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Postharvest Technology for Agricultural Products in Vietnam

Proceedings of an international workshop held at Hanoi, Vietnam, 8–9 December 1994

Editors: B.R. Champ and E. Highley

Sponsors:
Ministry of Agriculture and Food Industry, Vietnam
ASEAN Food Handling Bureau
Australian Centre for International Agricultural Research

Contents

Address of Welcome

LADIES and gentlemen, on behalf of the Organising Committee, I would like to welcome overseas and Vietnamese scientists, and other participants from various institutions in Vietnam, to this international workshop.

Postharvest technology is an important issue in Vietnam at present because we are seeking to reduce our postharvest losses and to improve the quality of our agricultural products. We therefore much appreciate the opportunity to host this meeting in our country.

We are pleased that this workshop is being attended by Dr Bruce Champ, Coordinator of ACIAR's Postharvest Research Program, by Mr Khaliludin Ramly, the Director of the ASEAN Food Handling Bureau, and by more than 20 other overseas participants from countries including Australia, China, Thailand, Belgium, Netherlands, New Zealand, the Philippines, and Malaysia. There are also delegates from the International Rice Research Institute (IRRI), FAO headquarters in Rome, and the FAO Regional Office for Asia and the Pacific (RAPA) in Bangkok, Thailand.

The Vietnamese scientists participating are from the Postharvest Technology Institute, the Vegetable Research Institute, the Institute of Agricultural Engineering, the Plant Protection Institute, and the Institute of Animal Husbandry, all of which are part of the Ministry of Agriculture and Food Industry, the Research Institute of Agricultural Machinery Designing and Manufacturing (Ministry of Heavy Industry), the Aquaculture Research Institute (Ministry of Fisheries), the Hanoi Agricultural University No. 1, the University of Agriculture and Forestry in Ho-Chi-Minh City, Can Tho Agricultural University, the Hanoi Polytechnic University, and various other departments from the Ministry of Agriculture and Food Industry, the Ministry of Science, Technology and Environment, the Ministry of Fisheries and other State agencies. Journalists from various newspapers, Vietnam Radio, and television are also attending.

There are seven sessions in the workshop, during which 20 papers will be presented, 11 by visiting speakers and 9 by local specialists.

The Organising Committee has pleasure in asking Dr Bruce Champ to be chairman of the workshop as a whole and of its first session. Other sessions will be chaired by:

- Dr Phan Hieu Hien: second session
- Dr Mervyn Bengston: third session
- Dr Chris Yuen: fourth session
- Professor Ken Buckle: fifth, sixth, and seventh sessions.

Once again, thank you very much for your kind participation and cooperation. We wish you all a happy and successful workshop.

Dr Nghiem Chung Lan
Vice Director
Department of International Cooperation
Ministry of Agriculture and Food Industry
(Chairman of the Organising Committee)

Workshop Objectives

DR Lan, Mr Ramly, distinguished colleagues and guests, it is a great honour for me to participate in the opening of this international workshop.

I speak on behalf of ACIAR, the Australian Centre for International Agricultural Research and the various Australian organisations represented in this workshop. These include the University of New South Wales, the University of Western Sydney, the Australian National University, the Commonwealth Scientific and Industrial Research Organisation, the Queensland Department of Primary Industries, and private industry.

We would like to thank the Ministry of Agriculture and Food Industry for the opportunity given to us to explore the ways and means by which the international community, and Australia in particular, can assist development of postharvest technology in Vietnam. We look forward to working in partnership with the scientists in your institutions here in Vietnam.

The overall objective of the workshop is to review current issues in postharvest technology in Vietnam. To achieve this objective, we must first establish your perceptions of the problems in the postproduction sector in Vietnam. In doing so we must also define the importance you attach to solving the problems. That is, we must know in both monetary and social terms the cost to the community of the problems, and the chances that interventions can be made that successfully address these problems in a cost-effective way.

Having identified the problems and the type of activity needed, we look for a comparative advantage in Australia's research and development programs, so that we can achieve the best possible match of counterpart individuals and organisations. This is to provide the necessary resources and facilitate the transfer of existing technology and development of new technology.

Over the next two days we shall explore various components of the postproduction sector. We shall look first at the framework for cooperation in this part of the world to ensure we exploit its potential to the fullest extent — and, of course, change it if this is necessary.

We shall then look at the major commodities from the agriculture sector. First on the agenda are grains and the principal constraints to their safe handling and storage — moisture, temperature, pests, and spoilage diseases.

We shall then move to the perishable commodities, specifically fruit and vegetables, fish, and livestock products, where losses in marketing are particularly high because of their very short shelf life and their susceptibility to environmental stress.

We shall publish all the papers from the workshop and we would like the final volume to provide a detailed record of the current technology available that may be relevant to Vietnam's needs.

The published proceedings of the workshop must record also the situation in Vietnam with some estimate of the priorities that our colleagues in Vietnam attach to particular problems and loss-reduction or income-generating activities.

Dr Bruce Champ
ACIAR
(Workshop Chairman)

Opening Address

LADIES and gentlemen, first of all, on behalf of the Ministry of Agriculture and Food Industry, I would like to thank the Australian Centre for International Agricultural Research (ACIAR), the ASEAN Food Handling Bureau (AFHB), and ABR Development Pte Ltd for cooperating and assisting our Ministry to hold this workshop. We also would like to thank and welcome scientists from different countries, who are participating with Vietnamese scientists in this workshop on a very important aspect of agricultural production — postharvest technology.

Vietnam is an agricultural nation with a total population of 72 million. Over 70% of the people live in rural areas and are engaged in agriculture. Agricultural products make up about 40% of Vietnam's gross national product.

At present, Vietnam has over 7 million hectares of land under cultivation. Some 5.3 million hectares are sown to annual crops, of which rice is by far the most important: over 4 million hectares are sown each year to rice.

Before 1989, Vietnam suffered from food shortages, and had to import between a half and one million tonnes of food, mainly rice, each year. Since 1989, thanks to the new policies in economic development in general and in agriculture in particular, and with the application of advanced technologies, Vietnam can not only ensure the basic food needs of its population, but also has an annual surplus of 1.5–2 million tonnes of rice available for export. Food productivity in paddy equivalent has attained 25–26 tonnes per year. Paddy itself accounts for 22–23 million tonnes.

In addition to increases in rice production, there have been considerable improvements in the production of some other food crops, such as maize, short- and long-term cash crops, and tree fruits. There have also been advances in animal husbandry.

Nevertheless, there are still problems in agricultural production to be solved and, among these, the need to reduce postharvest losses has been accorded the highest priority. The results of research by many scientists has shown that annual postharvest losses in rice production amount to 13–16% of the total production. That means that, of the total annual production of 23 million tons of paddy, 3–3.5 million tonnes is being lost after harvest. This is equivalent to the average production from one million hectares of rice land.

Maize, and beans and other vegetables, are also subject to serious losses after harvest. Inadequate postharvest handling of agricultural products results not only in large quantitative losses, but the quality of products is also very much affected.

Postharvest technology has therefore become a serious concern in Vietnam in recent years. The national Post-Harvest Technology Institute has been established. Some positive results have been gained from the activities of the Institute, as well as those of relevant departments/sections of other research institutes and of the agricultural universities. However, these initial gains have, for the most part, been modest.

