of the mature fruit from all storage treatments turned translucent after 3 days at 22°C. The pulp of the half mature fruit was checked after 6 days at 22°C and the degree of translucency was about the same as that of the mature fruit. Translucency of the pulp is related to senescence which might be retarded if fruits were kept at low temperature under controlled atmosphere. The results from this experiment showed that the benefit of controlled atmosphere on the translucency of the pulp was limited (Table 3).

Storage temperature

The degreening of the shell of pineapple was affected by temperature. At 4°C the shell colour remained unchanged during storage for 2 or 3 weeks for both the mature and the half mature fruit. At 8°C and 12°C the shell colour of both types changed during storage. During storage at 22°C, following the low temperature storage, the shell colour of the mature fruit changed to light orange–yellow within 3 days while for the half mature fruit the colour change took 6 days. Degreening of the shell colour of pineapple was temperature dependent (Table 4). The shell colour did not appear bright yellow after fruit had been stored at any of the low temperatures used in this experiment. It was observed that the development of the yellow colour was better after storage at 12°C than at 4°C and 8°C, particularly at 4°C the fruit developed a coppery red colour which indicated that the fruit had suffered from low temperature injury (Table 4).

Pineapples stored at 4°C and 8°C did not develop internal browning during storage, but the symptom developed after they were transferred to 22°C (Table 5). Fruit previously stored at 4°C for 2 weeks developed symptoms of chilling injury and no development of internal browning. At 12°C fruit developed internal browning before or after they were stored at 22°C. It was found that about half of the sample did not show the symptom of internal browning while they were held at

Table 2. Development of internal browning (0 = none; 6 = complete browning) of pineapples under controlled atmosphere at 8°C.

Controlled atmosphere	Days at 22°C following CA storage					
	0		3		6	
	incidence	severity	incidence	severity	incidence	severity
2% O_2 + 0% CO_2						
Mature	0.0	0.0	2.0	2.0	–	–
Half mature	–	–	–	–	4.0	5.0
2% O_2 + 10% CO_2						
Mature	0.0	0.0	0.0	0.0	–	–
Half mature	–	–	–	–	6.0	5.0
1% O_2 + 0% CO_2						
Mature	0.0	0.0	0.0	0.0	–	–
Half mature	–	–	–	–	2.0	2.0
Air						
Mature	0.0	0.0	1.0	3.0	–	–
Half mature	–	–	–	–	1.0	1.0

Table 3. The effect of controlled atmosphere at 8°C on the translucency (0 = no translucency, 4 = maximum translucency) of pineapple pulp.

Controlled atmosphere	Days at 22°C following CA storage		
	0	3	6
2% O_2 + 0% CO_2			
Mature	0.5	4.0	–
Half mature	–	–	3.0
2% O_2 + 10% CO_2			
Mature	0.0	4.0	–
Half mature	–	–	3.5
1% O_2 + 0% CO_2			
Mature	0.5	3.0	–
Half mature	–	–	4.0
Air			
mature	1.0	3.5	–
Half mature	–	–	3.0

Table 4. The effect of low temperature storage on the shell colour (0 = green; 5 = yellow–orange) of pineapple under normal air.

Storage temperature	Original colour	Days at 22°C following low temperature storage		
		0	3	6
4°C				
Mature[a]	1.4	1.4	4.0	–
Half mature	0.3	0.3	–	3.0
8°C				
Mature	2.0	4.0	5.0	–
Half mature	1.0	2.5	–	5.0
12°C				
Mature	2.0	4.9	5.0	–
Half mature	0.6	3.8	–	5.0

[a] Pineapple stored for 2 weeks

12°C. The results from this experiment showed that internal browning can develop at 12°C without being subject to higher temperature storage.

At 22°C, the pulp of the mature and the half mature fruit had become translucent within 3 and 6 days respectively regardless of the previous storage condition (Table 6). When the half mature fruit were stored at 12°C for 4 weeks, without subsequent storage at 22°C, the flesh was slightly opaque but the fruit was severely diseased. This could have been due to initial bruising of the fruit during transit from Mexico.

Discussion

Paull and Rohrbach (1985) found that CO_2 at 5% had no effect on internal browning development in pineapples. CO_2 elevation has an additive effect with low oxygen concentration so that the optimum concentration should

Table 5. Development of internal browning (0 = none; 6 = complete browning) of pineapples stored at low temperature.

Storage temperature	Days at 22°C following low temperature storage					
	0		3		6	
	incidence	severity	incidence	severity	incidence	severity
4°C						
Mature	0	0	1.25	1.25	–	–
Half mature	0	0	1.0	1.0	2.0	5.0
8°C						
Mature	0	0	1.0	3.0	–	–
Half mature	–	–	–	–	1.0	1.0
12°C						
Mature	1.5	1.5	1.75	2.75	–	–
Half mature	–	–	–	–	5.5	5.5

be specified for each commodity. However, the effect of controlled atmosphere storage on pineapples was not extended to the fruits when they were removed to air. To overcome this problem, Hassan et al. (1985) suggested storing Mauritius pineapples in modified packaging until they reached consumers. This limitation of controlled atmosphere storage of pineapples indicates that the shelf life time after removal must be specified.

Table 6. The effect of low temperatures on the translucency (0 = no translucency; 4 = maximum translucency) of pineapple pulp.

Storage temperature	Days at 22°C following low temperature storage		
	0	3	6
4°C			
Mature	0.5	3.5	–
Half mature	0.0	3.5	4.0
8°C			
Mature	1.0	3.5	–
Half mature	–	–	3.0
12°C			
Mature	1.75	3.0	–
Half mature	–	–	2.0

The result of our experiments also agree with previous work (Wills et al. 1985; Paull and Rohrbach 1985) indicating chilling temperatures induced internal browning. The range of temperature that favours the development of internal browning is from 5°C to 21°C (Smith 1983). At 4°C fruit showed the development of chilling injury in the subsequent higher temperature storage with no development of internal browning. The same observation was reported with Mauritius pineapple (Hassan and Atan 1983). However, not all of the tested samples developed chilling injury which might have been related to the stage of maturity of each individual fruit. Grading of fruit by using shell colour cannot reliably reveal the physiological maturity of fruit (Smith 1983).

Chilling injury was more severe on bruised fruits than on undamaged ones. The bruised area extended as the fruit were stored for longer periods and became contaminated with microorganisms which resulted in spoilage of the fruit during subsequent storage at 22°C. Fruit stored at 8°C developed internal browning after being placed at 22°C. In other work, maximum development of internal browning for fruit stored at this temperature occurred within 10 to 20 days (Wills et al. 1985).

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The Effect of Sucrose Ester Coating on Ambient Temperature Storage of Several Fruits

M. Bepete, N. Nenguwo, and J.E. Jackson*

REFRIGERATION facilities are required for reducing the temperature of produce and holding it at the desired temperature until it is sold or used. Where this is not possible, other means of extending the shelf life have to be considered. One possibility is to reduce the gaseous exchange of the produce. This will lower the rate of respiration and therefore retard the rate of deterioration.

It has been found that sucrose ester coatings affect gaseous exchange (Kader et al. 1986; Lidster 1987) by reducing oxygen uptake and carbon dioxide loss. These coatings also reduce transpiration. It was therefore suggested that they might be useful when refrigeration facilities are not available. A trial was begun in January 1990 at the Horticultural Research Centre (HRC) in Marondera, Zimbabwe, using 'Semperfresh' as the sucrose ester.

Materials and Methods

Five experiments were conducted on grapes, apples, and passion fruit.

Experiment 1. 0 and 0.7% Semperfresh on five table grape cultivars — Black Sultana, Earlihane, Giant Isabella, Steuben and Thompson Seedless.

Experiment 2. 0, 1, and 1.5% Semperfresh on the apple cultivars Drakenstein and Mollies Delicious.

Experiment 3. 0, 1, and 1.5% Semperfresh on passion fruit (Purple variety, *Passiflora edulis).*

Experiment 4. 0, 1, and 1.5% Semperfresh on the wine grape cultivar Chenin Blanc.

Experiment 5. 0, 1, and 1.5% Semperfresh on the apple cultivars Anna, Elah, Michal, and Maayan.

Fruit from the HRC orchard were harvested at full maturity and treated immediately. There were 12–20 fruit per treatment.

The 'Semperfresh' concentrations were prepared by first mixing the required amount with a small volume of water in a blender. This slurry was then stirred into the required volume of water in order to achieve the desired concentration.

The fruit were dipped in the required concentration and allowed to drip dry. For the shelf-life observations, they were then placed on newsprint-lined trays in the laboratory. The control treatment (0% Semperfresh) was applied by dipping the fruit in water only.

The fruit were kept in the open at ambient temperature and observations made on daily weight changes and the occurrence of blemishes. Each fruit was discarded when symptoms of deterioration became obvious.

The results were analysed by analysis of variance (with arcsine transformation for percentage weight loss data).

Results

Table grapes

Coating table grapes with 0.7% Semperfresh significantly ($p < 0.0001$) reduced weight loss by between 2.2 and 19.1% (9 days after treatment) compared with controls (Table 1). The rate of weight loss reduction varied with cultivar, with Steuben showing least response and Thompson Seedless the highest. For shelf-life extension Thompson Seedless showed the greatest response — 12 days — followed by Black Sultana with 6 days (Table 2). Earlihane, Giant Isabella, and Steuben all had three days shelf-life extension for coated material. The main cause of loss of shelf life was disease development and shrivelling.

Table 1. Effect of Semperfresh on weight loss of table grapes after 9 days at ambient temperature.

Grape cultivar	Percent weight loss/bunch	
	0	0.7% Semperfresh
Black Sultana	25.3	15.9 ***
Earlihane	25.4	22.4 n.s.
Giant Isabella	27.4	19.5 ***
Steuben	14.8	12.6 n.s.
Thompson Seedless	33.6	14.5 ***

n.s. = not significant *** = significant at the 0.5% level

Apples

Weight loss by Drakenstein and Mollies Delicious six days after treatment was small and there were no significant differences between the different Semperfresh

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concentrations (Table 3). However for all three levels cultivar Drakenstein lost significantly ($p < 0.0001$) more weight than Mollies Delicious. The 1% Semperfresh coat had no effect on shelf life of Drakenstein but extended Mollies Delicious shelf life by 2 days (Table 4). The 1.5% coat extended Drakenstein shelf life by 4 days, but had no effect on Mollies Delicious.

Table 2. Effect of Semperfresh dip on the shelf life of table grapes held at ambient temperature.

Grape cultivar	Shelf life (days)	
	0	0.7% Semperfresh
Black Sultana	3	9
Earlihane	3	6
Giant Isabella	3	6
Steuben	9	12
Thompson Seedless	6	18

Table 3. Effect of Semperfresh on weight loss of fruit of apple, passion fruit and grape after 6 days at ambient temperature.

Fruit	Weight loss (%)		
	0	1.0	1.5% Semperfresh
Apple			
Drakenstein	5.2	5.5	5.7n.s.
Hollies Delicious	3.3	3.7	4.3n.s.
Passion fruit	27.3a	19.1b	18.5b**
Grape			
Chenin Blanc	17.5	19.1	15.2n.s.

n.s.= not significant; ** = significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Table 4. Effect of Semperfresh on the shelf life (days) of 2 apple varieties, passion fruit, and a wine grape variety held at ambient temperature.

Fruit	Shelf life (days)		
	0	1.0	1.5% Semperfresh
Apple			
Drakenstein	8	8	12
Mollies Delicious	2	4	2
Passion fruit	2	6	6
Grape			
Chenin Blanc	2	2	2

Weight loss of apples after 9 days was generally small and the response to Semperfresh not significant (Table 5), except for Michal and Maayan which showed significant reduction for 1 and 1.5% as compared with the control. There was no effect of Semperfresh coating on shelf-life extension of Michal and Maayan (Table 6). The 1.5% concentration had an adverse effect on Elah, reducing the shelf life, while the 1% coating had a positive effect. For Anna the 1 and 1.5% coatings extended shelf life by 3 and 4 days, respectively.

Table 5. Effect of Semperfresh on cumulative weight loss (%) of 4 apple varieties after 9 days at ambient temperature.

Apple variety	Weight loss (%)		
	0	1.0	1.5% Semperfesh
Anna	6.79b	5.13a	5.77a**
Elah	5.47b	3.52a	4.69b**
Michal	9.40b	6.67a	6.18a**
Maayan	8.29b	5.47a	5.26a**

n.s. = not significant; ** significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Table 6. Effect of Semperfresh on the shelf life (days) of 4 apple varieties.

Apple variety	Shelf life (days)		
	0	1.0	1.5% Semperfesh
Anna	12a	15b	16b**
Elah	14a	18b	llc**
Michal	9	9	9n.s.
Maayan	7	7	7n.s.

n.s. = not significant; ** significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Passion fruit

Coating purple passion fruit with Semperfresh significantly ($p < 0.05$) reduced weight loss (Table 3). However, there was no significant difference in weight loss between 1 and 1.5% concentrations. Semperfresh coating extended the shelf life of passion fruit by 4 days and, as with weight loss, increasing the concentration from 1 to 1.5% had no effect on shelf life (Table 4).

Wine Grape cv. Chenin Blanc

Treating Chenin Blanc with 1.0% Semperfresh accelerated weight loss (Table 3), whereas a 1.5% coating significantly ($p < 0.05$) reduced it. There was no effect of Semperfresh on shelf life (Table 4).

Discussion

The positive effect of Semperfresh on weight loss reduction and shelf-life extension of table grapes (almost 20% weight loss reduction for Thompson Seedless) was most probably due to reduction of moisture loss, as the untreated material shrivelled at a much faster rate than coated fruit. Gourley (1922) attributed the greatest loss in weight to moisture loss. That the extension of shelf life was related to weight loss further confirms this observation. Grape cv. Steuben had a longer shelf life for the control than other cultivars, most probably because of its thick skin, further supporting the notion that moisture loss is a major contributor to weight loss.

The variability in response to Semperfresh coating shown by both the conventional and low-chill apple cultivars might be due to differences in cuticle thickness or inherent ability to control water loss. However, the small weight losses suggest that the effect on shelf life was mainly a result of metabolic activity. This is supported by the observation that coated material had a lower rate of colour loss and texture deterioration. The importance of texture and ground colour as quality attributes was stressed by Smith et al. (1987).

The response of passion fruit to Semperfresh shows that increasing concentration from 1 to 1.5% is of little benefit to both weight loss reduction and shelf-life extension. The delay in the external wrinkling of the skin of treated fruit has important implications in the marketing of fresh passion fruit.

The wine grape Chenin Blanc showed no response to Semperfresh treatment, highlighting the variable range of responses to sucrose ester coatings.

The variability in the degree of weight loss for the various fruit types, apart from species and concentration differences, was also due to the magnitude of the mass:surface area ratio (Smith et al. 1987), with larger-sized fruit (with a higher ratio) such as apples, losing less weight than grapes.

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Effects of Different Precooling Methods and Times on the Storage Quality of Carambola Variety B_{10}

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CARAMBOLA or starfruit *(Averrhoa carambola* L., family Oxalidaceae) is quickly gaining market recognition (Sankat and Balkissoon 1992). It is popular in major markets of Singapore, Hong Kong, and Tokyo, as well as in Europe and America. Malaysia's exports of carambola are increasing annually (Mohd Idris 1987). However, postharvest handling is complicated by the thin epidermis, and the fragile, ribbed shaped, and easily damaged fruit. Storage of carambola at as low as 10°C was found to be an effective means of prolonging shelf life (A. Osman, unpublished data). The objective of the study reported here was to determine the effect of different precooling methods and times before cold storage (10°C) on the storage characteristics of carambola.

Materials and Methods

Fruit source

Fruit of commercial maturity were obtained from one of the fruit farms owned by FELCRA at Cheras, Kajang. Only sound fruit, free from any mechanical injury and rots were used in the study.

Precooling methods

Fruit were subjected to different precooling methods (room temperature, rapid cooling, and hydrocooling: hereafter denoted as RT, RC, and HDr, respectively) and times (0, 12, 24, 36, and 48 hours) before cold storage (10 ± 1°C; 85–88% relative humidity). Fruit for RT precooling were left at ambient temperature (27 ± 1°C; 60–80% relative humidity, RH), while fruit for RC precooling were placed near the fan (with air velocity of 6.4 metre/hour) of the cold room (5 ± 1°C; 61–84% RH). Hydrocooling was achieved by placing the fruit in a mixture of water and ice (to ensure that the water temperature was in the range of 0–3°C throughout the precooling time).

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Weight loss and surface glossiness

Three fruit × 3 replicates from each precooling method and time were weighed and assessed for skin surface glossiness on a scale from 5 = 100% of fruit surface glossy to 1 = 0% of fruit surface glossy) at 10-day intervals until day 40.

Measurements of other physicochemical parameters

Triplicate samples of 2 fruit from each precooling method and time were used in each determination. Texture was determined using the Instron Universal Testing Machine model 1140. Colour was evaluated subjectively according to the colour index for carambola (FAMA 1990).

The same 2 fruit used for texture determination were blended and pooled together for the determination of other parameters. Total soluble solids were determined using a hand refractometer (Kyoma HR-14 model). pH values were determined by Corning digital pH meter model 240. Titratable acidity was estimated by titrating the juice with 0.1 M NaOH using phenolphthalein as the indicator. Ascorbic acid was determined by the method of Ranganna (1977).

Results and Discussion

The results of this study are shown in Tables 1–4. The different precooling methods had a highly significant effect on all the physicochemical parameters. Hydrocooled fruits lost less weight and exhibited less colour change (Table 3). The different precooling times had a highly significant effect on all the physicochemical parameters except for rate of moisture loss and ascorbic acid content. For the physical parameters, values generally decreased with increased precooling times, but no consistent trend was observed for the chemical parameters.

The different storage times showed highly significant effects on all the physicochemical parameters studied. A longer storage time significantly reduced the surface glossiness, firmness, and titratable acidity, but significantly increased colour index, rate of moisture loss, ascorbic acid content, pH, and total soluble solids.

Significant interactions were shown between the three main treatments in most of the physicochemical parameters, suggesting that suitable combinations of these treatments could improve carambola quality during storage.

Conclusion

The three different precooling methods — RT, RC, and HDr — had variable influences on the physicochemical parameters associated with storage quality of carambola.

Table 1. Mean squares of the analyses of variance of four physical parameters of carambola variety B_{10}.

Source of variation	df	Colour index	Glossiness (score)	Rate of moisture loss	Firmness (kg force)
Precooling method (PM)	2	4.011**	1.731**	83.372**	1.502**
Precooling time (PT)	4	3.286**	0.803**	19.605	0.163**
Storage time (ST)	4	140.627**	120.003**	908.560**	18.000**
PM × ST	8	1.137	0.242**	29.320	0.901**
PM × PT	8	1.368	0.133**	16.051	0.128**
ST × PT	16	2.398**	0.156**	16.370	0.154**
PM × PT × ST	32	0.805	0.043	13.742	0.077**
Error	150	0.728	0.056	16.618	0.016
Total	224				

*, ** are significant at 5% and 1% levels respectively.

Table 2. Mean squares of the analyses of variance of five chemical parameters of carambola variety B_{10}.

Source of variation	df	Ascorbic acid (mg/100 g)	Titratable acidity (TA) (%)	pH	Total soluble solids (TSS) (°Brix)	Ratio of TSS:TA (%)
Precooling method (PM)	2	150.226**	16.484**	0.012**	2.090**	1.149**
Precooling time (PT)	4	21.192	3.509**	0.024**	0.721**	0.125**
Storage time (ST)	4	514.433**	74.704**	0.143**	0.403**	6.169**
PM × ST	8	60.898**	4.036**	0.004**	0.298**	0.289**
PM × PT	8	27.279*	1.264**	0.003*	0.489**	0.095**
ST × PT	16	26.662**	2.509**	0.013*	0.211*	0.205**
PM × PT × ST	32	13.391	0.583**	0.003*	0.105	0.055**
Error	150	12.102	0.239	0.001	0.109	0.035
Total	224					

*, ** are significant at 5% and 1% levels respectively.

Table 3. Mean values for colour index, glossiness, rate of moisture loss, and firmness of carambola variety B_{10}

Main effect[a]	Colour index	Glossiness (score)	Rate of moisture loss (%)	Firmness (kg force)
Precooling method (PM)				
RT	3.65	2.87	6.08	1.63
RC	3.43	2.69	6.69	1.46
HDr	3.19	2.56	4.86	1.35
$LSD_{0.05}$	0.31	0.09	1.31	0.09
Precooling time (PT)				
0 hours	3.58	2.85	6.99	1.54
12 hours	3.57	2.80	6.11	1.54
24 hours	3.61	2.76	5.95	1.46
36 hours	3.39	2.62	5.48	1.41
48 hours	2.96	2.53	5.31	1.44
$LSD_{0.05}$	0.39	0.11	NS	0.11
Storage time (ST)				
0 days	1.00	5.00	0.00	2.17
10 days	2.35	3.57	3.33	2.13
20 days	3.68	2.56	6.46	1.27
30 days	4.75	1.48	8.43	0.94
40 days	5.33	0.94	11.62	0.88
$LSD_{0.05}$	0.39	0.11	1.69	0.11
Grand Mean	3.42	2.71	5.95	1.48

[a] RT, RC, HDr are room temperature, rapid precooling and hydrocooling respectively.
NS – not significant.

Table 4. Mean values for ascorbic acid, titratable acidity (TA), total soluble solids (TSS), pH, and ratio of TSS:TA of carambola variety B_{10}

Main effect[a]	Ascorbic acid (mg/100 g)	Titratable acidity (TA) (%)	pH	Total soluble solids (TSS) (°Brix)	Ratio of TSS:TA (%)
Precooling method (PM)					
RT	28.29	6.04	3.78	8.15	1.43
RC	29.90	5.53	3.79	8.12	1.68
HDr	27.08	5.10	3.79	7.85	1.55
$LSD_{0.05}$	1.28	0.26	0.01	0.12	0.08
Precooling time (PT)					
0 hours	27.51	5.98	3.81	8.20	1.49
12 hours	29.39	5.65	3.75	8.10	1.52
24 hours	28.31	5.33	3.78	7.87	1.56
36 hours	28.67	5.52	3.81	8.04	1.58
48 hours	28.24	5.29	3.80	7.98	1.62
$LSD_{0.05}$	NS	0.33	0.01	0.15	NS
Storage time (ST)					
0 days	24.78	7.05	3.72	7.91	1.13
10 days	27.28	6.73	3.74	8.02	1.22
20 days	31.75	5.30	3.79	8.06	1.62
30 days	32.24	4.23	3.85	8.17	1.98
40 days	26.08	4.46	3.84	8.04	1.82
$LSD_{0.05}$	1.65	0.33	0.01	0.15	0.10
Grand mean	28.42	5.56	3.79	8.04	1.55

[a] RT, RC, HDr are room temperature, rapid precooling and hydrocooling respectively.
NS – not significant.

Generally, HDr gave the lowest value, followed by RC and RT. Precooling times of more than 24 hours showed a deteriorating effect on the storage quality. Although the three precooling methods affect the storage quality differently, all the fruits were unacceptable by day 40.

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Effect of Maturity, Damage, and Humidity on the Ripening of Plantain and Cooking Banana

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PLANTAIN and banana *(Musa* spp.) are major staple crops grown throughout the humid tropical zone. They provide both a primary source of carbohydrate and revenue for small-scale farmers. In sub-Saharan Africa, *Musa* crops provide more than 25% of the carbohydrates in the diet of more than 70 million people (IITA 1992).

Estimates of postharvest loss of *Musa* crops in the traditional marketing systems range from 20–80%. (FAO 1977; Olorunda and Aworth 1984). The causes of such high levels of loss remain unclear but Karikari et al. (1980), suggested that damage caused during harvesting and marketing was a major factor contributing to postharvest loss of plantain. A link between mechanical damage, early ripening, and economic loss of banana fruit suggested by Rippon (1974) and Littmann (1972), established that moisture loss from preclimacteric fruit hastened ripening. The experiments in this study investigated the effects of damage, fruit maturity, and storage humidity on the ripening and climacteric response of *Musa* fruit. The treatments simulated the types of damage and storage conditions experienced by fruit in the traditional, tropical marketing process.

Materials and Methods

The experiments in this study were carried out at Kade Agricultural Research Station (Ghana), Silsoe College (U.K.), and the University of the Philippines at Los Baños.

Three Ghanaian plantain cultivars were used in experiment 1 to determine the effect of damage and maturity on ripening. The plantain cultivars were harvested at three maturity stages based on days after flowering, viz: fully mature, mature, and immature. After harvest, fruit were systematically treated using four damage treatments: control (no damage), impaction, abrasion, and quasi-static loading (Ferris 1992). Rate of fruit ripening was assessed by recording changes in peel colour until stage 8 — yellow peel with large coalescing black spots (Von Loeseke 1949). Fruit moisture loss was measured by weighing fruit at regular intervals.

Experiments 2 and 3 were conducted in controlled environment rooms at Silsoe College. These experiments aimed to determine the effect of damage and humidity on fruit ripening. The plantain for these experiments were airfreighted from the West Indies by the St Lucian Ministry of Agriculture. In experiment 2, fruit were treated using three damage techniques: control (no damage), impaction, and abrasion. The fruit were then stored at low and high humidity: 55–65% RH and 96–100% RH, respectively.

In experiment 3, fruit were abraded at four levels: control (no abrasion), 10% of the peel abraded, 25% of peel abraded, and 50% of the peel abraded. Temperature was controlled at 20°C and relative humidity ranged from 70 to 85% RH. A porometer (Mk 2, Delta T Devices, Cambridge, U.K.) was used to compare the rate of water loss of control and abraded banana peel.

Experiment 4 was conducted at Los Baños. This experiment was to determine the effect of damage and humidity on the preclimacteric period of cooking banana. Ethylene produced by cooking banana fruit was measured in a static system using a Shimadzu gas chromatograph series GC–8A, fitted with a flame ionisation detector.

Results and Discussion

The results from experiment 1 (Table 1) confirmed that the more mature the fruit was at harvest, the more rapid was the rate of ripening (George and Marriott 1983). These data also showed that the largest reduction in ripening period was caused by abrasion to least mature fruit (Table 1). Abrasion also caused a significant increase ($P \leq 0.05$) in weight loss (Fig. 1). The effect of impaction on fruit ripening was inconsistent and only impaction of immature fruit caused a significant, though limited, reduction in ripening period.

Quasi-static loading had no effect on ripening. In a similar study by Maxie et al. (1968), involving compression damage of banana fruit, which are physiologically and morphologically similar to plantain and cooking banana, there was a substantial reduction in the preclimacteric period. The difference in results from these two compression studies may be explained by the severity of damage. The compression treatment used by

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Maxie et al. (1968) involved a loading treatment which disrupted the peel membrane. In contrast, although quasi-static loading caused a consistent pulp injury, the peel remained intact. This difference in response related to peel integrity is clearly an important factor in terms of ripening time and suggests that preclimateric green fruit are a highly robust storage unit that can withstand considerable pressure without loss of quality or ripening period, providing the peel is not corrupted.

Table 1. The effect of fruit maturity and damage on the ripening period of plantain

Fruit maturity	Types of damage				
	Control	Impact	Abrasion	QS loading[a]	Mean
Immature	22.3	20.2	13.7	22.1	19.7
Mature	15.1	15.2	11.1	15.1	14.1
Fully mature	11.9	12.0	10.0	11.3	11.3
Mean	16.4	15.8	11.6	16.3	

C.V. = 21.5% [a] Quasi-static loading
LSD (P≤0.05) for comparison of any mean in main table = 3.28.
LSD (P≤0.05) for comparison of mean at same level of maturity = 2.03

Experiments by Peacock (1973), found that a drop impact treatment and a 10% peel abrasion treatment reduced the 'green life' of bananas by only 11.5% in the most extreme case. Peacock considered this reduction was of no commercial significance. The results in experiment 1 confirmed that impact had a minor effect on ripening. However, abrasion caused a significant, ($P \leq 0.05$), 39% reduction in the ripening period of least mature fruit. Abraded fruit ripened 9 days earlier than the control. This considerable difference between the two experiments may be explained by the interaction between damage and storage humidity.

When the effect of abrasion on fruit ripening was studied at high and low humidity (experiment 2), it was revealed that abrasion and impaction had no effect on ripening of fruit stored at high humidity (100% RH). However, at 55% RH, abrasion caused a significant reduction in the ripening period (Ferris 1992). Evidently the accelerated ripening caused by abrasion is a passive effect dependent on humidity. Abrasion caused a reduction in the 'green life' of only fruit stored at a humidity of less than 100% RH.

Further investigation of abrasion at increasing levels of severity, on fruit stored at 75–85% RH, showed a power relation between abrasion and fruit weight loss (Fig. 2). The data in Figure 3 also show a power relation between level of abrasion and ripening period. These data sets show that, over the initial ranges, i.e. from 2–4% daily weight loss and 0–5% peel area abraded respectively, there was a dramatic reduction in ripening period. The significant change in weight loss and early ripening of abraded fruit may be explained by an increase in peel permeability to water. Figure 4 shows data obtained from porometric observations from sec-

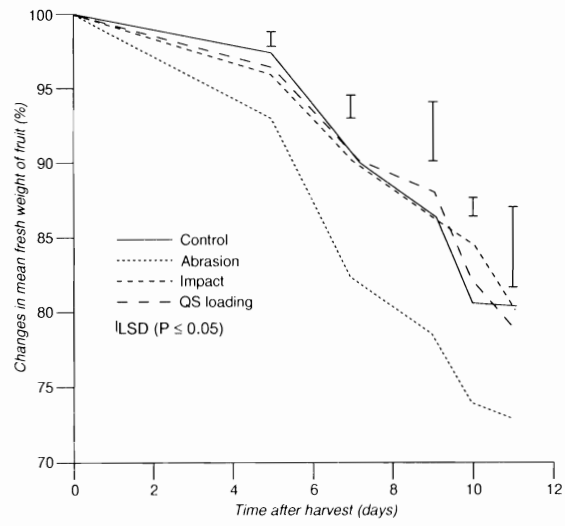

Figure 1. The effect of damage treatments on percent change in weight of French plantain stored at ambient tropical temperature and humidity: recorded temperature range, 26–31°C; recorded relative humidity range, 70–96%.

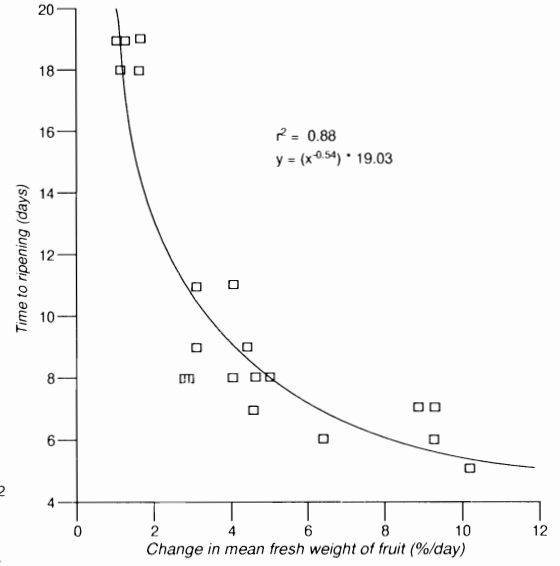

Figure 2. The power relation between average percent change in weight per day and time to ripening of bananas stored at 70–80% relative humidity and 20°C.

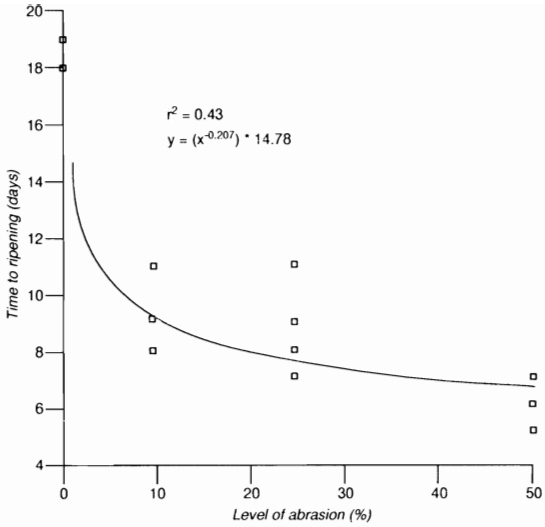

Figure 3. The power relation between percent abrasion and the time to ripening of bananas stored at 70–85% relative humidity and 20°C.

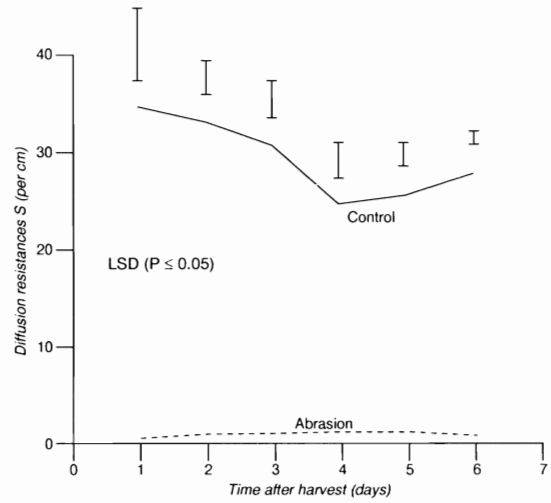

Figure 4. The effect of abrasion on the moisture diffusion resistance of banana peel stored at 70–85% relative humidity and 20°C.

tions of undamaged and abraded peel. The abraded peel shows a significant ($P \leq 0.05$) increase in peel permeability to water which is indicated in Figure 4 as a significant ($P \leq 0.05$) reduction in diffusion resistance, compared with the control peel.

When the effect of abrasion and humidity were studied in terms of ethylene production and climacteric response, it was found that abrasion caused a consistent increase in ethylene production. Fruit stored at 100% RH produced a stress ethylene peak in response to damage but, after this, ethylene produced by damaged fruit returned to near control levels after 2–3 days. Consequently, both damaged and control fruit stored at 100% RH entered the climacteric almost simultaneously after approximately 15 days (Thompson et al. 1992). In contrast, damaged fruit stored at low humidity reached peak climacteric ethylene production after 7 days and control fruit stored at low humidity reached peak ethylene production after approximately 10 days.

Conclusion

The results from this study have important commercial implications, as ripening determines the 'green life' or 'marketable period' of *Musa* fruit in the transport and marketing chain. Abrasion caused the most significant reduction in ripening period and it was considered that the accelerated ripening was caused by increase in peel permeability to water vapour. This water loss induced a water stress which triggered the climacteric response and hastened ripening. However, abrasion is not an active mechanism, because it does not induce the climacteric response independently. Banana fruit progressively lose water as humidity is reduced from 100%, and the rate of water stress is merely exacerbated by abrasion. The results also showed that although abrasion was a serious form of damage, a simple manipulation of ripening environment, i.e. high humidity storage, could enable a retailer to avoid the detrimental effects of peel damage. When high humidity storage is not feasible, it is of practical importance for the harvester and retailer to be aware that small changes in the level of abrasion, i.e. from 0–5%, may cause dramatic reductions in ripening period. Hence, working practices should aim to avoid or minimise damage when a long market life is desired.

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Modified Atmosphere Packaging by Perforated Polymeric Film and Its Effect on Physical Properties of Mango Fruit

T. Yantarasri, J. Uthaibutra, J. Sornsrivichai, W. Kumpuan, V. Sardsud, and N. Kana-Thum*

MODIFIED atmosphere (MA) packaging is a common technique to prevent weight loss, to provide better appearance, and to extend storage life of some fruits. However, each crop needs particular levels of gases (O_2 and CO_2) to prolong storage life while permitting normal ripening of climacteric fruits.

Although previous studies showed that PVC plastic film packaging of mangoes further enhanced the effect of disease control pretreatments in delaying and reducing anthracnose decay during storage, all types of plastic film inhibit the development of acceptable peel colour and normal ripening of flesh, regardless of storage temperature. Removal of the film after storage is therefore necessary. The study reported here showed that appropriate perforation of PVC film can control levels of O_2 and CO_2 within a packaged mango, as well as the rate of ripening of the fruit. Perforated film effectively halted undesirable anaerobiosis and made the removal of the film after storage unnecessary.

Fully mature-green mangoes, var. Nam Dok Mai, were pretreated with 1000 ppm hot benomyl solution at 55°C for 5 minutes. Each package contained three mangoes on a polystyrene tray over-wrapped with stretched PVC film of 0.01 mm thickness. More than three packages were needed in each treatment for analysis of gas composition inside the packages and for periodic destructive tests to determine ripening behaviour. The mango packages were perforated with different total pore areas and kept at ambient conditions (30°C; 70% RH).

Wrapping with film with any pore areas prevented shrivelling of the mango peel, which was significant in the nonwrapped packages. All perforated PVC films reduced weight loss from 32% in the control to less than 15% at pore areas less than 1 cm^2 (Table 1). Smaller total pore areas gave lower weight losses.

Headspace concentrations of O_2 and CO_2 inside the packages could be controlled at different levels by using an appropriate total pore area (Figs 1 and 2, Table 1). The level of O_2 inside the packages was the balance between O_2 consumption rate and O_2 influx rate through the package film and the perforated pore. Influx rate depends mainly on the total pore area (Fig. 3). Increasing total pore area from 0 cm^2 (unperforated film) up to infinity (control or nonwrapped package) therefore raised O_2 levels parabolically from about 5% up to 21%.

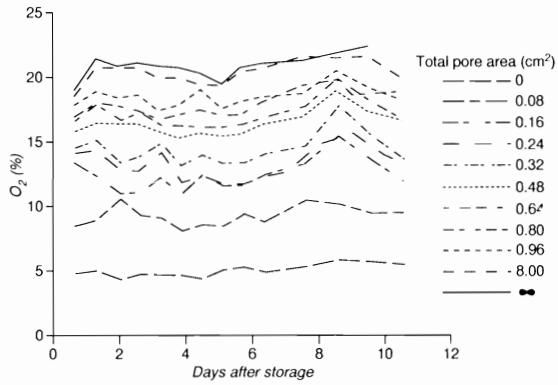

Figure 1. Headspace levels of oxygen inside PVC film packages perforated with various total pore areas during storage of mangoes for 10 days.