This is why the Ministry of Agriculture and Food Industry sees this workshop as important. It is considered a good opportunity for Vietnamese scientists and technologists to meet with and learn from foreign postharvest specialists. Our scientists seek to gain access to new and advanced postharvest technologies from other countries, so as to improve agricultural production in Vietnam.

I am very proud and honoured to provide the opening statement to this workshop. Best wishes to all of the participants, and have a successful workshop.

H.E. Dr Nguyen Thien Luan
Vice Minister of Agriculture and Food Industry

Overview Papers

Regional Strategies, Experience, and the Potential for Collaboration in Postharvest Handling and Storage of Food Commodities and Animal Feedstuffs

B.R. Champ*

Abstract

This paper examines the framework for international cooperation in technology for the handling and storage of food commodities and animal feedstuffs in Southeast Asia, making particular reference to Vietnam. The various opportunities for collaboration through national, regional, and global programs are explored in bilateral and multilateral modes. Strategic issues are identified that must attract a high priority in national programs for addressing problems that constrain development and improvement in agriculture and in public health and welfare. These include:

- quality assurance and the technology to implement programs that achieve this, whether with perishable commodities such as fruit, vegetable, meat, and fish, or durable commodities such as grain;
- value adding to commodities, including processing and other methods of income generation; and
- economic evaluation of problems and the interventions needed to solve them, as well as to establish the priorities for attention to such activities.

Specific topics are identified that cause the most significant losses and that are relevant to development assistance programs and transfer of technology from developed countries. These include management of moisture, temperature, pests, diseases, and mycotoxins.

BY taking a regional perspective on postharvest problems a number of benefits become apparent immediately.

First, we see that there is a commonality of problems. We all face similar issues and the principles involved in their solution are the same. In everyday terms, a problem shared may be a problem spared.

Second, there is a potential for widened scope in linked regional studies. There are great possibilities for adding new dimensions to investigations and certainly greater challenges to researchers.

Third, modern technology often requires multidisciplinary skills and capital intensive resources. This applies particularly where chemical analysis is involved. Analyses for the more recently discovered mycotoxins of importance, for example, require the use of expensive and sophisticated equipment of a type that one could not expect to find in every laboratory, but rather to be installed in some central facility and shared by many groups of researchers.

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Fourth, there are opportunities to conserve resources by collaboration in complementary programming. Overall, this will lead to much better utilisation of resources which are invariably scarce.

Finally, by taking a regional perspective there is an opportunity to focus regional resources on problems that have been identified to be of high priority. This will enhance the chance of success of rapid solution of these problems in the shortest possible time.

Needs in Regional Collaboration

In implementing regional programs, to maximise their value we need to ensure that certain basic criteria are met.

First, the various research groups involved need to standardise their research methodology and technology evaluation procedures. There will then be a basis for comparing results from different sources and for expanding the comparable data bases.

Second, multidisciplinary inputs and core programs must be of critical mass. Solutions to problems often need a range of inputs — chemistry, engineering, biometry, economics, for example — and if one or other of these is missing the research may fail.

Also, research teams that are too small may be uneconomic or ineffective.

A third basic criterion for maximising the value of regional research programs is the development of comprehensive, relevant, and usable data bases. The usefulness of data bases is usually directly proportional to their size, but there is a caveat: the data base must be readily accessible to all who want to use it.

Another very important need in regional collaboration is an understanding that the production and postproduction systems are linked. There must be a greater appreciation of the need, in increasing production, to also provide for effective means of handling the increase in commodity. A very relevant example here might be the need to develop handling systems for an extra rice crop harvested during the wet season when traditional drying methods are inapplicable. Pre- and postharvest activities must be integrated.

We also need to exploit economies of scale in interacting regional research and development programs to enhance the chances of success in problem solving. On the one hand, chance of success is enhanced by a stronger focus on the problem, and the other by permitting access to research resources that are not usually available in individual laboratories.

Harmonisation of regulatory frameworks for commodity inspection and treatment is a vital component of regional collaboration. Harmonisation provides for complementarity in research and the chances of adoption of new technology are greatly enhanced if there is a common acceptance of it throughout the region.

Last but not least in our consideration of regional collaboration requirements is the need for networking. Networking covers all areas of interchange of information and ideas. When all work together towards the achievement of common goals, great economies inevitably follow. This very workshop is a strand in our regional network. The contacts made and relationships established during it will further strengthen the network.

International Cooperation in the Region

International cooperation can be considered under three headings: bilateral collaboration; multilateral/global activities, and regional activities.

Bilateral collaboration

Bilateral collaboration encompasses normal scientific interchanges between individuals and institutions, externally funded projects, and assisted scientific collaboration such as that fostered by ACIAR through its support of research partnerships between scientific institutions. Recent externally funded projects in the postharvest area in Vietnam have included the Rice Postharvest Systems project of UAF, PHTI, and IDRC, and also work on sweet potato (NIAS/IDRC) and groundnuts (KKV/UAF/IDRC).

Multilateral/global activities

Among the organisations supporting multilateral and global activities FAO, WHO, Codex Alimentarius, and CGIAR and the International Agricultural Research Centers will be well known to most researchers. I mention in passing that these agencies generally seek to frame their activities around existing national programs, so as to synergise these.

FAO programs of interest include the strengthening of integrated pest management (IPM) in Vietnam, through Phase III of the Intercountry Program for IPM in South and Southeast Asia. Activities under this program in Vietnam are funded by Australia through FAO. Very recently, FAO has provided support for the formation of the new Association for Food Science and Technology in Vietnam. FAO has also been involved in assessment of postharvest losses in Vietnam.

WHO activities in Vietnam centre on determining the occurrence and significance of food-borne fungi and mycotoxins through support survey work of the International Agency for Research on Cancer (IARC). WHO also has a general interest, of course, in the whole area of nutrition and health.

The Codex Alimentarius and the Joint Meeting on Pesticide Residues seek to determine, through rigorous research, safe limits for the occurrence of pesticides and other residues in food, and to have these limits adopted by national regulatory agencies. Only through general adoption and harmonisation of maximum residue limits (MRLs) can food safety be ensured and one of the last barriers to unimpeded international trade in foodstuffs overcome.

The Consultative Group on International Agricultural Research (CGIAR) and the International Agricultural Research Centres (IARCs) supported by it make very important contributions to global problems in agriculture. They include the International Rice Research Institute (IRRI), the International Center for Wheat and Maize Improvement (CIMMYT), the International Centre for Living Aquatic Resources Management (ICLARM), and the International Food Policy Research Institute (IFPRI). Unfortunately, the postharvest subsector has not, so far, been particularly well served by the IARCs other than perhaps IRRI, and it is essential that this should change given the contribution that improved postharvest technology makes to increased food availability.

There are many discipline-based associations contributing to global exchange of postharvest information, too many to list exhaustively here. I mention, however, the International Association for Horticultural Science (ISHS), which has a Postharvest Commission whose activities are covered in a paper in these proceedings. Also worthy of note are the International Working Conferences on Stored-product Protection (IWCSPP) held every 4 years at selected locations around the world. The proceedings of the latest IWCSPP, held in Canberra in April 1994, have been published and were available for inspection during the workshop. The next IWCSPP will be held in Beijing in 1998. One hopes that many of Vietnam's food storage specialists will be able to attend. Other discipline-based activities of interest include the International Union for Food Science and Technology and the International Congresses of Entomology.

Regional activities

FAO does, of course, promote regional programs and networks within its global activities. Notable have been the Regional Network on Post Harvest Technology and Quality Control of Food Grains (REGNET) which played a very productive role until lack of funding forced its abandonment. The continuing role of REAPASIA, the Regional Association for Post -production Technology Institutions in Asia, has provided for valuable interchange between countries in the region concerned with production of all agricultural crops. In the mycotoxin area, occasional regional workshops have maintained a focus on this problem with the most recent workshop sponsored by the U.N. Environment Programme. Harmonisation of pesticide use must also be identified.

Another key player in regional activities is the ASEAN Food Handling Bureau (AFHB), based in Kuala Lumpur. Indeed, AFHB was a prime mover in the organisation of this workshop. The ASEAN Food Handling Project was funded as part of the ASEAN–Australia Economic Cooperation Program. Phase III of the project targets issues of quality assurance, food safety, and minimal processing. ASEAN agencies provide opportunities for problem management that may be based on a regional strategy and action plan that link with corresponding national plans.

The AFHB has collaborated with the Group for Assistance on Systems relating to Grain After-harvest (GASGA) in promoting drying technology in the region and addressing mycotoxin problems. In the latter area it has produced a regional Strategy and Action Plan for Control of Fungi and Mycotoxins in ASEAN Food and Feedstuffs, complementing the activities of the GASGA Working Party on Fungi and Mycotoxins in Asian Food and Feedstuffs. Among many other valuable outputs, AFHB is actively promoting a series of publications on 'Suggested Recommendations for the Fumigation of Grain in the ASEAN Region'.

Other regional activities of interest include the work of the ASEAN Food Security Reserve Board (AFSRB), which is concerned with grain security, particularly rice, and of SEAMEO/SEARCA, based in the Philippines, which is coordinating, for example, IDRC-funded work on peanuts in Vietnam, and SEAMEO/BIOTROP which conducted a grain warehouse management course at the same time as this workshop.

It is regrettable that the ASEAN Grains Post Harvest Programme has been disbanded. The program provided, for more than 10 years, a technical service to the ASEAN region's grain industries under the supervision of the AFSRB. At its peak it was supported by Canada, USA, Holland, and Australia, with Canada remaining the sole supporting country in its more recent phase of activity. It is hoped that ASEAN will provide a reincarnation at least of the annual workshops which provided for valuable interchange in the region.

High Priority Strategic Issues

High priority strategic issues in current regional cooperation are quality assurance, value adding, and economic assessment.

Quality assurance strategies for durable commodities such as cereal grains rest on the proper management of moisture, temperature, and pests, and the control of fungi and mycotoxins. The key objectives for perishable commodities are extension of shelf life, development of minimal processing techniques, and establishment of cost-effective quarantine treatments that are acceptable to importing countries.

Value adding is seen as essential to increasing the contribution of agriculture, through export income, to national economies. This is particularly significant to Vietnam, which has abundant labour resources to engage in food processing and other value-adding activities.

Linked with quality assurance and value adding is food safety which must be an integral part of all programs aimed at increasing availability of food for domestic consumption and export. Measures taken to enhance production or prevent deterioration after harvest, as well as processing methodology, must maintain contamination by biological organisms or chemical residues within prescribed and internationally acceptable limits.

Last but not least, we must mention economics. We must ensure that all our interventions in the postharvest subsector yield favourable economic returns. Clearly, any activity which costs more than it yields should not be engaged in. However, the objective measurement of returns from research interventions is itself a challenge and subject to ongoing study. Researchers, research agencies, and funding bodies need to keep this in mind when planning their programs.

Postharvest Technologies for Food Grains in Vietnam: Situation and Perspectives

Le Doan Dien*

Abstract

Vietnam is predominantly an agricultural economy in which rice is the major crop and the staple food. Great efforts are therefore being made to improve paddy production and postproduction practices.

Annual food production in Vietnam has increased by an average of about 40% over the past 10 years, but postharvest losses of agro-products in general, and of food grains in particular, remain relatively high. The average annual paddy loss in Vietnam is 13–16%. This is equivalent to about 1.6 Mt of harvested rice, valued at an estimated US$350–360 million.

The Post Harvest Technology Institute of the Ministry of Agriculture and Food Industry is providing instruction at Ministerial and national levels for the establishment of standards for food grains, especially paddy and rice, and inspection using specialised equipment. To reduce quantitative and qualitative postharvest losses of food grains, attention has been focused on the following activities and operations: harvesting; prestorage activities (threshing, drying, cleaning, grading); storage (different methods of storage, integrated pest management, use of biopesticides for storage of food grains); milling and processing especially processing of pulses; and quality control and standardisation.

Vietnam is seeking to develop linkages with its Asian neighbours to exchange information on postharvest technology.

VIETNAM is predominantly an agricultural economy based on paddy production. As rice is the staple food and a very important component of the agricultural sector, all efforts are being concentrated on it.

Food production increased from 17.6 Mt/year during the period 1981–1988 to 22.2 Mt during 1989–1992, and reached 25 Mt in 1993. Up until 1989, when it achieved self-sufficiency in paddy production, Vietnam had to import 0.5–1 Mt/year of food for domestic consumption. Since then a surplus of 1.4–1.9 Mt of paddy has been exported each year. Having attended to their own food security needs, Vietnamese peasants have started focusing their attention on agro-products for export, such as rice, maize, coffee, tea, rubber, groundnut, vegetables and animal products.

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Rapid Economic Development

Vietnam's economy has developed relatively rapidly in recent years, gross domestic product (GDP) growing by an average of 5.2% a year over the 1986–91 period. This compares very favourably with other countries in the region. The living standards of the Vietnamese people have clearly improved, leading to a continuously escalating demand for higher quality goods. In order to tap international markets Vietnam must, for its part, increase the quality of the goods it has to offer. Thus, to increase its economic competitiveness Vietnam is seeking to export, rather than raw agricultural products, processed foodstuffs that meet international standards and requirements.

For sustainable development, Vietnam must engage its abundant labour force, make effective use of its natural resources, maintain its biodiversity, improve its physical environment, and broaden its cooperative relations with other countries, especially those in Asia.

High Postharvest Losses

It must be emphasised, however, that postharvest losses of agro-products in general, and of food grains in particular, are relatively high.

For example, the average annual paddy loss in Vietnam is 13–16% (Table 1). This is equivalent to about 1.6 Mt of harvested rice, valued at an estimated US$350–360 million. Losses are greater for non-rice food crops such as sweet potato, cassava, and potato: about 1.15 Mt (US$80.86 million) each year for these three commodities. The annual loss of maize can be as high as 100,000 t (US$13–15 million). This evaluation excludes postharvest losses of vegetables, pulses, and other agricultural products.

Table 1. Postharvest losses (%) of paddy in Vietnam.