Similarly, CO_2 inside the packages is the result of a balance between the CO_2 production rate and CO_2 egress through the package film and the perforations. Outflow rate also depends mainly on the total pore area (Fig. 3). Reducing total pore area raised CO_2 levels exponentially, from 0.15% to 9.6%. However, at a pore area of 0 cm^2 (unperforated film) the level of CO_2 declined. Thus, the maximum CO_2 concentration did not occur in unperforated packages. This may be related to the suppression of respiration rate at O_2 concentrations lower than 5% and the interference of anaerobiosis. In all unperforated packages, slight off-flavour development was observed.

Although a rise of climacteric CO_2 inside the packages was found during the second day, ethylene levels were maintained at an average of 0.1–0.3% for all treatments. Thus, the result showed adequate permeability of ethylene gas even in the unperforated packages. Fluctuation of O_2 and CO_2 levels at all treatment shown in

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Figure 1 and Figure 2 were probably due to the unsteady respiration rates of mangoes caused by variations in ambient conditions during storage (27–34°C; 55–91% RH). Since gases mainly permeate the pore area rather than the film surface, adequate perforation can be achieved regardless of the type of plastic film or thickness for the purpose of controlling the level of gases, and preventing moisture loss, shrivelling, and fermentation.

Altering the MA by perforation changed the rate of ripening. However, unperforated film stops the pro-

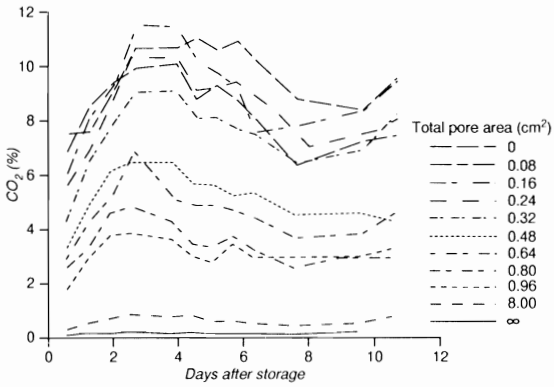

Figure 2. Headspace levels of carbon dioxide inside PVC film packages perforated with various total pore areas during storage of mangoes for 10 days.

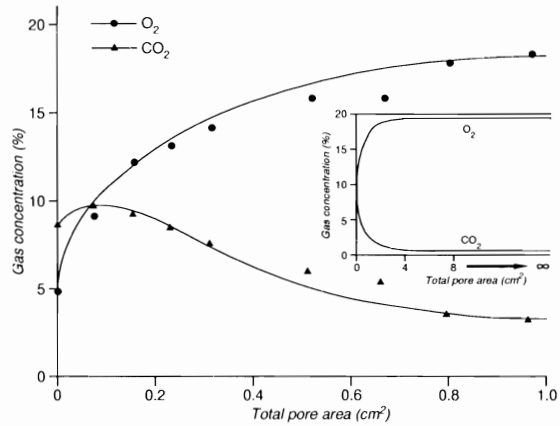

Figure 3. Relationship between average headspace concentrations of oxygen and carbon dioxide inside PVC film packages with various total pore areas during ambient storage of mangoes for 10 days.

Table 1. Effect of perforation on MA conditions inside mango packages, colour and some physical-chemical changes during storage at ambient temperature (27–34°C), 70% RH

Total pore area[a] (cm^2)	MA in package during 11 days CO_2 (%) average (range)	O_2 (%) average (range)	C_2H_4 (%) average (range)	Colour hue[b] (a/b) at 8 days Peel	Flesh	Firmness at 5 days (kg/cm^2)	Acidity at 5 days (%)	Weight loss at 12 days (%)
0.000	8.41 (6.5–10.1)	4.73 (4.2–5.4)	0.104 (0.014–0.234)	–0.49 G	–0.09 WG	2.31	1.02	11.37
0.080	9.62 (7.5–11.0)	8.97 (8.0–10.5)	0.216 (0.049–0.325)	–0.47 G	0.16 GY	1.25	0.53	11.78
0.160	9.08 (6.1–11.5)	12.11 (10.0–13.5)	0.292 (0.068–0.484)	–0.36 G	0.17 Y	1.33	0.26	11.96
0.240	8.43 (5.7–10.4)	13.04 (11.6–14.7)	0.315 (0.052–1.074)	–0.26 G	0.18 Y	1.47	0.30	13.30
0.320	7.52 (4.3–9.0)	14.06 (13.2–15.3)	0.216 (0.114–1.365)	–0.21 G	0.21 Y	1.39	0.27	13.47
0.480	5.28 (3.3–6.5)	16.13 (15.3–17.2)	0.260 (0.064–1.412)	–0.30 G	0.19 Y	1.55	0.27	13.66
0.640	4.68 (2.9–6.8)	16.81 (15.9–18.0)	0.148 (0.078–0.243)	–0.17 GY	0.19 Y	1.39	0.11	13.83
0.800	3.52 (2.6–4.9)	17.70 (16.8–19.2)	0.179 (0.052–0.430)	–0.02 GY	0.20 Y	1.35	0.11	14.24
0.960	3.14 (1.8–3.9)	18.25 (17.4–19.0)	0.314 (0.047–0.586)	–0.19 GY	0.23 Y	1.23	0.14	14.76
8.000	0.61 (0.3–0.8)	20.10 (18.5–21.3)	0.164 (0.046–0.330)	–0.09 GY	0.17 Y	1.55	0.12	20.63
∞	0.15 (0.1–0.3)	20.61 (18.8–22.1)	0.106 (0.036–0.166)	–0.13 Y	0.17 Y	2.19	0.21	32.32

[a] Total pore area on 500 cm^2 wrapped film surface of mango package. [b] G – Green, Y– Yellow, W– White

cesses, resulting in a significant delay of the loss of firmness, a decline of acidity, and the increase of total soluble solid content (TSS) (Table 1). It also kept the peel and the flesh at green stage and produced a fermented flavour and taste. The interruption of the ripening processes in unperforated packages is possibly due to the lack of enough O_2 to complete the processes (lower than 5%). Since most of the plastic films have lower permeability to gases than the PVC film used in the experiment, this suggests that most of the available plastic films cannot supply the O_2 needed for proper ripening by O_2 influx through the film alone. Adequate perforation will be needed in any commercial MA technique for ambient storage of mango. For Nam Dok Mai mangoes, perforation of minimum pore area of 0.1 cm^2 is sufficient to maintain O_2 level higher than 9%, to reduce weight loss by 64% compared with the control, and to prevent fermentation.

Regardless of perforation, all fruits ripened at about the same period of 5 days after harvest. There was no significant effect on loss of firmness, reduction in acidity, the increase of TSS, and colour development of the flesh of ripened mangoes (Table 1). However, perforation significantly delayed colour development of the peel, so that the flesh cloured first. The inhibition of carotene pigmentation in the peel can be related to O_2 tension inside the package but not to CO_2 accumulation. To develop peel colour to the marketable stage, a minimum total pore area of 0.64 cm^2 will be required to bring O_2 above the 16% essential for peel colour development to greenish. For the flesh, a minimum total pore area of 0.08 cm^2 is needed to bring O_2 level to the 9% adequate to allow colour development. In the packages with the small pore areas, when the fruits began to be overripe, a significant delay of the decline of acidity was observed, as well as an acceleration of the loss of firmness.

Productivity and Postharvest Behaviour of Black Sapote in the Israeli Negev Desert

Avinoam Nerd and Yosef Mizrahi*

Abstract

Seedlings of black sapote (*Diospyros digyna*) were planted at two sites in the Negev: Qetura with hot summer temperatures and saline water (4 dS/m); and Besor with mild temperatures and freshwater (1 dS/m). Trees started to bear fruit in the third year and fruit yield ranged from 2–24.5 and 6.1–61.4 kg/tree at Qetura and Besor, respectively, in the fifth year. Average fruit weight was 115 g at Qetura, and 50% higher at Besor. Fruit ripened at Qetura in the winter (Dec.–Feb.) and at Besor in the spring (Apr.–May). Full-sized fruit were harvested and stored at 10°C and 20°C (85% relative humidity). The average time from harvest to softening was 29 days at 10°C and 13 days at 20°C. At the softening stage, fruit of the two storage treatments were similar in water loss (11–16%), pH (6.4–6.9), acidity (0.02–0.04 meq/g fruit weight), and EC (2.3–3.0 dS/m), but reducing sugars content was higher at 10°C than at 20°C (14.6–17.5% vs 11.5–14.5%). Wrapping the fruit in plastic film extended the time between harvest and softening by 40–50% at 20°C. Carbon dioxide evolution rate did not change during storage, while ethylene evolution had a climacteric peak. The fruit lasted at best 10 days after softening for the fruits stored at 10°C and 7 days after softening for those stored at 20°C.

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Storage and Ripening of Kenyan Mangoes

J.K.T. Imungi*

Abstract

Firm, mature-green mangoes of the Kenyan Ngowe variety were stored at ambient temperatures (22.2±1.3°C) in sealed nonperforated plastic bags (gauge 150) with or without potassium permanganate inserts, and in perforated fibreboard cartons. Initially, then after three days, and thereafter every two days during storage, the fruits were analysed for weight loss, pH, acidity (total titratable, fixed and volatile), total soluble solids (as °Brix), total carotenoids content, skin and flesh colour, ascorbic acid content, and overall skin condition, all as indicators of ripening. It was observed that the fruits stored in fibreboard cartons were fully ripe and ready to eat after the 5th day of storage and that beyond the 9th day of storage the fruits could be considered overripe and unacceptable. The fruits stored in plastic bags on the other hand, were fully ripe after the 7th day of storage and became unacceptable after the 11th day. There was no significant difference between the ripening rates of the fruits stored in plastic bags, with and without potassium permanganate inserts.

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The Storage of Sapodilla (*Manilkara achras* L.) at 10, 15, and 20°C

Mohamad Nordin bin Abdul-Karim*, Latifah Mohd Nor†, and Abdullah Hassan†

Abstract

An increase in temperature led to an increase in weight loss in stored sapodilla. Fruit stored at 10°C for 28 days, 15°C for 21 days, and 20°C for 16 days exhibited excessive wilting. Fruit stored for 21 days at 20°C had begun to rot. The loss of cell integrity was reflected in reduction in fruit size, and changes in colour and firmness.

The storage temperature and time did not greatly affect the pH and total soluble solids of the fruit. The total sugar content was influenced by storage temperature for all storage duration except day 10.

Fruit stored at 10°C for 28 days failed to ripen properly, indicating chilling injury. Sensory evaluation performed on ripened fruits showed that organoleptic attributes of the fruits were not affected by storage temperature and time.

Carbon dioxide and ethylene productions were greater and their peaks reached earlier, at higher storage temperatures. The ethylene peaks coincided with those of carbon dioxide when storage was at 10 and 15°C The ethylene peaks were reached one day earlier at ambient and 20°C.

Sapodilla of Jantung variety could be stored at 10°C for 21 days, 15°C for 16 days, and 20°C for 10 days. Prolonged storage at 10°C led to chilling injury.

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Factors Influencing the Ripening of 'Chanee' and 'Monthong' Durians

Peerasak Chaiprasart and Jingtair Siriphanich*

Abstract

To understand the differences in ripening pattern of the two most important durian cultivars in Thailand, 1-amino-cyclo-propane-1-carboxylic acid (ACC) content, ACC-synthase, and ethylene forming enzyme (EFE) activities were analysed in the husk and the pulp of mature 'Chanee' and 'Monthong' durians. ACC in both tissues of the two cultivars gradually increased from harvesting until the fruit were fully ripe. Higher accumulations of ACC were found in the pulp and in 'Chanee'. ACC-synthase activity was low at harvest. It gradually increased in 'Monthong' and peaked 6 days after harvest. In 'Chanee', it rose more rapidly, peaking at day 3. ACC-synthase activity in the pulp was about 5–10 times lower than that in the husk. EFE activity was also lower in the pulp, and there was a higher activity of this enzyme in 'Chanee'. The results indicated that the slower ripening rate in 'Monthong' was due to the activity of both enzymes.

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Effects of Ethylene Application on Fruit Postharvest Characteristics of *Cucumis metuliferus* Mey.

A. Benzioni, S. Mendlinger, and M. Ventura*

Abstract

Cucumis metuliferus Mey. (kiwano, melano) is a climbing annual with yellow–orange fruits and a green, juicy mesocarp. The plant originates in Africa and is currently exported as a speciality ornamental fruit to the European market. The best prices are received for large and homogeneously orange-coloured fruits. We surmised that the export season might be advanced by applying treatments designed to enhance colour development and improve fruit quality. In this work, the effect of ethylene application on fruit pigmentation, ripening, and quality was studied.

Application of 160 ppm ethylene for 24 hours to mature-green fruit caused a rapid decrease in chlorophyll and a gradual increase in yellow pigments in the fruit peel. Treated fruit turned yellow–orange and softened much more rapidly than untreated fruit, which were still not fully ripe three months from harvest. The response to ethylene was affected by fruit age, decrease in chlorophyll after ethylene application being smaller in immature than in mature-green fruit; correspondingly, increase in yellow pigments was considerably less in the former. Response to treatment with 1.6 ppm ethylene was slight, 16 and 160 ppm having a much more significant effect on fruit pigmentation.

It seems that by harvesting fruit when still green and treating it with ethylene a few days before marketing it should be possible to extend the export season.

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Part 5 — Postharvest Diseases and Disorders

Mango Postharvest Disease Control: Effect of Rain at Harvest, Fungicide Treatments, and Fruit Brushing on Fruit Appearance

Tony W. Cooke* and Greg I. Johnson†

In Australia, postharvest treatment of mangoes cv. Kensington Pride with hot benomyl for control of anthracnose (*Colletotrichum gloeosporioides*) has been practiced for almost 20 years. More recently, a dual treatment of hot benomyl followed by prochloraz has been introduced to provide control of anthracnose, stem-end rot (caused by *Dothiorella dominicana, Lasiodiplodia theobromae*, and *Phomopsis mangiferae*), and alternaria rot (caused by *Alternaria alternata*) on export mangoes. In commercial packing sheds, the fruit are then brushed following treatment to dry them, and to remove spray residues, sooty mould, and scale insects. Generally, the treatments have been well accepted, but there have been occasional reports of skin damage (Fig. 1) following packing shed treatment of fruit harvested after rain. As a consequence, growers have been reluctant to follow the recommended procedure (Fig. 2) after rain, and rain-harvested fruit have suffered increased wastage due to disease.

Figure 1. L–R: nil blemish; superficial skin damage; shrivel damage and associated dehydration.

In an experiment conducted with fruit from southern Queensland, mangoes were harvested following rain, and around 18 hours later were subjected to the recommended packing line treatments. Some fruit were excluded from particular components of a hot benomyl, prochloraz, and fruit-brushing regime, and the impacts of the individual components and their combinations on fruit appearance were assessed during storage at 22°C.

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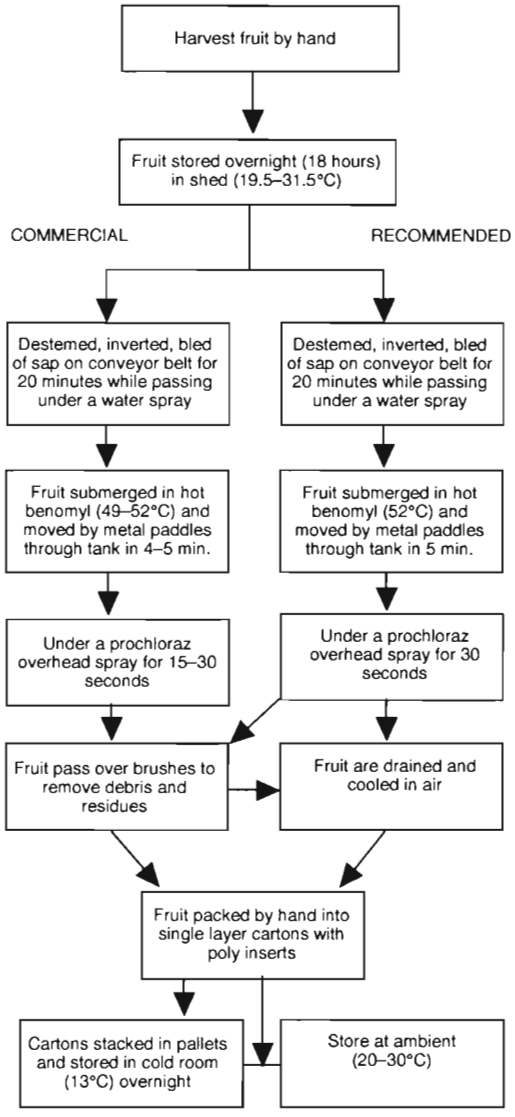

Figure 2. Mango packing line system comparing the recommended treatments and what tends to be the commercial situation, following rain at harvest.

Hot benomyl treatment rendered the fruit prone to post-dipping damage from fruit brushing. Damage, as superficial skin browning, was more severe when the fruit were also treated with prochloraz before brushing (Fig. 3). Fruit shrivel (Fig. 4) (severe skin damage resulting in dehydration and associated skin shrivel) and weight loss (Fig. 5) after 13 days at 22°C, were more severe on mangoes that received the combination treatment of hot benomyl followed by prochloraz followed by brushing.

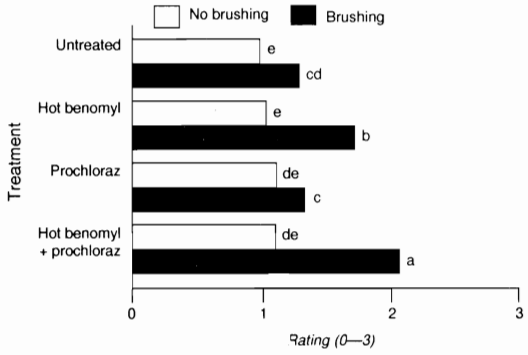

Figure 3. Skin damage on mangoes stored one day at ambient (18–28°C) and 13 days at 22°C. Ratings: 0, nil; 1, slight; 2, moderate; 3, severe.

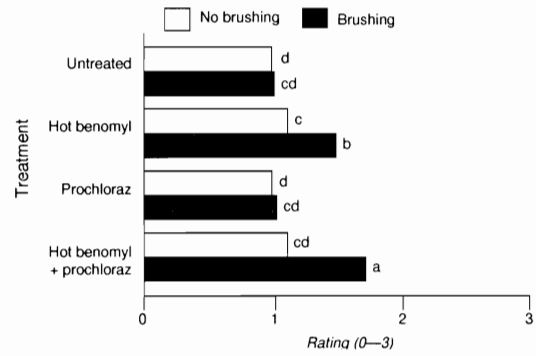

Figure 4. Shrivel damage on mangoes stored one day at ambient (18–28°C) and 13 days at 22°C. Ratings: 0, nil; 1, slight; 2, moderate; 3, severe.