Losses during harvesting (grain left in the field)	1.3–1.7
Losses during threshing (unthreshed or spilled)	1.4–1.8
Losses during drying and cleaning	1.9–2.1
Transport losses	1.2–1.5
Storage losses (highly variable)	3.2–3.9
Milling losses	4.0–5.0
Total accumulated losses	13.0–16.0

Sources: Post Harvest Technology Institute, National Statistical Department, and FAO Post Harvest Loss Project (VIE/80/014).

Besides quantitative losses, losses in quality are also significant. Mould infestations arising from improper storage technologies may cause reductions in concentrations of amino acids in general and of some essential amino acids in particular.

Postharvest Operations

Drying and storage

Postharvest operations in general, and drying and storage of food grains in particular in Vietnam are mainly traditional manual ones, causing losses and inefficiencies throughout the postproduction system.

In the Red River Delta the farmers use a sickle for cutting rice stalks. Whether the stalk is cut short or long depends on what use is to be made of the straw. Stalks with unthreshed panicles are tied in bundles and left in the field for some hours. Hand harvesting is arduous work that leads to back pain and cut fingers. Paddy losses result from shattering and uncut stalks left in the field. Sheaves of rice are carried home on the shoulder, by cart pulled by buffalo, men or children, by small motorised tracter, or by bicycle. Losses due to shattering occur along the way, and during loading and unloading.

The rice is threshed within a few hours of harvesting. Both pedal and small motorised threshing machines are used. Preliminary cleaning is done using a rake and a broom. Sun drying is carried out by women and children in the farmer's yard over 3 days in the rainy season, and 2 days in the dry season. The grain is considered dry if it breaks with a solid sound when bitten. The grain is cleared using an electric fan, a cleaning wood drum, or the wind. Dry paddy is stored in wooden boxes with capacities ranging from 500–1000 kg. Losses occur due to rodents, insects, and moisture.

Postharvest operations in the Mekong Delta are similar to those in the Red River Delta, but losses are higher, averaging 20% for the summer–autumn (wet season) paddy crop. However, two well-built and equipped silos of 10000 and 48000 t capacity, at Tra Noc and Cao Lanh, respectively, have made a significant contribution to maintaining the quality of rice for local consumption and export.

Marketing

During the long periods of extreme economic difficulties and food shortages in the late 1970s and early 1980s, the marketing system was strictly organised and controlled by government. In the present transition period, individual farmers may sell their surplus crops to the State trading organisations, private traders, or direct to consumers in the local markets. Food crops such as maize, sweet potato, and cassava are used mainly for local consumption in the raw form. Because of a lack of postharvest technologies and investment capital, the production and export of any of these crops cannot be increased, although the potential exists to do so. For the present, rice is the main product being handled through various postproduction operations.

Some small traders at the village level may open rice mills, buying paddy from farmers for milling and sale to consumers and the State rice trading organisations. Some traders transport rice from one village to another or to the cities for sale, but they have to apply for trading permission and pay a trading tax. There are no accurate statistics showing the number of private traders and the quantities of rice marketed through this channel, but it is estimated that over 60% of rice, by quantity, passes through the network of food trading organisations.

Rice for export is handled by the State rice trading organisations — VINAFOOD I, II and III. The provincial VINAFOOD has its own warehouses, retail stores, and rice mills with milling capacities of about 15 t/day. In each district, there is also a food company, under the supervision of the provincial VINA-

FOOD. The district food companies, which have warehouses and small-scale rice mills of about 300 kg/day capacity, are struggling to survive, because of cash-flow problems and obsolete milling and storage facilities.

Postharvest Research and Development

The Post Harvest Technology Institute (PHTI) of the Ministry of Agriculture and Food Industry (MAFI) is providing instruction at Ministerial and national levels for the establishment of standards for food grains, especially paddy and rice, and inspection using specialised equipment. The Food Equipment Manufacturing Factory No 1 (FEMF No 1) in Hanoi and the FEMF No 2 in Ho Chi Minh City can manufacture threshers, dryers, rice mills, and other farm equipment. Due to the lack of funds and motivation, these factories are operating at well below full capacity. For instance, the FEMF No 1, created 25 years ago, has reduced the workers from 900 to 300 for the time being. The number of professional staff is 60 (including electrical, industrial, and mechanical engineers, and accountants). Its raw materials (belts, steel) are imported. Some rice milling companies in the northern and central provinces have ordered equipment and spare parts from this factory.

To reduce quantitative and qualitative postharvest losses of food grains, attention has been focused on the following activities and operations: harvesting; pre-storage activities (threshing, drying, cleaning, grading); storage (different methods of storage, integrated pest management, use of biopesticides for storage of food grains); milling and processing, especially processing of pulses; quality control and standardisation; etc.

Since improvements in the postharvest subsector have high potential for increasing agricultural production and economic efficiency through job creation and increasing farm incomes, it is attracting much attention. In addition, upgrading of postharvest activities will help remove the bottle-necks appearing in the preharvest stage and will stimulate production. This will make a decisive contribution to the process of diversification in the preharvest stage, enrich the cropping system, improve the crop rotation system, increase the possibilities of crop production, and use the abundant labour force in rural areas for increasing farmer incomes. Such results will have a significant impact on agricultural output.

In the coming years, agriculture will continue to play an important role in the national economy. The former policy of 'food self-sufficiency at all costs' has been replaced by a more comprehensive food strategy, taking into account the interrelationships between agriculture and industry, namely agro-industry, between food crops and industrial crops, between cultivation and animal husbandry, between ecological conservation and agricultural productivity, and between pre- and postharvest stages.

To overcome problems relating to agricultural production and help agriculture realise its full potential, the Vietnamese Government has paid much attention to the postharvest activities of drying, storage, processing, and quality control of food grains. It is considered one of the priority targets in the economic development policy in general, and the rural development policy in particular.

Postharvest activities in general, and drying, storage, and processing of food grains in particular, have played a major role in the growth and structural transformation of Vietnam's economy. These problems have close links with the agro-food industries. They also have close links with the service sector in the framework of a market-orientated economy, and in the transition of Vietnam from a low income, predominantly agrarian economy to a prosperous diversified economy with both agriculture and manufacturing sectors. In the framework of government policies on industrialisation and modernisation of the economy in general and of agriculture in particular, postharvest technologies in Vietnam must be well equipped and integrated. Optimal combination of traditional and modern technologies in different postharvest sectors (threshing, drying, cleaning, grading, storing, processing, controlling quality, packaging, distributing, etc.) must be achieved.

The major contributions of postharvest activities of foodgrains are:

- enterprise creation, particularly small-scale enterprises;
- growth in output and diversification of the economy;
- job creation, especially in rural areas;
- rural development; and
- export growth.

Regional Collaboration

Vietnam and its neighbours in Asia share similarities in land and climatic conditions, and in customs and habits. Cultural and scientific exchanges between the Asian countries are increasing daily.

In the field of postharvest technologies in general and drying and storage technologies for food grains in particular, the Asian countries can usefully exchange experience. Cooperation in the development of postharvest technologies would bring mutual benefits to Vietnam and its Asian neighbours.

We therefore take this opportunity to propose establishing a joint project on reducing postharvest losses of foodgrains by strengthening postharvest technologies, including drying and storage. This could be organised under the auspices of, and with the technical and financial support of, ACIAR, AFHB, and the Asian Development Bank.

The main objectives of such a project would be as follows:

- To reduce postharvest losses of food grains by applying appropriate technologies from the various countries in Asia, while taking advantage of exchanges of knowledge between scientists of Asian countries.
- To train scientific researchers of Asian countries on specific topics in the field of postharvest technologies and agro-industry (for example, prevention of mycotoxins in foodgrains, outdoor storage of foodgrains in plastic enclosures or small-scale mobile silos, with the technical support of ACIAR etc.).
- To increase the research potential of the different institutions involved in postharvest activities and agro-industry from Asian countries.
- To develop a program of short- and long-term research and development cooperation on problems of the postharvest subsector in agriculture and agro-industry among countries of Asia.
- To establish a network of different countries for execution and implementation of specific topics of general interest.

Postharvest Technology Research, Development, and Technology Transfer at the International Rice Research Institute

M. Gummert, B. Douthwaite, and R.M. Lantin*

Abstract

Reduction of postharvest losses is one way to increase rice production on the same, or even smaller, land area. The Engineering Division of the International Rice Research Institute (IRRI) has developed or adopted a number of harvest and postharvest technologies for farm and contract-level operations. These include the reaper, the axial-flow thresher, two small-area stripper harvesting systems, the flat-bed dryer, and a low-temperature in-bin drying and storage system (LT-IBDS). To ensure significance of the development process, target groups such as local manufacturers and end-users are involved at an early stage of development for verification of the technology's feasibility, functionality, durability, and profitability. Dissemination activities include collaboration with National Agricultural Research Systems (NARS), and provision of information packages and prototypes for national and international agencies. A technology evaluation network with NARS in Indonesia, Thailand, the Philippines, and Vietnam has recently been established for technology verification under different technical and socioeconomic conditions.

VIRTUALLY all consumers whose staple food is rice live in developing countries, most of them in Asia, where 90% of the world's rice is grown. About 80 to 100 million additional people must be fed each year, again most of them in less developed and poorer countries (Lampe 1994). In 30 years an estimated 870 Mt of unmilled rice will be needed each year, 70% more than today (Lampe 1994).

Yet the additional rice production must come from the same or a smaller area of land because of a reduction in the area of rice cultivated. Prime rice land is being lost to industrialisation and urbanisation in the faster-growing Asian countries. If environmental concerns result in policies that remove marginal lands from rice production and hasten the shift from intensive to less-intensive cropping systems, the area under rice cultivation will decline even faster (Hossain 1994).

Under these limiting conditions, there are two ways to increase production which have to be followed simultaneously to ensure that the increase in Asian rice production keeps up with population growth: increasing the yield by breeding, adoption, and utilisation of new, genetically engineered rice plants with higher yields and resistance to pests and adverse environments; and reduction of production and processing losses. In the Philippines postproduction losses can reach 10–39% (Fig. 1). In Vietnam paddy losses are estimated to be 30% during the wet season (Quick 1994). Assuming that the postharvest sector in the Philippines has improved, and using the lower value of 10% for 1991, the total postproduction losses would have been 0.97 Mt[1].

This paper describes briefly the postharvest technologies developed at the International Rice Research Institute (IRRI) and outlines the role that IRRI plays in the development and improvement of the rice postharvest sector in the region.

The International Rice Research Institute (IRRI)

The International Rice Research Institute was established in 1960 in the Philippines by the Rockefeller and Ford Foundations. Its mandate is to undertake

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[1] Total production of paddy in the Philippines in 1991 was 9.67 Mt (IRRI 1993).

basic research on the rice plant and applied research on all phases of rice production, management, distribution, and utilisation, with the objective of attaining nutritive and economic benefits for the people of Asia and other major rice-growing areas (IRRI 1989).

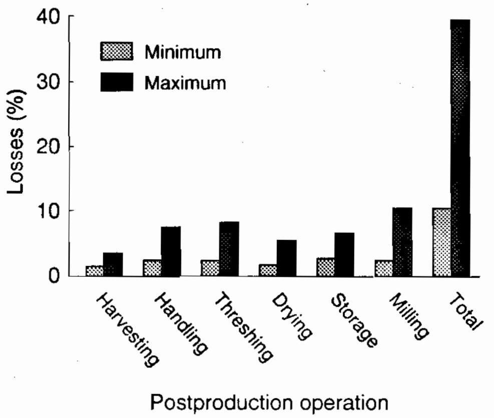

Figure 1. Range of total losses in postproduction operations in the Philippines (after De Padua 1978).

Today IRRI is one of 17 international agricultural research centres supported by an informal association of 41 public and private sector donors which form the Consultative Group on International Agricultural Research (CGIAR).

IRRI's goal

IRRI's goal for its fourth decade, with IRRI a partner in a growing community of strong national rice research systems, is:

- To improve the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes.

IRRI can, however, contribute to only a limited extent to the achievement of this goal which it shares with many other institutions and with national governments (IRRI 1989).

IRRI's objective

- To generate and disseminate rice-related knowledge and technology of short- and long-term environmental, social, and economic benefit and to help enhance national rice research systems.

The achievements and the relevance of IRRI's work depend largely on partnership and information exchange with national scientists, extension workers, and policy-makers (IRRI 1989). In this context IRRI generates knowledge and technologies to achieve the objective, which then can contribute to the achievement of the goal.

IRRI's Agricultural Engineering Division

Among the 17 international research centres IRRI is the only one which has an Agricultural Engineering Division. Within IRRI's goal and strategies the Agricultural Engineering Division contributes technologies and coordinates systems that will:

- raise profitability;
- enhanced productive efficiency;
- elevate human dignity and reduce drudgery;
- help with employment generation; and
- conserve resources.

The Division's activities include mechanisation and application of the principles of engineering to areas of concern and relevance to a rice-dependent agriculture (Quick 1994).

The Division is aware that even the simplest engineering technology is often too expensive for most resource-poor low-income farmers. Therefore, the target groups also include contractors and bigger farmers, who are often the innovators adopting new technologies. At a later stage of dissemination the new technologies then become available for poorer farmers. Experience shows that technologies used by farmer–contractors or other contractors can also be beneficial for the poor farmers. In the case of the axial flow thresher, benefits include reduced harvesting costs, losses and weather risks.

Development of Postharvest Technologies at IRRI

Since its inception, IRRI Engineering has developed or adopted a number of technologies for farm and contract-level postharvest operations. Technologies for harvesting and threshing consist of the reaper, the axial-flow thresher and, more recently, the two small-scale stripper harvesting systems[2]. A small ride-on stripper–combine harvester is under development. IRRI has also developed some dryer models. However, only the flat-bed dryer has been successfully applied in regions with conditions favourable to mechanical drying. IRRI engineers have also developed a rice-hull furnace to be used with the 2 t capacity flat-bed dryer. The recent adaptation of a Korean In-Bin Drying and Storage System (IBDS) to the conditions of the humid tropics seems to have potential for seed producers and cooperatives. For the processing of paddy, IRRI engineers have developed a portable grain cleaner, a centrifugal huller and, for remote

[2] Stripper rotor was developed by Silsoe Research Institute, U.K., and patented by the British Technology Group. The IRRI stripper development was funded by the British Overseas Development Administration (ODA). Technology transfer is supported by the German Government.

areas, two models of the rice micro mill with different capacities and of a design based on Chinese Engelbert-type mills.