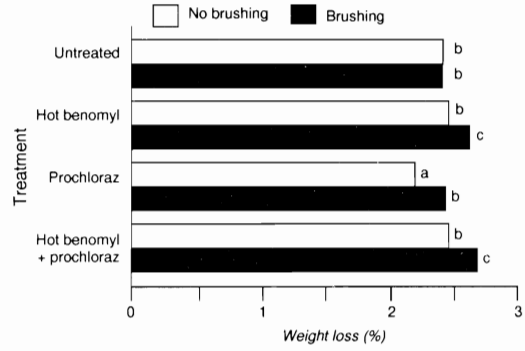

Figure 5. Weight loss of mangoes stored 13 days at 22°C.

Sour Rot Disease on Citrus Fruits: Importance and Control

Klaus Richter*

THE fungus known as *Endomyces geotrichum* Butler & Petersen (anamorph, *Geotrichum candidum* Link ex Pers.) is the agent responsible for sour rot disease on citrus fruits and for postharvest decay in several other crops. It has been reported in most areas where citrus is grown, and occurs on all cultivars (Whiteside et al. 1988).

The fungus also causes diseases in humans and animals. It has been reported by Gumowski and Girard (1985) that *G. candidum* is the aetiological agent of gastrointestinal disorders, chronic urticaria, asthma, and rhinitis. Human isolates of *G. candidum* obtained from patients of the medical clinic of Leipzig University were found to be pathogenic to different cultivars of citrus, tomatoes, and carrots. These results are in accordance with those of El-Tobshi and Sinclair (1965) who stated that human and animal isolates of *G. candidum* are pathogenic to different fruits and vegetables. This example underlines the importance of sour rot disease to humans.

Although losses due to sour rot are relatively small worldwide, the fungus has often been found on the market in Germany in the last few years. Figure 1 shows that from 1984 to 1988 a steadily increasing incidence could be measured.

The long-term use of benzimidazole fungicides may be the cause for this appearance. *Geotrichum* is insensitive to benzimidazole fungicides used to control the other major citrus decays. In fact, applications of this chemical may even increase the incidence of sour rot. Tests with benzimidazole fungicides in vitro and in vivo demonstrated stimulating effects on sporulation of *G. candidum*. Formation of conidia after application of 1000 ppm active ingredient benomyl, carbendazim, or TBZ was up to 2 times higher than in untreated controls (Table 1).

Figure 2 shows that oranges treated with the same concentrations were more susceptible to infection by *G. candidum* than untreated ones.

The results given above indicate that effective control measures are needed to eliminate or minimise the risks associated with the importation of infected or spore-contaminated fruits.

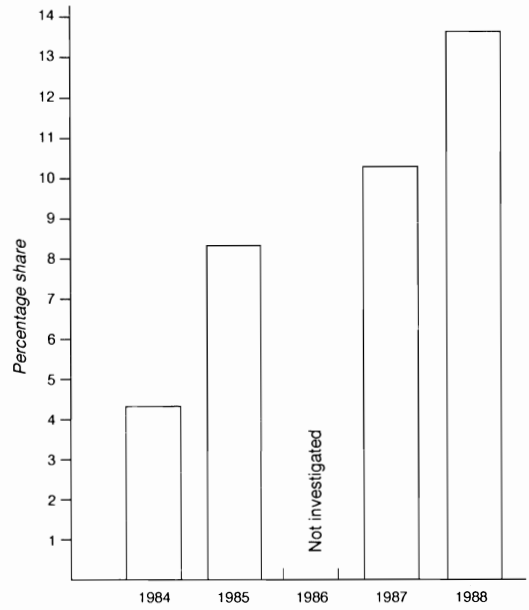

Figure 1. The share of sour rot (%) from total loss in citrus fruits imported from Cuba (Leipzig Market; average of 4 cultivars)

Table 1. Effect of benzimidazole fungicides on growth and sporulation of *Geotrichum candidum* (% of untreated control)

Criterion	Fungicide (1000 ppm active ingredient)		
	Benomyl	Carbendazim	TBZ
Mycelial growth colony diameter (mm)	58.1	79.9	90.1
Sporulation per cm^2 (10^5 conidia/cm^2)	128.6	185.7	140.0

All efforts should be directed to establishing integrated control strategies as follow:

1. Safe picking and handling after harvest and importation, and control of peel-sucking insects, to prevent injuries. According to Baudoin and Eckert (1985)

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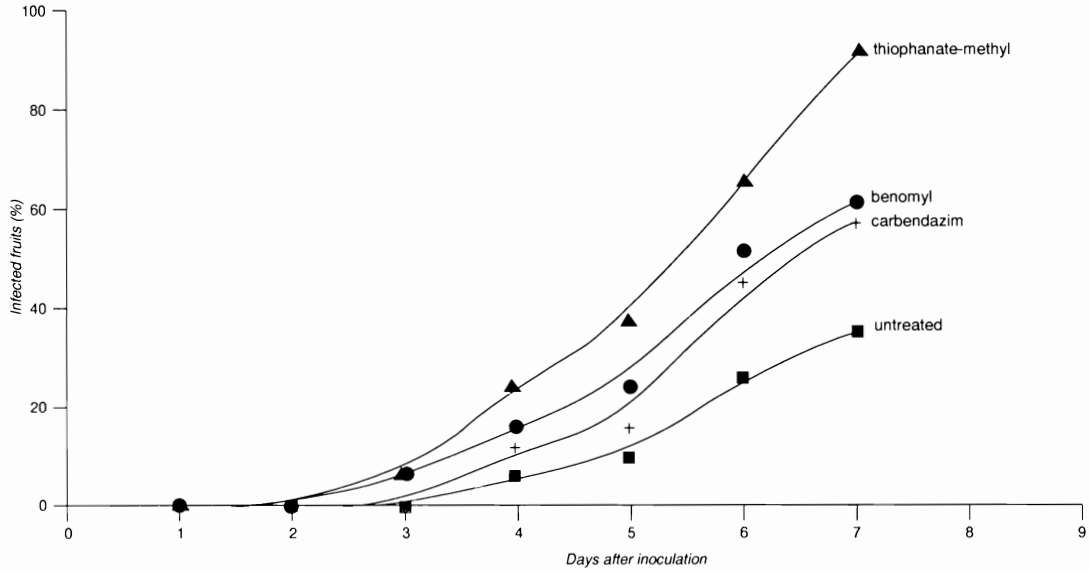

Figure 2. Effect of benzimidazole fungicides on the incidence of sour rot (1000 ppm active ingredient; 26°C; *Citrus sinensis*)

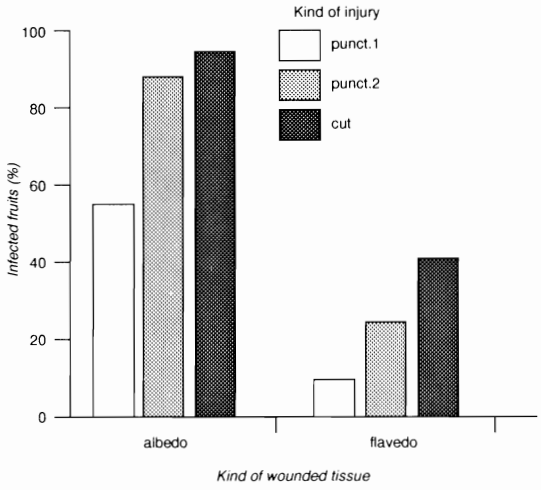

Figure 3. Influence of injuries on the incidence of sour rot (*Citrus sinensis*, 8 days after inoculation, average of 3 fruit colours)

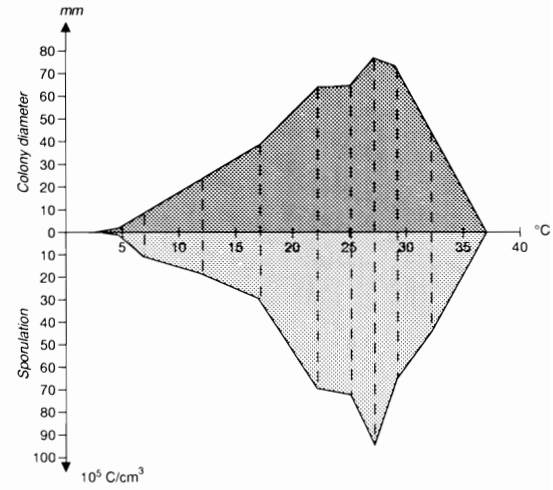

Figure 4. Influence of temperature on growth and sporulation of *Geotrichum candidum* (26°C, 7 days after inoculation)

deep wounds to the albedo may lead to high infection levels, as Figure 3 shows.

2. Cooling after harvest and during transport and storage reduces the speed of fungal development, but cannot completely inhibit mycelial growth and sporulation (Fig. 4)
3. Removal of infected fruits is necessary to prevent further distribution of the disease, because one infected fruit is able to contaminate up to 20 healthy ones in a box.
4. For special postharvest treatment against *G. candidum*, sodium-o-phenyl-phenate is usually applied

Table 2. Influence of growth regulators and auxin-like compounds on *Geotrichum candidum* in vitro and in vivo

Criterion	Untreated	Chemical compounds (active ingredient/concentrations, ppm)								
		Ethephon 3000 (1)	A 250 (2)	B 250 (3)	C 125 (4)	D 1000 (5)	Combinations			
							1+2	1+3	1+4	1+5
Mycelial growth colony diameter (mm)	79.5	49.5	78.4	48.6	78.6	69.3	0.0	13.7	1.5	3.7
Sporulation (10^4 c/cm^3)	440.7	62.9	708.0	106.4	617.5	626.7	0.0	12.3	0.7	0.0
Germination of conidia (%)	89.6	0.6	83.6	64.2	–	–	1.0	5.4	–	–
Infected fruits (%) (*Citrus sinensis*)	92.0	48.0	25.0	34.0	–	11.3	10.0	14.0	–	11.4

A = 2,4-dichlorophenoxy acetic acid
B = 2-(2,4-dichlorophenoxy-methyl)-benzimidazole
C = 2-methyl-4-chlorophenoxy acetic acid
D = n-propylammonium-4-chlorophhenoxyacetate

during the washing process, and guazatine, which is more effective, is applied after washing in aqueous formulations (Whiteside et al. 1988).

As was shown by El-Kazzaz et al. (1983), ethylene either inhibits or stimulates the development of certain postharvest fruit-infecting fungi depending on the time of application.

In our experiments we found that ethephon, the degreening agent, in combination with auxin-like compounds gave good results in controlling the disease (Table 2).

In addition to 2,4-D (A), compounds with lower toxicity than 2,4-D, which have auxin analogue activity and contain the 'dichlorophenoxy'-group, also reduce mycelial growth, sporulation, and disease incidence, possibly by delaying the onset of fruit senescence. These preliminary results may stimulate further investigation in the field into the use of growth regulators.

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Hot-water Control of Anthracnose on Mango Varieties Arumanis, Golek, and Manalagi

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MANGOES of the Arumanis, Golek, and Manalagi varieties have high commercial value in Indonesia. Observations made at the central market in Kramatjati, Jakarta, showed that most of the three varieties were damaged by microorganisms, including *Colletotrichum gloeosporioides*. Amounts of damage to the three varieties were 31.1%, 24.4%, and 16.4%, respectively.

Various techniques to control anthracnose have been tested, including dipping in 500–1000 ppm benomyl solution at 52°C for 5–15 minutes. Previous studies indicated that dipping in hot water was enough to prevent anthracnose, but the temperatures and times needed were not known with any precision.

During 1992, mangoes of the Arumanis, Golek, and Manalagi varieties, picked as commercially mature fruits in Kraton, Pasuruan, East Java, were studied at the Post Harvest Laboratory of Malang Horticulture Research Station.

Preliminary studies to determine the proper concentration of *Colletotrichum gloeosporioides* inoculum indicated that Arumanis, Golek, and Manalagi developed anthracnose 7 days after inoculation at a concentration of 110 000 spores/mL at room temperature.

Harvested fruit were inoculated with *Colletotrichum gloeosporioides* solution at a concentration of 110 000 spores/mL, then incubated for 24 hours at room temperature. Hot-water treatment was applied in a factorial randomised block design. The first factor was variety (Arumanis, Golek, and Manalagi) and the second dipping treatment (no dipping, water dipping at room temperature, and hot-water dipping at 49, 51, or 53°C for 5 and 10 minutes). Each treatment involved 15 fruit and 3 replications. Fruit were stored at room temperature (27–33°C) and 52–61% relative humidity for 7 days to observe anthracnose.

The results of the observations showed that there was no interaction between varieties and dipping treatment, but there were significant differences between dipping treatments and disease occurrence and spread (Tables 1 and 2).

Table 1 indicates that hot-water treatment at 49°C for 10 minutes, or 51°C or higher for 5 minutes, gave the best suppression of anthracnose on mangoes of the three varieties, and Table 2 that hot-water treatment at 51°C or higher for 10 minutes was the most effective.

The difference of anthracnose intensity on Arumanis, Golek, and Manalagi might be due to differences in fruit characteristics (Table 3). Fruit ripening showed that

Table 1. Average percentage of fruit number attacked by anthracnose following dipping at 49, 51, or 53°C for 5 or 10 minutes and 7 days storage under ambient conditions.

No.	Treatment	Arumanis	Golek	Manalagi	Average[a]
			(% fruit number)		
1.	No dipping	13.89	55.00	52.22	40.37a
2.	Dipping at room temperature	8.33	50.56	57.22	38.70ab
3.	Dipping 49°C, 5 min	18.89	34.44	42.78	32.04ab
4.	Dipping 49°C, 10 min	0.0	23.33	36.11	19.81abc
5.	Dipping 51°C, 5 min	4.44	20.00	16.11	9.38bc
6.	Dipping 51°C, 10 min	0.0	5.55	3.33	2.96c
7.	Dipping 53°C, 5 min	0.0	15.00	7.22	7.41c
8.	Dipping 53°C, 10 min	0.0	0.0	5.00	1.67c
Average[a]		5.69y	25.49x	27.50x	
Not inoculated		1.67	25.00	15.56	

[a] Means followed by the same letter in the same column (a, b, c) and in the same row (x, y) were not significantly different at 5% LSD test.

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total soluble solids were significantly higher in Golek and Manalagi than in Arumanis mangoes (Table 4).

Hot-water treatment of Golek appeared to change fruit skin colour. The skin became more yellow compared with that with no hot-water treatment. Also, fruit treated with hot water ripened more rapidly, though there were no differences in fruit quality.

Table 2. Average percentage area of spread of anthracnose per fruit following dipping at 49, 51, or 53°C for 5 or 10 minutes and 7 days storage under ambient conditions.

No. Treatment	Arumanis	Golek	Manalagi	Average[a]
		(% area of fruit affected)		
1. No dipping	1.15	2.56	5.00	2.90ab
2. Dipping at room temperature	0.72	3.63	5.29	3.21ab
3. Dipping 49°C, 5 min	2.64	1.90	2.53	2.36ab
4. Dipping 49°C, 10 min	0.0	1.37	1.14	0.84abc
5. Dipping 51°C, 5 min	3.17	0.88	2.70	2.25ab
6. Dipping 51°C, 10 min	0.0	1.52	0.37	0.63b
7. Dipping 53°C, 5 min	0.0	3.87	0.89	1.59ab
8. Dipping 53°C, 10 min	0.0	0.0	1.20	0.40b
Average[a]	0.96y	1.97x	2.39x	
Not inoculated	0.54	9.94	4.78	

[a] Means followed by the same letter in the same column (a, b, c) and in the same row (x, y) were not significantly different at 5% LSD test.

Table 3. Characteristics of mangoes of Arumanis, Golek. and Manalagi at harvest

Variety	Skin thickness (mm)	Vitamin C (mg/100 g)	TSS (%)	Acidity (%)
Arumanis	2.14a*	28.74b	10.07a	0.82b
Golek	1.59b	64.06a	9.00b	1.26a
Manalagi	2.29a	30.90b	10.57a	0.50c

* Means followed by the same letter in the same column (a, b, c) were not significantly different at 5% LSD test.

Table 4. Average acid content, vitamin C, TSS content, and hardness of fruit flesh of ripe mangoes, averaged over dipping treatments

Cultivar	Acid content (%)	Vitamin C (mg/100 g)	TSS (%)	Hardness (kg)
Arumanis	0.08a	8.24c	20.25b	3.64a
Golek	0.07a	35.37a	20.79a	3.43a
Manalagi	0.07a	16.80b	21.09a	2.68b

* Numbers in the same column followed by the same letters were not significantly different at 5% LSD test.

Efficacy of Propiconazole against Fungi Causing Postharvest Disease on Eksotika Papaya

Sepiah M.*

FUNGI known to damage Eksotika papaya fruit during storage are *Alternaria alternata*, *Botryodiplodia theobromae*, *Botryosphaeria ribis*, *Colletotrichum capsici*, *Fusarium solani*, *Gilbertella persicaria*, *Phomopsis caricae-papayae*, *Ceratocystis paradoxa*, and *Cladosporium oxysporum* (Sepiah 1992). Of these pathogens, *Colletotrichum capsici* was the most important, affecting almost all stored fruit. Many previous reports indicate that benomyl, thiabendazole, or daconil can control fruit diseases of papaya when applied either before or after harvest (Broadrick et al. 1972; Fraire Mora 1973; Bolkan et al. 1976; Couey and Farias 1979; Alvarez et al. 1977; Couey et al. 1984). However, these fungicides were found to be ineffective in controlling fruit diseases of Eksotika papaya (Sepiah et al. 1991). Propiconazole and prochloraz showed more promise when used to treat disease infection on the fruit. Since then, further studies have been conducted using these two fungicides to determine their proper and effective usage in controlling postharvest diseases of Eksotika papaya.

This paper presents some of the results of the studies using propiconazole to control diseases of papaya during storage.

Materials and Methods

The effect of propiconazole on growth of fungi isolated from diseased fruit during storage was assessed on amended potato dextrose agar (PDA). The final concentrations of propiconazole incorporated into PDA were 0.1, 1.0, 5.0, 10.0, and 50 ppm. PDA without the fungicide was used as a control. The diameters of the mycelia on amended agar in 90 mm petri dishes were measured daily for 5 consecutive days. Growth of the fungi on the 10th day was also observed. Three replicate plates per concentration of fungicide were used for each fungus.

Observations were made on the effect of propiconazole on fruit disease during storage after treatment by spraying, or dipping for 0.5, 1.0, or 2.0 minutes in 200 ppm or 400 ppm of the fungicide. Fruit of Eksotika papaya at colour stage 2 or 3 (showing a tinge of yellow) were used. The treated fruit were placed in boxes lined with sponge. Each box contained seven fruit. Four boxes were prepared for each treatment. All boxes were kept at ambient temperature (25–33°C). After 24 hours, three boxes of each treatment were transferred to a cold room held at 10°C.

Fruit retained at ambient temperature were observed every 2 days for 8 days for skin colour development (Table 2) and disease incidence. The fruit kept in the cold room were transferred to ambient temperature after 3 weeks of storage. Fruit skin-colour development and disease incidence were observed until the fruit became overripe.