IRRI Engineering collaborates with social scientists and other researchers in a multidisciplinary approach to develop problem-solving technologies.

Harvesting and threshing

In Thailand, Malaysia, and some areas in the Philippines (where some imported mechanical reapers are already being used because of labour shortage during harvest) there is a growing demand for labour-saving harvesting technology. These are areas where industrialisation draws part of the rural labour force to the cities. Labour shortage during harvesting can increase harvesting costs. Delayed threshing caused by non-availability of machines or labour is one of the major causes for quality losses in postharvest operations (Mendoza et al. 1988; Paz and Cabacungan 1992).

Reaper

The mechanical reaper, which was developed at IRRI in collaboration with the Chinese Academy of Agricultural Mechanisation Sciences (CAAMS), was not adopted by farmers in Asian countries, for several reasons. It is unable to harvest under difficult conditions, such as flooded fields and in lodged, weedy, short, and thin crops (Douthwaite 1993). Furthermore, the reaper is a relatively complicated machine and quality of manufacture, repair, and maintenance have proven to be a problem for machines made by small- and medium-scale manufacturers.

The need for alternative economical and efficient small-farm harvesting systems that can operate even in adverse conditions led to the development of the small-area stripper harvester systems at IRRI.

Stripper harvesting systems

Stripper harvesting involves stripping or combing the grain from the crop while the plants remain anchored. Most of the straw is left unharvested in the field. The principle of operation of the harvesting element is shown in Figure 2. The rotor, fitted with keyhole teeth, spins upwards as the machine moves forward, combs the grain from the straw and throws it into a collection container or a rethreshing unit. The upward rotation of the rotor with respect to the crop allows the rotor to pick up fallen crop (Douthwaite 1993).

In collaboration with Silsoe Research Institute, IRRI has developed two stripper harvesting systems for harvesting rice in groups of small fields to meet the need for labour-saving harvesting technologies. The simplest system, the stripper gatherer (SG) system, consists of the SG800 harvester (Fig. 3), a thresher/cleaner TC800, container modules, and a trailer which enables the system to transport itself to the field (Fig. 4).

The SG800 harvester collects the harvested grain, together with some straw, in a container. When the container is full it is changed and the collected material is rethreshed using the lightweight axial-flow thresher/cleaner. Up to 1 ha/day can be harvested by 7–10 labourers.

Harvesting costs using the SG system in the Philippines are lower than costs for comparable harvesting systems (Table 1; Fig. 5). The payback period is around 1 year. A manufacturer in Isabela, Philippines, started commercial production of the SG system and has sold 23 units.

IRRI's counterparts have frequently asked for a machine which produces grain cleaner than that harvested using the SG800 harvester. IRRI's second pedestrian-controlled stripper harvester, the stripper

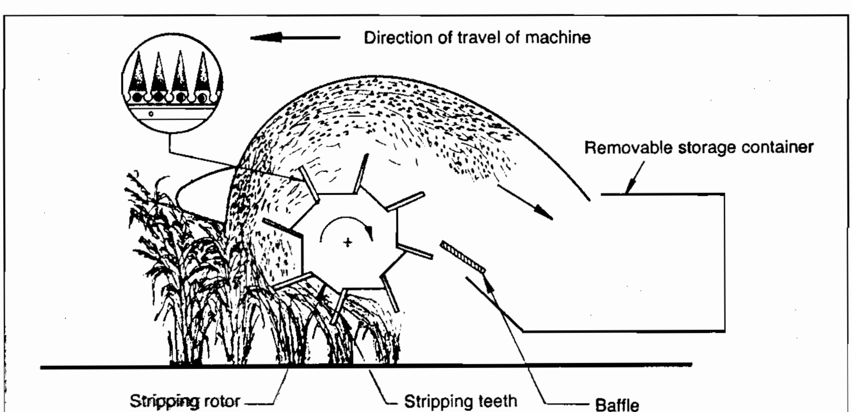

Figure 2. Operation of the Silsoe Stripper Rotor System (from Douthwaite 1993).

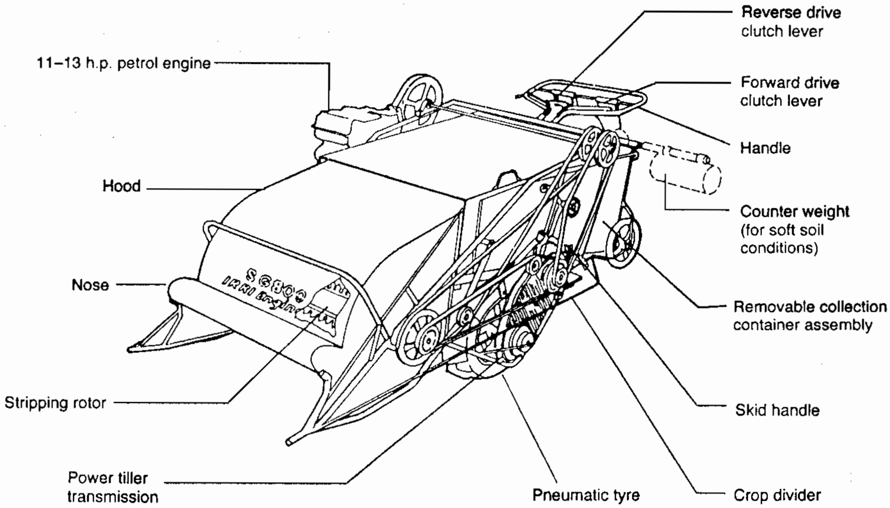

Figure 3. The SG800 stripper gatherer harvester (from Douthwaite 1993).

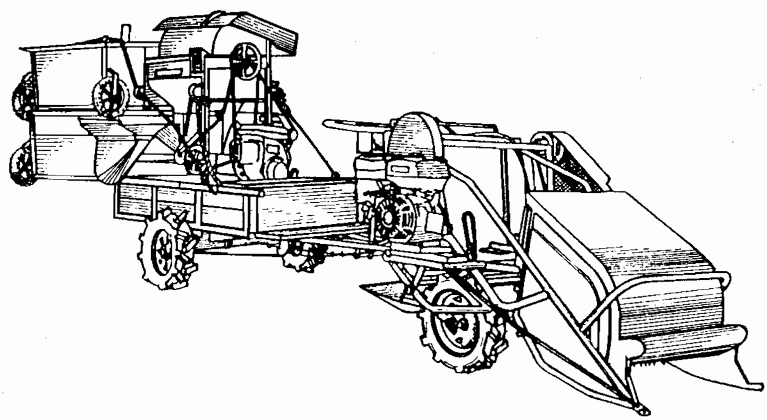

Figure 4. The SG800 system in transport mode (from Douthwaite 1993).

thresher (ST600), includes a rethreshing and straw separation rotor (Fig. 6). Final cleaning of the harvested grain is needed but can be carried out quickly and easily on a small, lightweight cleaner (Douthwaite 1993). The ST600 harvester can also harvest wheat and mungbeans.