Another batch of papaya was harvested and treated with double hot water (DHW) followed by dipping in 300 ppm propiconazole for 3 or 5 minutes. Control fruit received DHW alone. For every treatment, 20 boxes containing 10 fruit per box were prepared. All boxes were left at ambient temperature for one night before they were transferred to the 10°C cold room. After 2 weeks, fruit were returned to ambient temperature. Observations were made on fruit skin colour and disease incidence.

Results and Discussion

In general, the fungicide reduced the growth of all the fungi tested but sensitivity to it varied depending on the isolates (Table 1). Growth of *B. ribis*, *F. solani*, *A. alternata*, *C. capsici*, *C. gloeosporioides*, and *P. caricae-papayae* was significantly reduced at 0.1 and 1.0 ppm. while growth of *G. persicaria* and *Mucor* sp. was significantly affected with concentrations of 10 and 50 ppm.

Although growth of both *Colletotrichum* species was significantly affected at 1.0 ppm propiconazole, *C. gloeosporioides* was considered more sensitive. Complete growth inhibition of *C. gloeosporioides* occurred at 5 ppm, while for *C. capsici* it occurred at 50 ppm.

These observations indicate that propiconazole can reduce fungal growth or delay the formation of diseases on papaya caused by common pathogens such as *Colletotrichum* species, *P. caricae-papayae* or *A. alternata*, but is less effective against *G. persicaria* or *Mucor* sp.

Fruit treated with propiconazole and kept at ambient temperature reached stage 4 or 5 skin colour after 3 days storage. The fruit were free from disease symptoms until the 6th day after treatment. Disease developed on overripe fruit. Disease symptoms were mainly found near the stem end and caused by *C. capsici*. Only fruit treated

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Table 1. Average growth diameter (mm) of the fungi from Eksotika papaya on potato dextrose agar incorporating different concentrations of propiconazole.

Fungus	Propiconazole concentration (ppm)						
	0	0.1	1	5	10	50	MSE
Botryosphaeria ribis 409	41.15a*	26.11b	18.52c	8.72d	5.66de	0.00e	102.71
Alternaria alternata 402	33.50a	29.27ab	24.69b	15.30c	12.97c	4.38d	58.32
Colletotrichum gloeosporioides 411	28.40a	28.36a	11.25b	0.0c	0.0c	0.0c	108.97
C. capsici 403	37.59a	35.58a	22.92b	12.75c	5.47d	0.0d	90.08
Phomopsis caricae-papaya 410	62.21a	61.77a	34.92b	9.13c	6.66dc	0.0d	185.52
Mucor sp. 407	81.63a	81.00a	79.63a	78.02a	76.08a	28.55b	131.87
Gilbertella persicaria	81.75a	80.72a	77.77a	73.77a	46.31b	0.0c	262.81
Fusarium solani	46.09a	27.69a	24.88b	15.02c	0.0c	0.0c	129.25

* Values within rows followed by a common letter are not significantly different at P = 0.5.

Table 2. Effect of propiconazole treatment on fruit colour development (values are mean colour stage*) during storage at 10°C for 3 weeks and after transfer to ambient temperature.

Treatment		Original colour	3 weeks at 10°C	3 days at ambient after cold storage	6 days at ambient after cold storage	Average
Untreated		2.6a†	3.7a	4.5abc	5.6ab	4.1b
Propiconazole	spray	2.6a	3.9a	4.9a	5.7ab	4.3a
200 ppm	0.5 min**	2.5a	2.7a	4.5abc	5.8a	4.1a
	1 min	2.6a	3.8a	4.4bc	5.6ab	4.1a
	2 min	2.5a	3.8a	4.1c	5.6ab	4.0b
Propiconazole	spray	2.6a	2.8a	4.4bc	5.5ab	4.1a
400 ppm	0.5 min	2.5a	3.8a	4.2bc	5.4b	4.0a
	1 min	2.5a	3.9a	4.6ab	5.7ab	4.2a
	2 min	2.5a	3.0a	4.2bc	5.4b	3.9c
MSE		0.25	0.74	0.56	0.28	0.47

* 1 = all green, 3 = more green than yellow, 6 = full yellow; † Values within rows followed by a common letter are not significantly different at P = 0.5; ** Dip immersion time

with two minute dips in fungicide were free from disease up to 8 days after treatment.

These results indicate that treated Eksotica papaya can be kept at ambient temperature for up to 5 days, when they have reached the ripening stage suitable for consumption, with minimal disease development.

Fruits stored at 10°C can develop normal (ripe) skin colour after 3 weeks of storage. Three days after removal to ambient temperature, almost all fruit were in stage 4 or 5. There was no significant difference between the skin colour of control and treated fruit (Table 2).

At the time of removal from cold storage to ambient temperature, there was no significant difference between the treatments on the percentage of surface area of fruit affected by disease. However, if the number of fruit with disease symptoms was considered, only those fruits treated for 1–2 minutes with fungicide dips were significantly less affected than control fruit (Tables 3 and 4).

Development of disease symptoms was considerably faster after removal of the fruit to ambient temperature. Within 3 days, the number of control fruit affected by disease increased from 11% to 85%, while those treated

Table 3. Effect of propiconazole treatments on percentage of fruit with disease

Treatment		Days after 3 weeks storage at 10°C		
		0	3	6
Untreated		11a*	85ab	100a
Propiconazole	spray	7ab	52b	84abc
200 ppm	0.5 min†	3ab	52b	85abc
	1.0 min	0b	25bc	62cd
	2.0 min	0b	7c	55de
Propiconazole	Spray	3ab	52b	88ab
400 ppm	0.5 min	3ab	40b	74bcd
	1.0 min	0b	37b	63dc
	2.0 min	0b	7c	37e
MSE		3	19	17

* Values within rows followed by a common letter are not significantly different at P = 0.5.
† Dip immersion time.

with 200 or 400 ppm for 1 minute increased to 25 and 37%, respectively. Only those fruit dipped in fungicide for 2 minutes were significantly less affected by the disease compared with the control.

The major pathogens on treated fruit were *Colletotrichum capsici* and *P. caricae-papayae*. Other fungi isolated from diseased control fruit were *A. alternata* and *G. perceria*. The incidence of disease caused by *P. caricae-papayae* on fungicide-treated fruit was higher than that for disease caused by *C. capsici*.

Table 4. Effect of propiconazole treatments on average percentage of surface area of fruit affected by disease (disease symptoms).

Treatment		Days after 3 weeks storage at 10°C		
		0	3	6
Untreated		0.4a*	5.96ab	28.25a
Propiconazole	spray	0.8a	8.81a	22.30a
200 ppm	0.5 min†	0.1a	5.25ab	22.87a
	1.0 min	0.0a	1.74bc	9.76b
	2.0 min	0.0a	0.48c	5.96b
Propiconazole	Spray	0.03a	6.85a	26.33a
400 ppm	0.5 min	0.07a	2.22bc	12.85b
	1.0 min	0.0a	1.93bc	9.10b
	2.0 min	0.0a	0.18c	4.18b
MSE		1.87	59.13	2.45

* Values within rows followed by a common letter are not significantly different at P = 0.5.
† Dip immersion time

The results suggest that spraying and dipping for less than 2 minutes in propiconazole has no significant effect on the disease severity of Eksotika papaya.

Most of the fruit treated with DHW alone reached skin colour 4 and 5 within 2 days after storage for 2 weeks at 10°C. Less than 3% of the fungicide-treated fruit was affected by disease compared with DHW-alone fruit (17%). Fruit treated with fungicide for both dipping periods were significantly less affected by disease compared with DHW-alone fruit, even after the fruits became overripe, i.e. at skin colour stage 6 (Table 5).

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Table 5. Effect of double hot water (DHW) followed by propiconazole used at 300 ppm with different dipping period on disease of Eksotika papaya.

Treatment	Skin colour			% fruit area with disease symptoms		
	Days after 2 weeks storage at 10°C			Days after 2 weeks storage at 10°C		
	1	2	3	1	2	3
DHW alone	2.0b*	4.3b	6.0a	0a	1.03a	21.6a
DHW + propiconazole dip for 3 min	2.1b	3.7c	5.6a	0a	0.15b	3.8b
DHW + propiconazole dip for 5 min	2.2a	4.7a	6.0a	0a	0.07b	2.4b
MSE	0.07	0.26	0.16	0	7.02	286.7

* Values within rows followed by a common letter are not significantly different at P = 0.5.

Freckle Disease of Banana

C. Abayasekera, A.M. Karunaratne and N.K.B. Adikaram*

FRECKLE disease of bananas was first reported in Hawaii in 1917 (Carpenter 1918, 1919) and later in Fiji (Campbell 1926), New Caledonia (Johnston 1963), Papua New Guinea (Shaw 1963), and the Philippines, Taiwan, Thailand, Burma, Sri Lanka, India, the Congo, and Georgia, USA (Wardlaw 1961). The disease is now widespread in Sri Lanka and has become a major problem in the production of good quality fruits for export. In this paper we report on freckle disease of banana var. Ambul and its control.

On fruit, the freckles appear as soon as the bunch has shot, initially as minute, grey-brown, circular spots of about 0.25 mm diameter with a water-soaked halo of 1–1.5 mm diameter around each spot. As the fruit matures, the individual freckles increase in size up to 2 mm and turn dark-brown or black. The transparent water-soaked halo remains until the peel turns yellow. A typical freckle is rough to the touch, and heavy infections may give a reddish-brown colour to the fruit. Freckles are common on most banana varieties in Sri Lanka, and have been observed in three forms, viz., raised spots that are rough to the touch, smooth spots, and raised spots with a surrounding sunken area. There is a sharp rise in freckling after 8–9 weeks of bunch development, and the blemishes are most noticeable at the time of harvest (Fig. 1).

There is usually more freckling on the exposed side of the banana bunch than on the side of the bunch facing the tree. Further, freckles are most abundant on the inner face of the inner whorl and the outer face of the outer whorl of each hand, i.e. the rain exposed areas of the fruit.

Freckles are also found in the leaves of banana trees particularly the older ones, with symptoms similar to those on fruit. The infection of the fruit takes place from the inoculum provided by the leaf lesions. Fungal structures are found mainly in the upper surface of the leaf lamina, midrib and petiole. An aggregation of freckled areas has a sooty appearance and is rough to the touch. The two or three youngest leaves of the plants are rarely affected.

Two closely related fungi, *Macrophoma musae* and *Phyllosticta musarum,* were found associated with freckles, the latter being more common (Meredith 1968). The perfect stage of both species is described as *Guignardia musae* although minor differences in the morphology of conidia and ascospores exist between the two. The conidia of *M.musae* are spherical, while those of *P. musarum* are oval or irregular in shape. The conidia of both species are covered with a gelatinous envelope bearing a hyaline apical appendage especially during wet weather. The ascospores of *M. musae* are ellipsoidal and wider in the mid-region with obtuse ends, while those of *P. musarum* are wider at the ends with a curvature towards the mid-region. *M. musae* was cultured on oat agar medium. A greenish-grey colony turning black, developed. *P. musarum* could not be cultured on any of the common mycological media. Spermatia of *P. musarum* were observed in abundance during wet weather. They were cylindrical to dumb-bell in shape. The brown-black spots which are the freckles are an aggregation, or single pycnidia or perithecia of the above fungi (Fig. 2).

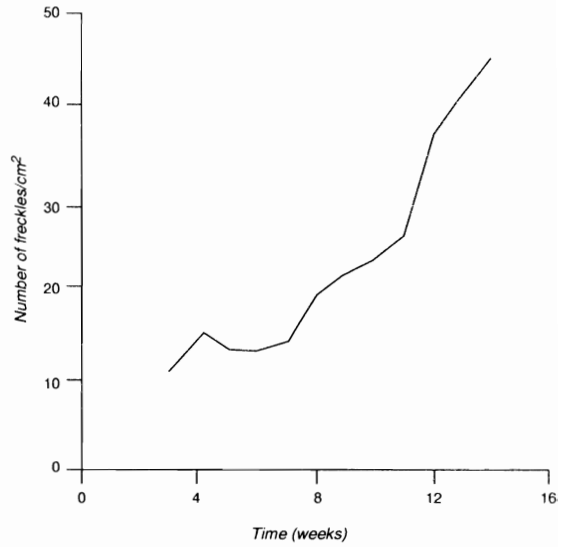

Figure 1. Freckling pattern during the development of banana bunch in the field.

Freckling is severe on fruit that develop during rainy weather. A direct correlation between rainfall and freckling was observed (Fig. 3).

In Hawaii, control of freckle disease has been effected

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by spraying leaves and fruits with maneb (Kumabe and Yee 1964). At a 0.8 ha site in the Central Province of Sri Lanka, field control trials were conducted adopting a combination of three measures: cutting and burning the freckled leaves, debris, etc.; bagging the newly emerged bunch; and a monthly spray with Polyram-M (maneb 80% WP, BASF, Germany (1 kg/400 L water plus 2 L of sticker-spreader per ha). Bunches harvested following a 20-week period of treatment on banana plants, showed a very high reduction of freckling (Fig. 4, Table 1). The fingers from treated plants were larger than those from the control and had 45–50% more fresh and dry weight (Table 1). The total number of fingers in both remained almost equal.

The fingers from treated plants were smooth-skinned, unstained, and of excellent quality compared with those from the control plants. The results of this work suggest that the measures used achieved a very high control of freckling and improvement of fruit quality.

Table 1. Freckling and the size and fresh weight of fruit from treated and control plants.

	Treated	Control
No. of freckles/cm^2	4.0	33.0
Av. fruit size (cm^3)	129.4	78.7
Av. fresh fruit weight (g)	76.9	51.8

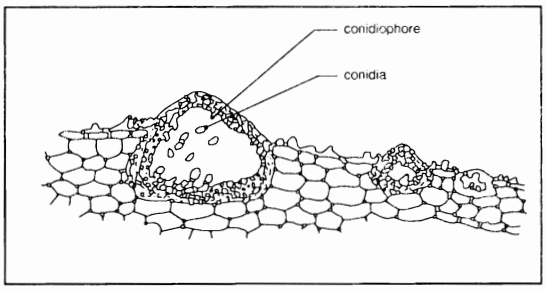

Figure 2. Transverse section of freckled banana skin showing pycnidia of *Macrophoma musae*.

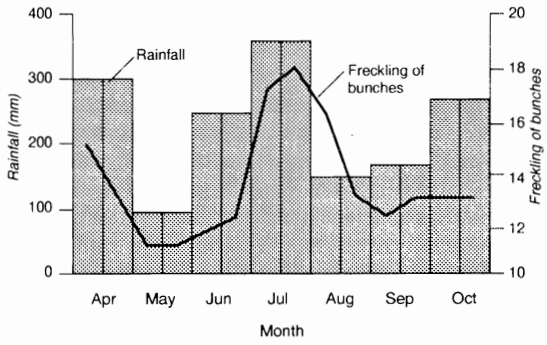

Figure 3. Relationship between average monthly rainfall and incidence of freckling in bananas (no. freckles/cm^2).

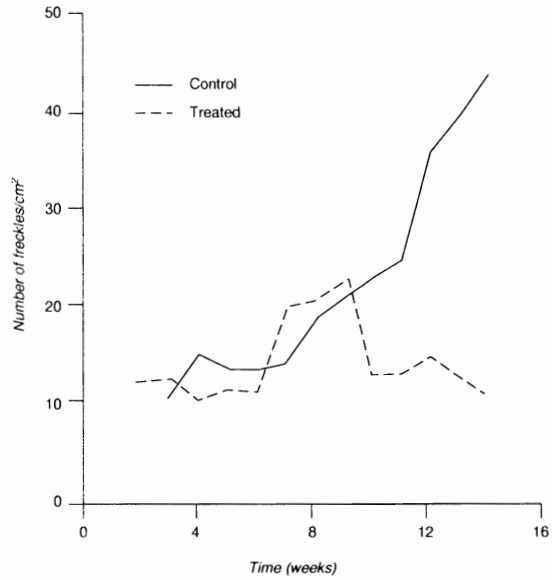

Figure 4. Freckling pattern during the development of bunch in treated (–) and control (– –) plots.

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Phytophthora Fruit Rot of Durian (*Durio zibethinus* L.)

Rattiya Pongpisutta and Somsiri Sangchote*

DURIAN *(Durio zibethinus* Linn.) is an important fruit crop in Thailand, with production areas in the east and south of the country. *Phytophthora palmivora* (Butl.) Butl. is one of the important fungi attacking durian. It infects ripe fruit and causes a soft brown lesion on the skin. The fungus can invade the flesh eventually causing it to rot. Some work has been done on control methods, including use of chemicals such as metalaxyl, fosetyl-Al, and phosphoric acid. This paper reports studies on factors affecting infection of fruit of *P. palmivora* and control of phytophthora fruit rot.

Experiment 1. Investigation of fruit rot of durian from Rayong province. Fifty durian fruit of each cultivar — Kob, Chanee, Kanyao, and Monthong — were harvested from an orchard in Rayong province. The fruit were ripened at room temperature. Disease incidence was assessed at ripening.

Experiment 2. Biology of P. palmivora. Durian fruits rotted by *P. palmivora* were collected from Sura Thani, Nakhon Si Thammarat, Rayong, and Chanthaburi. They were assayed for *P. palmivora* using selective media (BNPRAH). The morphological characteristics of the isolates obtained were studied. Pathogenicity of the isolates was checked by wounding durian fruits using a needle to make a circular opening in the area between the spines and applying inoculum as mycelial discs, sporangia, or zoospores. The inoculated fruits were kept in a moist chamber for 21 hours, then removed and ripened at room temperature. Disease incidence and severity were measured at ripening. The optimal incubation period was determined by inoculating fruit with mycelial discs at a wound made at the juncture of spines (3 sites per fruit). Inoculated fruit were incubated for 4, 6, 8, 10, 12, and 14 hours in a moist chamber, then removed and ripened at room temperature, using 10 fruit/incubation period. Disease incidence and severity were checked at ripening.

Experiment 3. Cultivar susceptibility. Four cultivars of durian — Kob, Chanee, Kanyao, and Monthong — were compared for their susceptibility to *P. palmivora.* The fruit from each cultivar were inoculated with mycelial discs of *P. palmivora* as described (using 10 fruit/cultivar). Inoculated fruit were incubated in a moist chamber for 21 hours, then ripened at room temperature. Disease incidence and severity were checked at ripening.

Experiment 4. Control. Three chemicals — etridiazole, fosetyl-Al, and phosphonic acid — were tested for their effectiveness against *P. palmivora* at concentrations of 0, 1000, 2000, 3000, and 4000 ppm. Fruit were inoculated as described, incubated for 21 hours, then dipped in the chemicals for 5 mins (using 10 fruit/chemical/concentration). The fruit were ripened at room temperature. Disease severity was checked at ripening. Dipping time, an effective concentration, and the superior chemical were selected from the tests. Durian fruits were inoculated as above and incubated for 14 hours in a moist chamber. The inoculated fruit were dipped in the test chemical for 0, 1, 2, and 3 mins (using 10 fruit/dipping time). They were ripened at room temperature and disease severity was checked at ripening.

Results

Investigation of fruit rot of durian from Rayong province. Phytophthora fruit rot was found on the ripened fruit of the four cultivars of durian. Higher percentages of phytophthora fruit rot were found on cv. Chanee than the other cultivars.

Biology of P. palmivora. Isolates of *P. palmivora* obtained from Chanthaburi, Nakhon Si Thammarat, Rayong, and SuratMani were similar in their morphological characteristics. *P. palmivora* could infect the wounded parts of the juncture of the spine of durian with mycelia, sporangia, or zoospores. The highest percent-

Table 1. Disease severity (lesion mean diameter in mm) on durian fruit treated with fosetyl-Al at 2000 ppm at different dipping times

Dipping time (minutes)	Disease severity (lesion diameter in mm)
0	49.8a*
1	6.3b
2	8.2b
3	8.1b

* Means followed by the same letter are not significantly different at 5% level by DMRT.

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age of infection resulted using mycelial infection. The highest disease incidence and severity were obtained when fruit were incubated for 14 hours after inoculation.

Cultivar susceptibility. Chanee, Kob, Kanyao, and Monthong cultivars were susceptible to *P. palmivora*.

Control measures. Etridiazole and fosetyl-Al at a concentration of 4000 ppm controlled fruit rot, but etridiazole caused skin damage. For fosetyl-Al at 2000 ppm at different dipping times of 0, 1, 2, and 3 minutes were tested. Dipping time could be reduced to 1 minute without reducing effectiveness (Table 1).

Postharvest Fruit Rot of Banana Caused by *Colletotrichum musae* (Berg.& Curt.) Arx. and Its Control

Todsaporn Tongthieng and Somsiri Sangchote*

COLLETOTRICHUM musae (Berk & Curt) Arx. is the causal organism of anthracnose, crown rot, and fruit rot of bananas during storage and transportation. It can invade the fruits and form latent infections on unripe fruit and survive as dormant mycelium. Many postharvest chemicals have been used to control this disease, including thiabendazole, benomyl, thiophanate-methyl, and prochloraz. Shelf life of treated bananas can be extended by packing in polyethylene bags with ethylene absorbent in cold storage. This paper reports studies on anthracnose disease on banana and control measures for long-term storage.

Experiment 1. Investigation of anthracnose on bananas from different producing areas. Mature-green bananas (25 hands/location) were collected from different producing areas including Nakhon Pathom, Nonthaburi, Pathum Tbani, and Ratchaburi. The fruit were ripened at room temperature. Disease incidence and severity were checked at ripening.

Experiment 2. Relationship between the disease severity, respiration and ethylene production of banana fruits. Twenty-four bananas were used in this experiment. Twelve were inoculated with *C. musae* using a conidial suspension prepared from a 7-day-old culture at a concentration of 10^4 spore/mL. The other 12 fruit were not inoculated. All fruits were placed in jars (3 fruits/jar) connected to an airflow system. Ethylene and carbon dioxide production were sampled each day until the fruit were ripe. Ethylene was measured by gas chromatography with a flame ionisation detector and carbon dioxide using gas chromatography with a thermal conductivity detector. The amounts of ethylene and carbon dioxide were converted to rate of respiration (mL CO_2/kg/hour) and ethylene production (mL/kg/hour). They were plotted against the disease severity to show their relationship.

Experiment 3. Evaluation of chemical for postharvest dips. Mature-green bananas were inoculated with *C. musae* at the concentration of 10^4 spores/mL and incubated in the moist chamber for 24 hours. The inoculated fruit were then dipped in chemicals including benomyl, imazalil, prochloraz, thiabendazole, and thiophanate-methyl at concentrations of 0, 250, 500, and 750 ppm for 3 mins, using 6 hands/treatment. The fruit were ripened at room temperature. Disease incidence and severity were checked at ripening.

Experiment 4. Control measure for long-term storage. The experiments were divided into two portions. (a) Thirty hands of mature-green banana were harvested, cleaned, and hydrocooled. Half of them (15 hands) were dipped in test chemicals and the other half in water for 3 mins, then packed in plastic bags (5 hands/bag) with an ethylene absorbent. They were further packed in cartons and stored at 15°C. (b) Forty-five hands of mature-green bananas were harvested, cleaned, and hydrocooled. Thirty hands were inoculated with a spore suspension of *C. musae* at a concentration of 10^4 spores/mL, and incubated in a moist chamber for 24 hours. The other 15 hands were sprayed with water and incubated in the same way. After 24 hours, 15 hands were dipped in the test chemicals and the other 15 in water for 3 mins. All bananas were packed in plastic bags (5 hands/bag) with an ethylene absorbent. They were further packed in cartons and stored at 15°C for 1 month.

Results

Investigation of anthracnose on banana from different producing areas. Bananas collected from different producing areas showed different percentages of disease incidence. Anthracnose appeared as the fruit started to ripen. Disease incidence on bananas from Nonthaburi, Nakhon Pathom, Ratchaburi, and Pathum Thani were 87.2, 83.0, 78.0, and 77.0%, respectively. Disease severity on bananas from Pathum Thani was the highest at 21.7%. Isolates of *C. musae* from these areas were similar in their morphological characteristics.

Relationship between the disease severity, respiration, and ethylene production of banana fruits. Diseased fruit produced higher amounts of carbon dioxide and ethylene than healthy fruit. Carbon dioxide production of diseased fruit reached the climacteric peak on the third day of the experiment at 94.35 mL CO_2/kg/hour, but on healthy fruit peak production was 84.44 mL CO_2/kg/hour on the fifth day. Ethylene production by the diseased fruit was also higher than for the healthy. They reached the climacteric peak on the third day at

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67.42 mL/kg/hour while for healthy fruit peak production was 58.43 mL/kg/hour on the fourth day of the experiment.

Evaluation of chemicals for postharvest dips. Imazalil 500 ppm was the most effective chemical. It completely controlled anthracnose on bananas, while disease incidence on the untreated fruit was 52.2%.

Control measures for long-term storage. After storage at 15°C for 30 days, the untreated inoculated fruit had begun to develop disease symptoms, while the other groups were unblemished. All fruit were ripened at room temperature for 6 days. Disease incidence on the fruit packed immediately after precooling, and on fruit inoculated after precooling, were 6.3% and 45.5%, respectively. Fruit treated with imazalil showed no disease symptoms (Table 1).

Table 1. Effectiveness of imazalil at 250 ppm (3 minute dip) in controlling anthracnose of banana after storage at 15°C for 30 days.

Treatments	Disease incidence (%)
Untreated fruit	6.3b*
Dipped in imazalil at 250 ppm. for 3 mins.	0.0c
Fruit left at room temperature for 24 hours, then dipped with imazalil at 250 ppm for 3 mins.	0.0c
Fruits inoculated with *C. musae*, incubated in a moist chamber for 24 hours, then dipped in water for 3 mins.	45.5a
Fruits inoculated with *C. musae*, incubated in a moist chamber for 24 hours, then dipped in imazalil at 250 ppm for 3 mins.	0.0c

* Means followed by the same letter are not significantly different at 5% level by DMRT.

Application of *Candida guilliermondii* in Commercial Citrus Waxes for Biocontrol of *Penicillium* on Grapefruit

R.G. McGuire*

COMMERCIAL processing of fruits may alter surface microflora at the same time that it increases susceptibility to disease through injury (Lim and Khor 1982). This is especially true with quarantine treatments that seek to eradicate insect pests from within fruits with heat or chemicals. Although such treatments may concomitantly reduce the numbers of decay pathogens, they stress the fruits. Treatment with forced air at 46–48°C over 3–5 hours for disinfestation of Caribbean fruit fly [*Anastrepha suspensa* (Loew)] is tolerated by grapefruits (*Citrus paradisi* Macf.); treated fruits, however, are often more susceptible to attack by *Penicillium digitatum* and *P. italicum*, especially later in the season (McGuire 1991). The yeast, *Candida guilliermondii*, antagonises the development of *Penicillium* on grapefruits (Chalutz and Wilson 1990). Research reported here has sought to test the efficacy of using this yeast to control *Penicillium* decay on grapefruits after hot-air treatment. An important consideration has been how the yeast might be applied commercially.

Materials and Methods

Strain US-7 of *Candida guilliermondii* (NRRL Y-18314), which was originally isolated from the surface of a lemon [*Citrus limon* (L.) Burm. f.] fruit in Florida by Wilson and Chalutz (1989), was used throughout these trials. The short-term survival of this strain in various citrus fruit coatings was measured by mixing the yeast, in 1 mL of water at a concentration of 5×10^5 cfu/mL, with 4 mL of undiluted fruit coating. Coatings included FMC 214, FMC 223, and FMC 705 (FMC Corp., Lakeland, FL), Decco Citrus Lustr® 402 (Atochem N. America, Monrovia, CA), and Nature Seal™, an experimental USDA coating (Table 1). Mixing the yeast with 4 mL of 0.1 M phosphate buffer (pH 6.8) supplemented with 0.1% peptone served as a control upon which to base percentage recovery. Besides an initial sampling immediately after the yeast was introduced into a coating or the buffer, dilutions were cultured at 10, 20, 30, 45 and 60 minutes on malt yeast extract agar supplemented with streptomycin, cephalexin, and Bravo® (MYEA-scb) at 40, 50, and 20 mg/L (a.i.), respectively. In a subsequent test that evaluated long-term survival, yeast suspensions in water were added to the 0.1 M peptone/phosphate buffer or fruit coatings (thus diluted to 80% of full strength) to concentrations of either 5×10^5 or 5×10^7 cfu/mL, and 0.1 mL of a coating suspension was applied to 4.25 cm disks of Whatman® No. 1 filter paper. The papers were stored at 13°C for 2 months. Each week two papers from each treatment were washed for 30 minutes, each in 10 mL of peptone/phosphate buffer, and dilutions of 0.1 mL were plated onto MYEA-scb. Tests of short- and long-term recovery from fruit coatings were each conducted three times.

Table 1. pH and major constituents of various fruit coatings applied to grapefruit postharvest.

Coating	pH	Major constituents
FMC 214	6.5	Water, alkali-soluble resins, food grade surfactants
FMC 223	7.0	Water, alkali-soluble resins, food grade surfactants, oleic acid, propylene glycol, NH_4OH
FMC 705	11.0	Water, petroleum wax, polyethylene, anionic and non-ionic surfactants, KOH
Decco 402	7.5	Water, alkali-soluble resins, fatty acid soaps, propylene glycol
Nature Seal	6.0	Water, methylcellulose, emulsifier, plasticiser

Early, middle, and late season 'Marsh' white grapefruits were obtained throughout the 1991–1992 growing season from a packinghouse in central Florida. Except for grading, fruits were unprocessed and were obtained within 24 hours of harvest. Because fruits from many growers were received in a mixture from the packer at each harvest date, replication within each harvest was not possible; the one early, two middle, and one late season harvests, however, constituted four replications over the season. Fruits were initially washed then separated into one of three subsets comprising the fruit coatings FMC 223, FMC 705, and Nature Seal. Four treatments within each coating compared control fruits

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not heated by quarantine protocol and not inoculated with the yeast, control fruits heated but not inoculated, and heated fruits subsequently inoculated with *C. guilliermondii* at calculated rates of 10^4 or 10^6 cfu/cm^2 of fruit surface. Each treatment consisted of 72 fruits.

Except for controls that were not heated, fruits were placed into plastic bins that were stacked within a hot air chamber (Sharp et al. 1991), and air at 48°C (58–90% relative humidity) was forced through the column of fruits at an average of 0.4 m^3/second for 3 hours. Because late season fruits are more susceptible to heat damage, however, fruits harvested in April were treated at 47°C. After heating was completed, fruits were allowed to cool to 25°C, then coatings with and without *C. guilliermondii* were applied by dipping fingers into the suspension and spreading this over individual fruits. Coatings were at 80% of their undiluted strength after addition of the yeast suspension or addition of sterile water in the case of control fruits. Fruits were then placed into storage at 13°C for 2 months. During this time, fruits were examined weekly, and those showing signs of decay were discarded. Two fruits lacking signs of decay were sampled weekly by washing each for 1 hour in 100 mL of peptone/phosphate buffer within quart-size plastic freezer bags. One-tenth mL dilutions of the wash were cultured on MYEA-scb, and after 5 days at 24°C all yeast colonies were counted. Individual colony counts were then referenced to the surface areas of the washed fruits calculated from their diameters.

Results

The recovery of *C. guilliermondii* was dependent upon the fruit coating into which it was mixed (Fig. 1). Survival was greatest in Nature Seal, an emulsion primarily of methylcellulose, and averaged over 80% after 60 minutes. Recovery from the waxes FMC 214 and FMC 705 was also satisfactory, averaging 70 and 55%, respectively. Constituents of FMC 223 and Decco 402, however, quickly killed most yeast cells.

When stored on filter papers as suspensions in the dried fruit coatings, or in dried buffered peptone, populations of *C. guilliermondii* initially declined then either stabilised or appeared to rebound (Fig. 2). After 60 days, whether applied at 5×10^4 or 5×10^6 cfu/filter, recovery was about equal, but again dependent upon the coating. Recovery from Nature Seal remained between 10^4 and 10^5 cfu/filter during the last month, similar to that in the dried buffered peptone. In the waxes FMC 223 and FMC 705, recovery ranged from 10^2 to 10^3 cfu/filter during this period.

Treatment with hot air and applications of *C. guilliermondii* significantly ($P \leq 0.0001$) affected the recovery of yeasts from grapefruit. Populations of native yeasts on control grapefruits before hot-air treatment averaged 3×10^2 cfu/cm^2 but declined to 2×10^1/cm^2 after treatment at 48°C (Fig. 3). These native populations thereafter recovered, often to levels as high as those that developed on unheated control fruits but, overall, heat significantly ($P = 0.06$) delayed population development. Applications of *C. guilliermondii* significantly ($P \leq 0.0001$) increased the numbers of yeasts recovered, with specific coatings determining the ultimate population levels. FMC 223 was more toxic to yeast cells in suspension than were FMC 705 and Nature Seal. Populations on fruits coated with FMC 223 therefore developed from a small number of survivors to a level approximately one tenth that on the other two coatings, the population development on which was not significantly different.

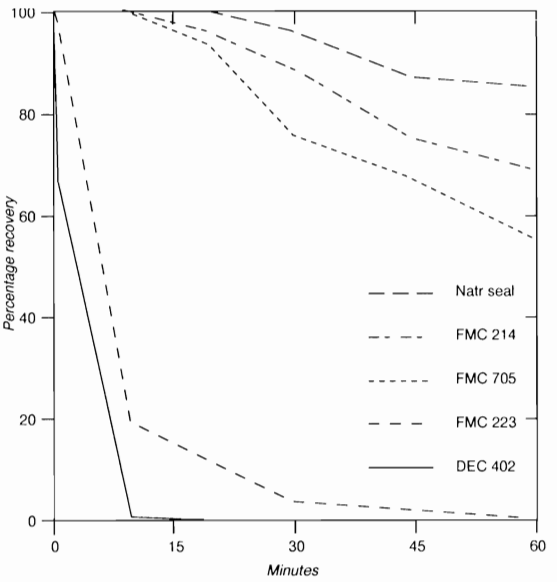

Figure 1. Recovery of *Candida guilliermondii* when mixed at a final concentration of 10^5 cfu/mL with various fruit coatings. Means of 3 tests.

Hot-air treatment of grapefruits significantly ($P \leq 0.0001$) accelerated their decay in cold storage regardless of which fruit coating was applied (Table 2). The shelf life of unheated control fruit surpassed the 60-day storage period of the experiment, whereas heated fruits averaged only 43 to 51 days before they needed to be discarded. Applications of *C. guilliermondii* generally prolonged shelf life ($P = 0.005$), but the rate of application, whether at 10^4 or 10^6 cfu/cm^2, was not a significant factor. By applying this yeast to grapefruits, however, shelf life was increased from 5 to 11 days or by 12–20%. Shelf life was affected by the type of fruit coating ($P \leq 0.05$); Nature Seal prolonged storage relative to FMC 223, but other comparisons were not significant.

Table 2. Shelf life of grapefruits comparing hot-air treatment and surface applications of *Candida guilliermondii* in the citrus coatings FMC 705, FMC 223, and Nature Seal.

Treatment		Citrus coating			Mean
Heat	Yeast	FMC 705	FMC 223	Nature Seal	
		Number of days to decay[a]			
None	None	67.21 a	65.63 a	64.56 a	65.80 a
Heat	None	43.74 b	44.19 b	50.92 b	46.28 c
Heat	10^4 cfu/cm^2	50.67 ab	50.66 ab	56.73 b	52.68 b
Heat	10^6 cfu/cm^2	54.71 ab	49.50 ab	57.40 ab	53.87 b

[a] Within columns, means followed by the same letter are not significantly different at P = 0.05 according to separation by LSD (least significant difference). Means of 200 fruits (600 fruits in 'Mean' column).

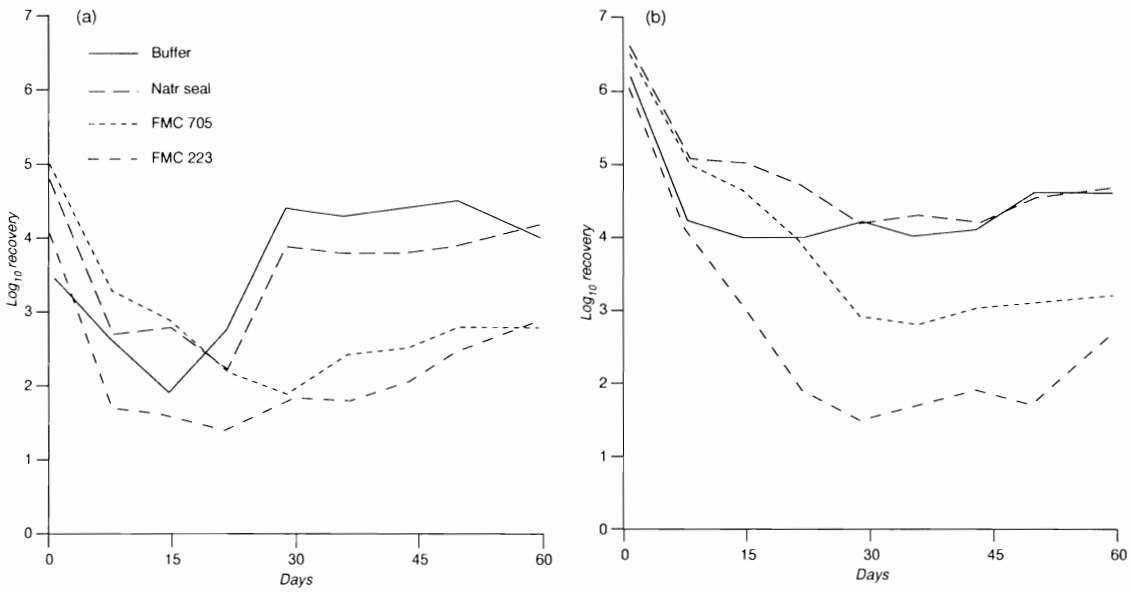

Figure 2. Recovery of the *Candida guilliermondii* from storage at 13°C when applied in various fruit coatings to filter paper disks at either 5×10^4 (a) or 5×10^6 (b) cfu/filter. Means of 3 tests.