Prototypes of the ST600 system have been shipped to IRRI counterparts in Thailand and Vietnam for verification.

In collaboration with counterparts in Thailand and Vietnam, IRRI Engineering has started to develop a small, ride-on stripper combine with a 1.4 m harvesting width as an alternative to more expensive and complicated combine harvesters available.

Table 1. Technical specifications of the IRRI stripper gatherer (SG) system for paddy harvesting.

Labour requirement:	7–10 people
Capacity:	1 ha/day
Cost of the harvest system including stationary thresher:	US$3130
Weight:	
SG800	240 kg
TC800	150 kg
Grain loss:	average 1.4%

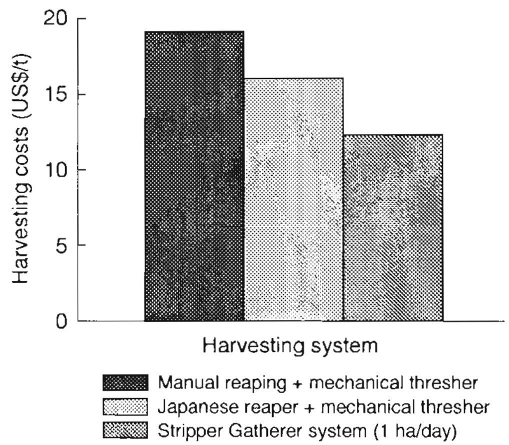

Figure 5. Harvesting costs of different harvesting systems in the Philippines (data from Douthwaite 1993).

Axial-flow thresher

The development of the axial-flow thresher and its introduction in Asia since 1971 is one of the big success stories of IRRI Engineering. When it was introduced, the thresher met the existing demand for labour-saving threshing technology. At present, modified axial-flow threshers are being used throughout Southeast Asia.

In Vietnam it was estimated that in 1988 there were hundreds of axial-flow thresher manufacturers in the Mekong Delta alone and that about 50 000 units had been built since the first threshers were fabricated by the Vietnamese Agricultural Machine Company (Phan H. Hien 1991). The technology has been modified to suit local needs by Vietnamese farmers and manufacturers. The Vietnamese thresher is equipped with a closed threshing drum with only 16 flat bar teeth made out of automotive leaf springs instead of the open drum with 128 cylindrical peg-teeth of the original IRRI design (Fig. 7).

Researchers from the University of Agriculture and Forestry (UAF), Ho Chi Minh City, have shipped a Vietnamese thresher to IRRI. Work is under way to analyse its performance under controlled conditions and compare it with the original IRRI design. It is claimed that the Vietnamese design, which is easier to manufacture, has lower power requirements and losses and that it performs better in difficult crop conditions. If the claims can be verified, then these features might also be of interest for other regions.

Drying

Traditional sun drying methods require good weather. Used with new multiple cropping systems, which allow 2–3 harvests per year, sun drying leads to high losses in the rainy season, because of crop spoilage caused by delays in drying.

Flat-bed dryer

IRRI engineers have developed a flat-bed dryer of 1 t capacity, with either a kerosene burner or a rice-hull furnace as heat source. The drying temperature is

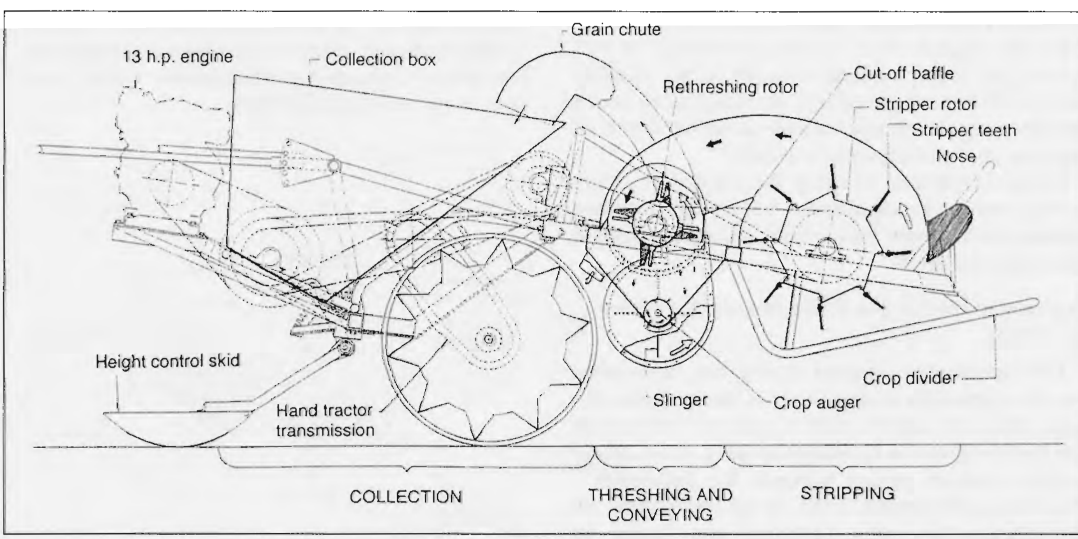

Figure 6. Longitudinal cross section of the ST harvester (from Douthwaite 1993).

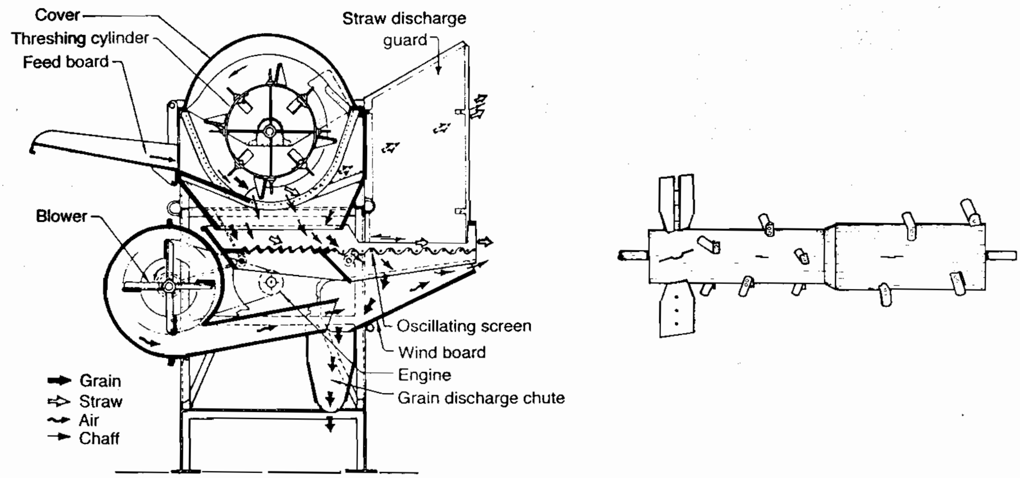

Figure 7. IRRI axial flow thresher TH7 (IRRI) and Vietnamese closed threshing drum with flat bar teeth (Nguyen Q. Loc 1993).