Discussion

One way that processed fruits may be predisposed to decay is through alteration of their surface microflora. Antagonists may be restored, but to be commercially acceptable, the application of a biocontrol agent must be compatible with packinghouse operations. Citrus fruits normally go through a waxing step, and this could be an ideal stage for application of an antagonist (Pusey et al. 1986). Waxes are already available that are compatible with *C. guilliermondii*, and other coatings, based perhaps upon derivatives of cellulose or another carbohydrate, can be developed to enhance its growth.

C. guilliermondii has advantages for use as a biocontrol agent over some bacterial species. This and many other yeasts can better survive adversity because they grow over a wide range of temperatures in extremely varied osmotic environments (Magan and Lacey 1986); they also utilise a large array of carbohydrates and organic acids (McLaughlin et al. 1990). Osmotolerance and the ability to subsist on nutrients available in the dried buffered peptone and fruit coatings may explain the yeast's survival on coated filter papers. A residual survival and an ability to subsist on a broad range of nutrients may also explain how native populations on heated fruits can rebound. The application of *C. guilliermondii* in a fruit coating that fosters its growth holds promise as a commercially acceptable method for biological control of postharvest pathogens of citrus fruits.

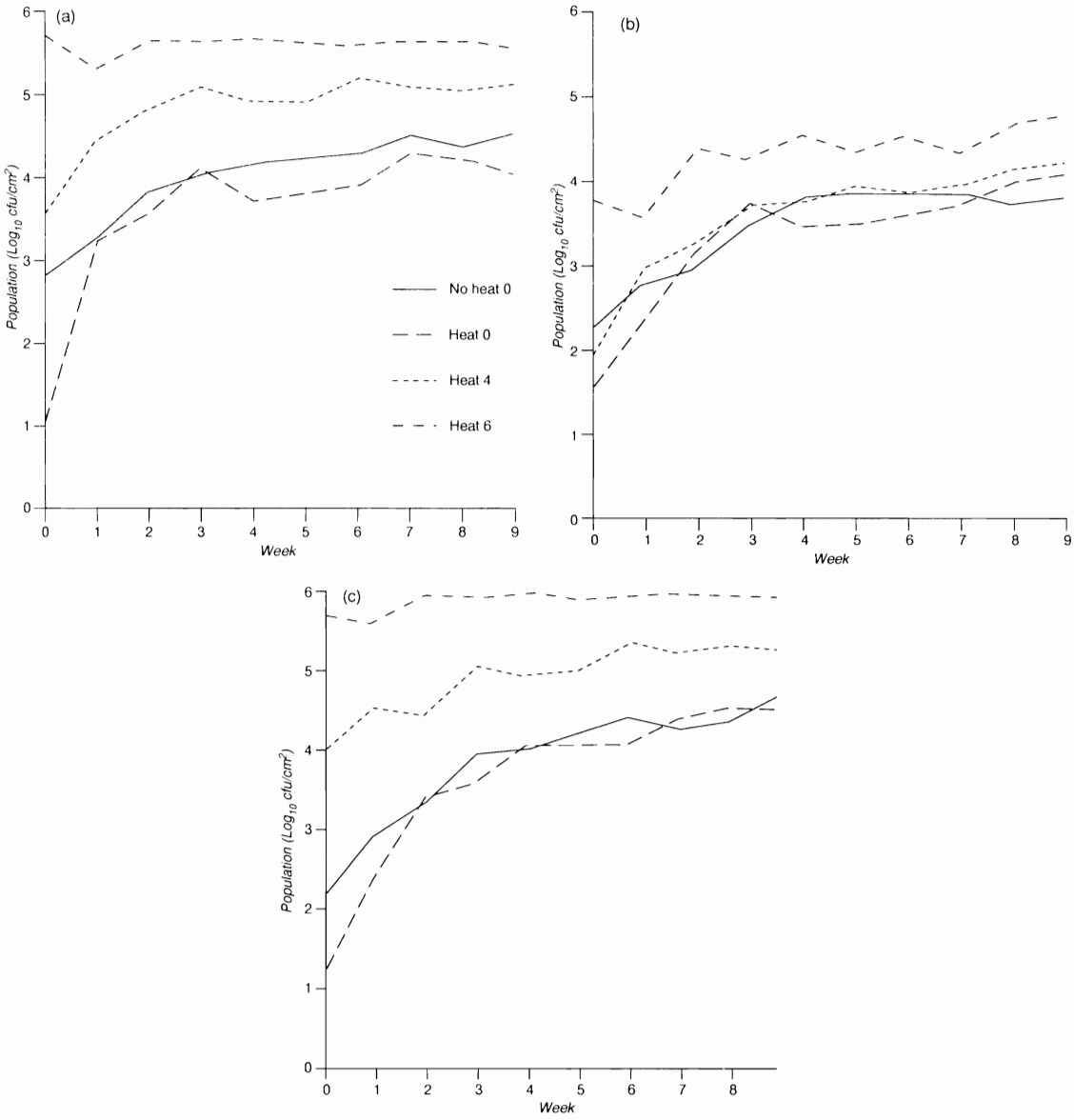

Figure 3. Development of populations of *Candida guilliermondii* on the surfaces of unheated and heated grapefruits that had been coated with FMC 705 (a), FMC 223 (b), or Nature Seal (c). Native populations (No heat 0, Heat 0) on control fruits are compared with applications of the yeast in the waxes to deliver 10^4 (Heat 4) or 10^6 (Heat 6) cfu/cm^2. Means of 4 tests.

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Phomopsis Fruit Rot of Mango and Its Control

C. Boonraung, U. Farungsang, and Somsiri Sangchote*

Phomopsis mangiferae Ahmed. causes stem-end rot on mangoes. Other stem-end rot pathogens of mangoes can be controlled by heat, and chemical treatments such as benomyl. Dipping mangoes in hot water at 53°C for 10 minutes controlled anthracnose and stem-end rot effectively. Hot benomyl (0.05%, 50°C) was reported as an effective control measure of *P. mangiferae* for 2 weeks. In this study, the biology of *P. mangiferae* and the modification of available control treatments for other stem-end rot pathogens were evaluated.

Experiment 1: Isolates of P. mangiferae *from different production areas.* Mature-green mango fruits were harvested from different producing areas, including Chachoengsao, Nakhon Pathom, and Ratchaburi. The fruit were packed in cartons, 12 fruit per carton, and ripened at 25°C. At ripening, the fruit were checked for Phomopsis stem-end rot incidence. Diseased fruit were isolated for the causal organism by the tissue transplanting method. Isolates of *P. mangiferae* were tested on their virulence on mangoes cv. Nam Dorkmai by stem-end inoculation. The disease severity was checked at ripening. The most virulent isolate was selected for further study.

Experiment 2: Cultivar susceptibility. Four cultivars of mango — Okrong, Kaew, Nang Klamgwan, and Nam Dorkmai — were tested for their susceptibility to *P. mangiferae.* Fruit of each cultivar were inoculated at the stem end and incubated at 25°C. The disease severity was checked at ripening.

Experiment 3: Pathogenicity on the other fruits. Four kinds of fruit — papaya, guava, banana, and rambutan — were tested for their susceptibility to *P. mangiferae.* The fruit were inoculated and incubated as described above. The disease incidence was checked at ripening.

Experiment 4: Control measures. Mangoes cv. Nam Dorkmai were inoculated with *P. mangiferae* and incubated in a moist chamber for 14 hours. The fruits were then dipped in one of five chemicals — carbendazim, dithainon, imazalil, prochloraz, or mycobutanil — at a concentration of 750 ppm for 5 minutes for comparison with dipping in hot water at 53°C for 5 minutes. The treated fruit were ripened at room temperature. Percentage disease incidence was checked at the ripening.

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Results

Isolates of P. mangiferae *from different producing areas.* Mangoes from different producing areas showed different percentages of disease incidence. The highest disease incidence was found on mangoes from Nakhon Pathom. The isolates of *P. mangiferae* from these areas were similar in their morphological characteristics. There were no differences in the severity of disease caused by the different isolates, the isolate from Chachoengsao tended to be the most aggressive.

Cultivar susceptibility. The four cultivars showed some differences in their susceptibility to *P.mangiferae.* Mango cv. Kaew was the most susceptible, while cv. Nam Dorkmai was the least.

Pathogenicity on the other fruits. Banana, papaya, guava, and rambutan were infected by *P.mangiferae.* It infected at the wounded part of the fruit, fruit rot resulted. Rambutan was the most susceptible to this fungus.

Control measures. Dipping inoculated fruit in carbendazim, dithainon, imazalil, prochloraz, or mycobutanil (750 ppm), or hot water (53°C), and incubating for 14 hours, showed that all of these treatments could control the disease (Table 1).

Table 1. Percent unaffected area on mangoes cv. Nain Dorkmai after inoculating with *P.mangiferae* and dipping in different treatments for 5 minutes and ripening at room temperature.

Treatment	Area of fruit unaffected (%)
Carbendazim 750 ppm	99.5a
Dithainon 750 ppm	98.2a
Imazalil 750 ppm	98.1a
Mycobutanil 750 ppm	98.5a
Prochloraz 750 ppm	97.8a
Hot water at 53°C	99.8a
Water at room temperature	88.4b

Means followed by the same letter are not significantly different at 5% level by DMRT.

Management of 'Jelly-Seed' in Mango (*Mangifera indica* L.) cv. Tommy Atkins

David Mayne, V. Vithanage, and J.H. Aylward*

Abstract

'Jelly-seed' is a characteristic breakdown in the flesh of ripening mangoes starting from around the seed and progressing towards the surface of the fruit, causing it to develop an offensive taste and smell. This is a postharvest problem which starts at the preharvest stage. Until the last stages of this flesh breakdown, the affected fruit maintains a normal external appearance. A number of cultivars such as Tommy Atkins, Sensation, Kent, and Van Dyke are susceptible to this disorder and it is a worldwide problem whenever mangoes are grown. The cause of jelly-seed is unknown. Although a number of hypotheses based on harvest time, fungal, and nutritional aspects, have been put forward to explain this disorder, none of these has been experimentally proven. We believe that jelly-seed may be caused by a number of factors, one of which may be genetic. In our quest to find a management tool for this disorder, we investigated the effect of flowering time on jelly-seed incidence. Our results show that delaying the flowering can significantly reduce the incidence of jelly-seed in Tommy Atkins mango. The methods we developed to delay the flowering time and the significance of these results will be discussed.

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Session Summaries — Contributed Poster Papers

Overview Issues — Maturity Assessment — Postharvest Diseases and Disorders

Chairman: Dr Peter Hofman, Queensland Department of Primary Industries, Australia
Rapporteur: Dr Grantley Chaplin, Horticultural Consultant, Australia

Overview Issues

Dr Farooqi described a series of postharvest studies conducted on tropical fruit in Pakistan. These included low temperature waxing and chemicals, as well as disease control and packaging.

Interesting information on the potential for cultivation and processing of tropical fruits in Papua New Guinea was presented by Dr Ihekoronye and Mr Levi.

The need for careful quality control and detailed information about tropical fruits exported to temperate areas was emphasised by Professor Roy.

Maturity Assessment

Dr Blumenfeld carefully defined the various physiological stages of avocado — a major export crop of Israel. Special attention was given to the relationship of oil, dry matter, and taste to develop an objective maturity index.

Similarly, Dr Shanthi described maturity studies on Sri Lankan Ambul bananas. Professor Onnop and colleagues have established correlations between the physicochemical measurements and eating quality of various longan cultivars in Thailand.

Postharvest Diseases and Disorders

Mr Cooke analysed the relative effects of weather and packing-house operations on final quality of ripe Australian mangoes, rain at harvest being deleterious.

Time of flowering was shown by Mr Mayne to influence incidence and severity of 'jelly-seed' in Tommy Atkins in Australia and speculated that pollen 'quality' may be a factor.

Dr Richter showed how physical damage and storage temperature and chemical treatments influences the development of sour rot of imported citrus in Germany.

'Semperfresh' was investigated as an alternative to refrigeration on several fruit species by Mr Negoni in Zimbabwe. Benefits were found in only some cultivars.

Dr Hardjo investigated disease-control treatments for Indonesian mangoes to determine optimal treatment conditions. Dr Sepiah investigated disease control in a new papaya cultivar in Malaysia by assessing several chemicals in plate and fruit treatment studies.

Freckle disease has become widespread on most banana cultivars in Sri Lanka and export opportunities are thereby limited. Professor Nimol showed that improved cultural practices reduced the disease and also increased fruit yield.

Miss Ubol studied the internal CO_2 and C_2H_4 atmosphere of pre- and postharvest avocados by a new equilibration technique to monitor ripening of wrapped and unwrapped fruit. The method was simple, non- destructive, and gave consistent results.

Dr McGuire's poster was read by Dr Champ: a yeast antagonistic to *Penicillium*, applied to grapefruit in commercial waxes was found to extend storage life of fruit by up to 20%.

General discussion on hot-water treatments indicated that treatment definition, equipment, and actual treatment conditions require special attention, as does commercial appreciation of recommended treatments. It was noted that pulp and/or peel temperatures are the important factors in treatment efficacy rather than water temperature.

Mango ripening disorders are a continuing source of interest and speculation.

Storage and Ripening*

Chairman: Dr Alex Buchanan, Editor, ASEAN Food Journal
Rapporteur: Dr Lindy Coates, Queensland Department of Primary Industries, Australia

NINE poster-papers relating to the storage and ripening of tropical fruit were presented in this session.

Mr Kouno from Japan described an online device to detect hollowness and measure ripeness of watermelons by acoustic impulse responses. The device provides an alternative to the traditional slapping method for detecting hollow or overripe watermelons. The signal produced from tapping the fruit is assessed using a wave-analysing device. Fruit maturity can be related to the frequency of the signal produced.

Mr Kouno also reported on a feasibility study conducted into the use of near infrared (NIR) spectroscopy for measuring internal quality of pineapples and mangoes. It was found that the sugar content of fruit could be adequately correlated with NIR reflectance properties.

Dr Kadiyala from India reported on the distribution of minerals in Alphonso mangoes during ripening. This was correlated to internal breakdown ('spongy' tissue) in the mesocarp. Calcium, phosphorus, and potassium levels varied throughout the peel and flesh of fruit. It was found that 'spongy' tissue was low in calcium and high in potassium.

Dr Kadiyala also described the effect of calcium on the physicochemical changes in Alphonso mangoes during ripening. Calcium chloride was applied as either a preharvest spray or by postharvest vacuum infiltration. Calcium-treated fruit showed delayed ripening, although some internal fruit breakdown did result from the treatments.

Several papers dealt with low-temperature storage of tropical fruits.

Ms Yon from Malaysia reported on the effects of low temperatures on the storage life and quality of carambola/starfruit (cultivar B_{17}). Fruit storage life was dependent on both fruit maturity and storage temperature. Mature fruit had a longer storage life than immature fruit. Fruit held at 5 or 10°C had a storage life of up to 4 weeks, whereas fruit held at 15 or 20°C could be held for only 1 week.

Dr Mahendra from Indonesia presented the results of a study on the incidence of chilling injury in salak ('snake') fruit. He concluded that low temperatures (3–5°C and 7–10°C) extended storage life by up to 15 days, but the treatments caused chilling injury.

Mr Gomolmanee from Thailand reported on the use of sulfur dioxide fumigation to reduce chilling injury symptoms in longan fruit stored at temperatures of –25°C to 2.5°C. Chilling injury, which occurred in unfumigated fruit, was observed as dark brown discoloration of the fruit peel. The peel of fumigated fruit remained yellow-brown. Ion leakage from the peel could be used to indicate the chilling injury symptom.

Mr La-Ongsri from Thailand presented two papers on chilling injury in lychee. As in the

* Contributed poster papers on 'Storage and Ripening' were presented over two sessions in the conference program.

previous paper, chilling injury could be related to ion leakage from the peel. Chilling injury occurred in fruit stored at 0 and 2.5°C, but not in fruit stored at 5°C. The symptoms of chilling injury could be alleviated by fumigating fruit with sulfur dioxide followed by an acid dip.

Disinfestation and Primary Processing — Storage and Ripening

Chairman: Dr Onnop Wara-Aswapati, Suranaree University of Technology, Thailand
Rapporteur: Dr Wasim A. Farooqi, Nuclear Institute for Agriculture and Biology, Pakistan

SEVENTEEN presentations were made in this session. The first paper, from Mr Chen, outlined the general status of horticultural crops in the Jiangmen region of Guangdong Province, China, giving details of area, production, handling, and processing, with particular reference to quarantine. The second presentation was from Dr M.M. Saleh (Malaysia), who explained the fruit fly problem and disinfestation research in Malaysia. Professor Paull (USA) then spoke on the 'Insect quarantine treatments and fruit ripening'. The importance of the quarantine treatment on fruit was discussed, including the side-effect of fruit ripening. Since quarantine treatment is mandatory, however, treatment must be adjusted so that accelerated ripening of fruit does not create a problem in fruit marketing.

Dr Sharp (USA) discussed the use of microwaves as a quarantine treatment to disinfest commodities of pests. She noted that microwaves were a safe postharvest treatment without health hazard. Hot water and cold treatments to control fruit flies were also discussed and compared. In cold storage methodology, the possibility of chilling-injury to the fruit was also highlighted. Mrs Yuniarti of Indonesia then described experimental work on the effect of pH and sugar content on apple cider quality. Dr Wuryani of Indonesia made a presentation on the osmotic dehydration of membrane-coated pineapple. In this paper, the benefits of this experimental work on this process in pineapple were described and discussed.

Mr Seberry of Australia described the effects of plantation and postharvest factors on shelf life of 'Williams' banana. The use of calcium carbide in ripening was also explained, as well as environmental (ecosystem) factors that influence the quality of fruit. Bananas from Queensland and northern NSW of the same variety grown under different conditions behaved differently, particularly as regards postharvest chilling sensitivity. The fruit from Queensland (comparatively warmer climate) were more sensitive to chilling than those grown in NSW.

Next presentation in this session was from Dr Acedo from the Philippines, who spoke about the optimisation of indigenous ripening systems for bananas in the Philippines.

Professor Mizrahi of Israel explained the productivity and postharvest behaviour of black sapote (black persimmon) grown in the Israeli Negev Desert. Experimental work carried out on this fruit was described and discussed. Professor Imungi then spoke on storage and ripening of Kenyan bananas. He noted that fibrous and non-fibrous varieties of mangoes were grown in Kenya. Those mango varieties which contained fibres (thread-like structures in the pulp) were consumed locally, while non-fibrous mango varieties were exported.

The next speaker was from Malaysia. Mr Karim explained his work on the storage behaviour of sapodilla. Following storage at various temperatures (10, 15, and 20°C), the quality of the fruit was assessed.

Dr T. Akinga from Japan described fundamental studies on the respiratory properties of some tropical fruits grown in Okinawa. He said the cost of an infrared gas analyser (IRGA) for estimating respiration was so high that not all laboratories or institutions involved in such studies could afford to buy one. He had therefore investigated the chemical estimation of gas (CO_2) released by the fruit and had found this method to be suitable and significantly cheaper.

Professor S. Ben-Yehoshua of Israel, in his presentation, described the methodology of reducing decay and thus extending shelf life of bell-pepper and mango fruits by modified atmosphere (MA) packaging. He mentioned that this technique works and has beneficial effects. Perforation in the polyethylene packaging was found more effective for better storage and even ripening of fruit. Dr S. Wilson Wijaratnam of Sri Lanka presented a paper on the modified atmosphere storage of bananas at chilling temperatures, describing some of the research done in this area. The use of MAs reduces the risk of incidence of physiological disorder (chilling injury) to banana fruit.

Dr Jingtair Siriphanich of Thailand spoke about the factors that influence the ripening of 'Chance' and 'Monthong' durians. The experimental work carried out in his laboratory was explained and discussed. The next presentation was from Professor A.K. Thompson of U.K. regarding storage of fresh pineapples. He explained the possible use of modified and controlled atmospheres, as well as hypobaric storage technology for the conservation of fresh fruit. The economics of some of the techniques, such as hypobaric storage, is a limiting factor at present.

The last speaker of this part of the session was Dr Benzioni of Israel. She spoke on the effects of ethylene application on fruit postharvest characteristics of the kiwano (*Cucumis metuliferus*). Ethylene application helps to obtain an even colour and accelerates ripening for uniform supply.

Conclusion

The presentations made in this session highlighted the important problems of fruit production, handling, storage, and distribution, i.e. disinfestation, processing, storage, and ripening. Disinfestation of fruit by the use of fumigants (chemical) or even in some cases low-level gamma irradiation (~ 200 Gy) is necessary when quarantine regulations require it. While using disinfestation techniques there is always a risk of side-effects such as accelerated ripening or even skin-injury as, for example, by ethylene dibromide fumigation in the past. Similarly, the availability of appropriate storage facilities, especially in the developing countries of Asia, is an important consideration. The positive effects of MA and CA storage were discussed. This type of storage, as well as extending shelf life, significantly reduces the possibility of chilling injury to the fruit. There is a need for more research on CA and hypobaric storage of tropical fruit.

It is the responsibility of the scientific community to do research on postharvest aspects of fruit so as to develop a 'technology' which is cheap, technically feasible, and acceptable to the consumers, and offer it to the growers and traders so that everyone receives the benefits of the research.

Workshop Reports

Controlled Atmospheres/Modified Atmospheres

Conveners: Adel Kader and Daryl Joyce

Conclusions and Recommendations

1. CA/MA must be considered as a supplement to (not a substitute for) maintenance of optimum ranges of temperature and relative humidity for extending postharvest life and retaining good quality of fruits.

2. Successful application of CA/MA technologies will depend upon minimising/avoiding stresses caused by physical damage, high temperatures, low temperatures (chilling injury), water, and ethylene. Effective control of postharvest diseases [using an IPM (integrated pest management) approach, including heat treatments, fungicides, and/or fungistatic levels of CO_2] is essential to maximising the benefits of CA/MA.

3. Use of CA during transport vs use of MA packaging depends on value of the commodity, length of postharvest life desired, and comparative cost, including environmental impact.

4. Even under the best CA/MA conditions, postharvest life of most tropical fruits will likely be limited to 2–6 weeks for transport and/or temporary storage at 10–16°C (depending on commodity and variety) plus 3–10 days of subsequent ripening (if needed), distribution, and keeping at the consumer's home. This will permit use of sea transport instead of air transport.

5. Research is needed to identify the optimum CA/MA conditions for intact and lightly-processed tropical fruits, especially those for which little or no information is available. The potential for fungistatic and insecticidal CA should be examined. The cost–benefit ratio of CA/MA and of ethylene removal merits evaluation.

6. CA/MA is very promising for lightly-processed fruits and should be evaluated for tropical fruits, including microbial safety considerations.

7. Research on CA/MA requires specialised facilities for gas mixing and analysis costing US$100 000 or more. Thus, it would be advisable to select one research centre in each country to focus on this research area.

Postharvest Physiology

Conveners: Robert Paull and Connie Lizada

THE attempt was to project future physiology research directions without reference to a specific crop. The directions can be grouped in various ways, all having difficulty associated with the importance of a crop to a region, and length of time needed to develop information or resources. This difficulty precluded us from placing the various research areas in priority order. For ease of presentation two research areas can be used to group the topics considered.

A. Information and Technology Development

The areas falling under this topic were germplasm resources specifically related to postharvest characteristics. This overlays with molecular biology, preharvest factors influencing postharvest response, water relations of tropical fruit, physiology of the plant response to disease, control of ripening, cause of postharvest disorders, including responses to heat and cold, physiology of minimally processed fruit, controlled and modified atmospheres, and development of non-destructive maturity indices.

B. Applied Research and Information Gathering

This is taken strictly from a plant physiology perspective. An area that would enable the transfer of physiology data to the commercial sector is the development of baseline data on tropical fruit. This would include respiration and ethylene production rates, temporal patterns of respiration and ethylene production rates, response to ethylene at all stages of handling at very low and ripening induction levels, and time–temperature responses to cold and heat. The crop–time parameter matrix would be useful not only for research to appreciate the gaps in our knowledge but also to those involved in commercial handling.

A worldwide network of individuals directly involved in tropical fruit postharvest research may take as a prime objective the development of such a tropical fruit crop physiology–knowledge matrix. This network does not necessarily have to be formal or permanent. A small ad-hoc group with key members from different tropical regions of the world may be more effective.

Disinfestation

Conveners: Nathan Ganapathi and Peter Hofman

THE working group on disinfestation felt that harmonisation should be achieved locally (within the country) as well as internationally (between countries). It also agreed that a generic approach to disinfestation could in the long run standardise disinfestation treatments. (Generic approach refers to grouping pests and diseases into groups, e.g. genera/species of fruit flies.)

The definition of disinfestation must be spelt out clearly, e.g.

- The old definition or concept in relation to fruit fly disinfestation would be expecting 100% mortality — zero tolerance — no live larvae.
- The other definition that needs to be considered would be in relation to irradiation — live larvae but nil capacity to multiply. Could we consider probit 9 emergence based on sterility or probit 9 emergence based on total mortality of larvae.
- One of the problems encountered in irradiated commodity is that there is no clear-cut way to determine if the larvae have been irradiated.

A systems approach is needed to ensure tested commodity has nil or very low infestation levels. More information will be required for this.

Disinfestation can be divided into two major areas:

- preharvest, where not much information is available; and
- postharvest which is generally associated with plant quarantine treatments.

It was decided that two approaches are possible, one practical, the second idealistic.

For a generic approach to disinfestation the following must be determined. Disinfestation of: naked insects; insects in fruits; and fruits alone.

The concept of generic approach will have to look at the range of doses in relation to the pests and the commodity.

There is a need to build up or collate a database on the tolerance range of fruit flies to heat and cold.

One question that was raised was 'Can physiological tolerance of insects be grouped?'

The working group also emphasised the fact that as far as possible there needs to be standardisation of rearing media and facilities used.

In relation to protocols, an understanding has to be reached as to what probit levels we are aiming at.

Toxicological studies and end-point mortality will also have to be considered.

The pest risk analysis concept also needs to be developed further. There is a need to develop more scientific data and, based on these, to make recommendations to plant quarantine organisations to accept new proven treatments. The working group concluded that to overcome problems encountered in disinfestation there must be a coordinated international approach.

Diseases

Conveners: Greg Johnson and Sing Ching Tongdee

Conclusions and Recommendations

1. In any research on the storage of tropical fruit, disease control is a primary consideration, yet the expertise to adequately address the problems often is not available. The move away from the use of postharvest fungicides will require far greater understanding of pathogen biology than is necessary for the implementation of control techniques based on chemicals. The appointment of specialist postharvest pathologists to undertake research on the biology of postharvest pathogens should be considered in many developing countries.

2. Considerable basic research is required to document the causes of disease in many tropical fruits. Such work is underpinned by training in mycology, and access to an affordable identification service. Workshop participants deplored the introduction of fees for identification services, and endorsed the need for the establishment of an identification service and central culture collection within the region. Regional workshops to train local pathologists in the identification of fungi should be considered. A manual of standard methods for culturing fungi for identification, and diagnostic test-kits for use by non-specialists are also required.

3. The development of proposals for the funding of research on the storage of tropical fruit should actively involve a postharvest pathologist, to ensure that this important research area is adequately resourced.

4. Fine tuning of disease-control technology may be necessary when it is introduced into a country, with attention paid to ensuring that disease-control efficacy is maintained and unacceptable fruit damage avoided.

5. In developing alternatives to fungicides, specific approaches that should be considered in the region include the following.

   - Studies on infection processes and other aspects of pathogen biology.
   - The assessment of biological control agents for fruit pathogens, as they become available under licence from research programs undertaken outside the region.
   - Greater focus on disease-control strategies in the development of heat-disinfestation protocols.
   - Evaluation of preharvest control strategies (including copper fungicides) for the control of postharvest diseases.
   - Identification of preformed antifungal compounds in fruit, and the assessment of the disease-control potential of plant extracts.
   - Development of standard techniques to assess fruit resistance to pathogens.

Biocontrol of Diseases

Conveners: Lise Korsten and Lindy Coates

THE two main issues dealt with in the biocontrol workshop were the initiation of biocontrol programs, and commercialisation.

As regards the former, the importance of selecting the correct isolate and screening assays was highlighted, and the inherent problems associated with these techniques were discussed. It was suggested that in vitro and in vivo techinques should be run in parallel, even though this is laborious and time consuming.

A few alternative approaches were discussed, such as selective plating techniques and evaluating the spectrum of the antagonist activity against other plant pathogens, which would make biocontrol products more attractive for commercialisation.

The use of industrially important microorganisms currently used in the food processing industry was also discussed, particularly in the context of postharvest biocontrol applications.

The second aspect highlighted in the workshop was commercialisation, and at what stage researchers should hand over to commercial companies. It was suggested that researchers should pursue biocontrol beyond the semicommercial stages, in order to strengthen their negotiating base with commercialising companies. It was also clear that at this stage a specialised team should be established, including a fermentation consultant.

Specifications giving the exact format of the biocontrol agent should be provided before scaling-up of fermentation technology. This must be done in order to provide the most effective form of the antagonist.

The importance of following an integrated approach was once again highlighted, as were problems associated with patenting of biocontrol concepts. The latter is an issue that should be addressed by research groups working in the postharvest arena of tropical crops.

Finally, it was agreed that biocontrol workers should be proactive and establish a working group that can promote alternative disease control options, including not only bioaugmentation but also natural plant products, physical and environmental manipulations, etc., as dealt with in this conference. Such proactive approaches should be aimed at dealing realistically with the public perception of pesticides and alternative control strategies.

Molecular Biology

Conveners: Colin Brady and Porntip Chaimanee

A small group of eight discussed the application of molecular techniques to the advantage of tropical and subtropical horticulture.

The range of techniques available was considered. It was noted that sequence databases were expanding rapidly, and the expanded information base was reducing the initial cost of gene isolation and gene characterisation. The point was made, and not disputed, that genetic manipulation for commercial release should initially involve modifications of the endogenous genes and avoid the introduction of non-plant genes and homologues of the endogenous gene from other species. The need to express genes isolated solely on the basis of cross species homology, and, after expression, confirm the function of the gene product was noted.

There was some emphasis on the advantage of working with plant breeders and, where possible, working with in-bred lines.

The commercial interest in enhanced pest resistance was noted, and the expense of research on pest resistance, with its need for statistical evaluation, was discussed.

There was discussion of desirable gene targets with emphasis on those regulating fruit colour, sugar-loading, and maturity.

A call was made for a registration of research interests in the application of molecular biology to tropical and subtropical fruits, and of a willingness to discuss cooperative approaches. Registered interests are in the following table. The workshop recommended that ACIAR or ASEAN seek to expand and maintain this register.

Activity	Detail	Reference
1. Breeding	Papaya – ripening variants	Hawaii, Paull
	Papaya	QDPI, Hofman
	Mango	CSIRO, Darwin
	?	MARDI
2. Tissue culture	?	MARDI
3. Transformation/ regeneration	Mango	Mexico
	Papaya	Hawaii, Paull
	Citrus	CSIRO, Brady
4. Molecular markers		
– RAPD		
– Targetted		
5. Protein isolation		
– Antisera	Polygalacturonase ┐ mango	Thailand, Porntip
	PME ┘	Silpakorn
– Sequence	Xylanase – papaya	Hawaii, Paull
6. Gene isolation	ACC synthase – papaya	Hawaii, Stiles
	β-1,4-glucanase – papaya	MARDI, Lam
7. Gene expression		

Trade and Marketing

Conveners: David Minnis and Godfrey Lubulwa

Marketing of Tropical Fruits

The market prospects for tropical fruits in Asia, Europe, and Japan were analysed in some detail.

In the short term, legislative changes in the EEC have implications for Asian countries supplying the European market. They reflect concerns about chemicals, consumer safety, and the environment that will, in the longer term, emerge more strongly in Asia.

Key issues subsequently raised during the workshop were:

1. World is operating in new era of free trade and opportunities are constantly changing.
2. Lack of market research in tropical fruits increases the risks of new ventures involving new crops.
3. R&D and technology transfer must be industry driven. At present there is a perception that it is researchers driving research.
4. Lack of funds for R&D was highlighted as an impediment. This is despite the fact that various governments in the region are making claims that exports are crucial for the development of their country.
5. There is technology available that is not being used because industry is unaware of it, or is unable to commercially adapt it. The technology transfer process needs to be strengthened.
6. Industry needs a vision for the future. It needs to keep setting new goals, with R&D supporting the vision.

Threats to Expanding Trade

1. The market share commanded by tropical fruits currently exported by various countries in Asia is at risk from South American competition.
2. Inferior and inadequate postharvest handling procedures are a constraint to expansion of trade.

Advanced postharvest technology is employed in South America, often directly transposed and adopted from the USA. If ASEAN countries are to compete with South American countries in the future they will need to have equivalent levels of postharvest technology.

3. Lack of markets in Asia due to limited access.
4. Improved sea freight technology is needed for perishable products such as tropical fruits. Without this technology export volume is restricted to air freight or short voyages.

Recommendations

1. That a multi-sectoral approach to R&D be adopted, so that research agencies together with the private sector are involved in jointly funded studies.

2. That a multidisciplinary approach to tropical fruits R&D be adopted.

3. That the commodity focus of R&D be on high value fruit and the marketing focus be on sea movement of tropical fruits.

4. That work be initiated to develop generic disinfestation procedures to meet the requirements of major fruit-importing countries.

5. That a mechanism for continuing and enhanced exchange of information on technical issues and market development be established.

6. That sustainability in R&D work be a matter of concern in developing countries. If trends in other countries are mirrored in Asia, the amount of government funds for horticultural research will decline. To offset this decline, the private sector will need to be financially involved and mechanisms for such involvement need to be developed.

Education and Training

Conveners: Alfred Ihekoronye and Colin Bunt

THE overall objective of this workshop was to identify means by which practical information on postharvest handling of tropical fruits could be disseminated more effectively to growers and packers.

A specific aim was to propose structural modules for training fruit growers and handlers in methods of handling fruit that will minimise quality losses.

Identification of Need

Dissemination of practical information is a challenge to the scientific community. There exists a wide range of information on various aspects of postharvest handling of many tropical fruits in the scientific literature but getting this information across, in language that is understandable to fruit growers, handlers, and traders is a task-specific problem. A mechanism is needed for doing this, perhaps through the establishment of linkages and networks among various countries. Participants in this workshop could act as primary vehicles for the implementation of such linkages.

Codes of Practice

Having identified the need for training and education for growers and postharvest fruit handlers, the next task was to determine the codes of practice needed in this area. Using the mango fruit as an example, a code of practice for its handling would need to cover:

- picking
- transportation from the orchard
- treatment and classification
- storage
- transportation to the market place.

Education and training would have to address issues on proper procedures that would minimise reduction in quality of the fruit at each link of the harvest–postharvest chain. To achieve this, training/education modules should comprise basic pamphlets, leaflets, and videos in simple language for the trainees.

Recommendation

It is recommended that a structural module for education and training of tropical fruit growers, handlers, and traders be implemented. Such a structure, when in place, will train tropical fruit producers on appropriate methods of handling their produce in order to minimise quality losses.

Research Network on Tropical Fruit Trees in Asia

Convener: Nazmul Haq

DR Nazmul Haq from Southampton University, U.K. presented for consideration by workshop participants details of an ambitious scheme to establish a comprehensive network covering all of Asia. The overall objective is to act as an umbrella framework for coordination of R&D activities in genetic resources, production, postharvest handling and processing, and socioeconomic and marketing aspects of promising tropical fruit trees in Asia. Initial support has been received from the Commonwealth Science Council and the International Centre for Unrecognised Crops. Bangladesh, India, Pakistan, Malaysia, and Sri Lanka had, Dr Haq said, expressed interest in the scheme.

Workshop participants were generally supportive but wondered where funding would come from and how the effort needed would be distributed among network participants. One delegate pointed out that there was no extension component in the plan, a serious omission. All agreed to fill in and return to Dr Haq as soon as possible an ICUC–IBPGR Questionnaire on Tropical Fruits.

Closing Remarks

It is a custom in Chiang Mai to set water containers beside the road so that travellers may refresh themselves. Since prehistoric times, fruits have also been wayside refreshers, plucked to be enjoyed along the way. As a consequence, the fruits themselves have been dispersed. The mango accompanied the spread of Buddhism throughout Asia, and later travelled further, with Indian, Arab, and European traders and adventurers.

Five hundred years ago, the determination and faith of Christopher Columbus in his journey to the Americas led to the flow of plants of commerce in trade from America to Europe and Asia. Where would Thai cuisine be without chilli and papaya, both originating in the Americas? Later there came pineapple, passionfruit, and avocado. In exchange, the fabled golden fruits — citrus, banana, and mango — were introduced into Europe, North America, and Africa.

There were yet other jewels: the durian, mangosteen, lychee, longan, and rambutan — the orphans — remained as seasonal pleasures for locals and intrepid travellers.

Legend says that, in centuries past, couriers raced across China to deliver fresh lychees to the Emperor. In the 19th century, Queen Victoria of England offered a prize to anyone who could deliver to her a fresh mangosteen. No-one claimed the prize. Nowadays, fresh tropical fruits, including mangosteen, can be transported by air around the world.

We have spent the last few days accepting the hospitality of Chiang Mai. We have enjoyed the fruits of research on tropical fruit — including the orphans, and the wisdom gained in their production, handling, and marketing. The time has come to return to our homes with new knowledge, contacts, and inspiration.

The success of this conference is due to the support of our sponsors, to the efforts of many staff and students of Chiang Mai University who attended to local arrangements, to help from many others in other agencies and, last but not least, to the paper presenters and participants who ensured a stimulating and enjoyable colloquium.

We thank you all.

B.R. Champ
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