43°C and drying time, depending on initial moisture content, is 4–6 hours. However, flat-bed dryer distribution is low because of high drying costs compared with sun drying and, because of absence of, or failure to enforce quality standards, a lack of incentive to produce better quality grain. However, under suitable conditions, flat-bed dryers are accepted and used even in the dry season. For example in Phu Tam Village, Vietnam, 47 modified flat-bed dryers are installed (Phan H. Hien, pers. comm., 1994). Conditions that support dryer use are: no market for wet paddy; sun drying of large amounts is not possible because of lack of pavements (transport is by boat); and drying costs are low because scaled-up dryers of capacity 10 t or more are being used.

Problems reported in using the flat-bed dryer are mainly uneven air distribution and a high moisture gradient in the grain bulk, which requires mixing at least once per batch.

Low-temperature in-bin drying and storage system (LT-IBDS)

Low-temperature in-store drying has been introduced successfully at farm level in the moderate climate of Korea, and by 1990 a total of 70 000 units had been installed in Korean farms (Fig. 8). A collaborative research project between the International Rice Research Institute (IRRI) in the Philippines and Hohenheim University, Germany, was funded by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH) to assess whether low-temperature drying can be applied under humid tropical conditions.

The outcome of the project showed the feasibility of low-temperature in-bin drying under IRRI conditions even for wet grains (24% and higher moisture contents) during the rainy season (Mühlbauer et al. 1992). Excellent milling qualities, high whiteness (Fig. 9; Table 2) and a good gemination rate were achieved using a wooden dryer of 5 t capacity and an electric heater (Fig. 10). The principle was adapted to locally available materials (plywood, concrete hollow-blocks) and components (kerosene burner) and is now being tested outside IRRI.

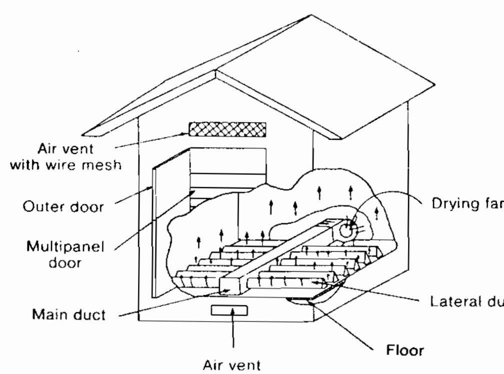

Figure 8. Korean in-bin drying and storage system (IBDS) (from Hong-Sik Cheigh et al. 1986).

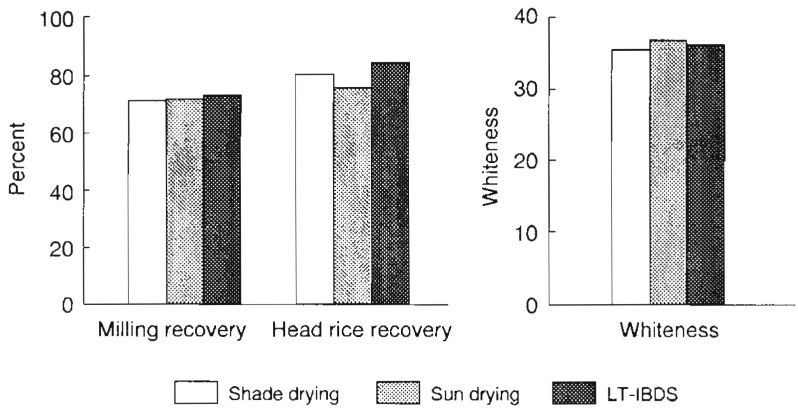

Figure 9. Milling recovery, head rice recovery, and whiteness of shade,-sun,-and LT-IBDS-dried paddy: average of four experiments, rainy season, Los Baños 1992.

Table 2. Technical specifications, LT-IBDS.

Drying bin capacity:	Flexible, depends on users needs	5–20 t
Temperature rise of drying air:	During good weather, dry season	none
	At night, during rain	6.9 K
Drying time:	Depending on initial moisture content, bulk depth, and dryer management	4 to 8 days
Drying air supply:	Centrifugal blower driven by electric motor or stationary combustion engine	
Heater:	Rice hull furnace, kerosene burner or utilisation of waste heat of stationary gasoline/diesel engine	
Specific energy requirement:	Depending on dryer set-up and operating conditions	0.05–1 kWh/kgH_2O
Installation costs:		≈US$1500

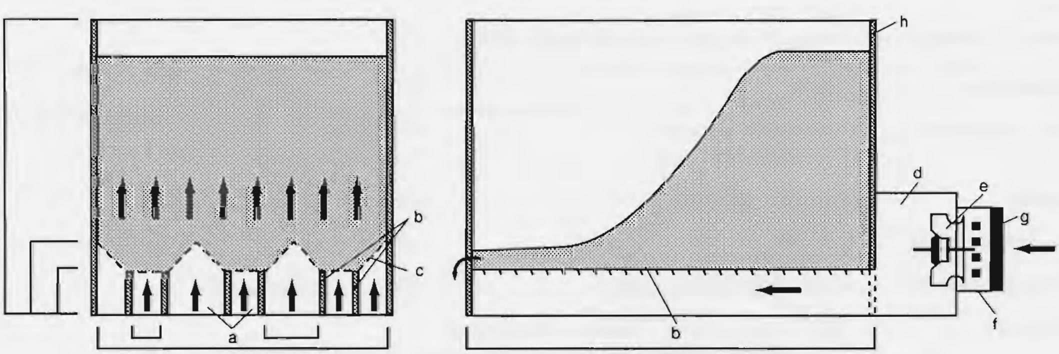

Figure 10. Test rig for IRRI low-temperature in-bin drying system: a, air ducts; b,air sweep floor; c, perforated sheet steel; d, expansion chamber; e, centrifugal fan; f, electric heater; g, air filter; h, rectangular bin.

The drying system has potential for seed producers and cooperatives, who have an incentive to produce high-quality grain. Currently efforts are under way to test low-temperature in-store drying on a pilot basis in selected countries of Southeast Asia and adapt it to local conditions as described later.

Micro rice mill

A Chinese Engelberg type mill was modified in order to allow local manufacturing without the need of casting the rotor. Two models with different capacities, the RM50 and the RM150, are available (Fig. 11; Table 3).

The mills are designed for milling paddy for home consumption and for custom milling in remote villages. Studies on adoption of the mill in some remote Philippine villages showed that it is generally accepted by women because it reduces the drudgery of hand milling, creates income, and improves their status in the family and community (Lampe 1994).

Significance of development through collaboration with target groups

Inclusion from the very beginning of the development process, of target groups such as local manufacturers and potential users (farmers or contractors) of the machinery is essential to verify:

- technical feasibility in terms of adaptation to locally available materials, functionality, and durability;
- profitability; and
- social acceptability of the technology in the targeted environment, to avoid, early in the development process, the creation of 'white elephants'.

After initial testing at the IRRI farm, the prototypes are brought to farmers' fields for testing. When the machines reach their final design, some prototypes are lent to farmers or contractors to test the performance and economics of the devices under actual conditions.

Local manufacturers in Los Baños, Philippines are subcontracted to produce prototypes first for IRRI, then for shipment to IRRI's counterparts. This approach results in the identification of manufacturing problems and modifications needed.

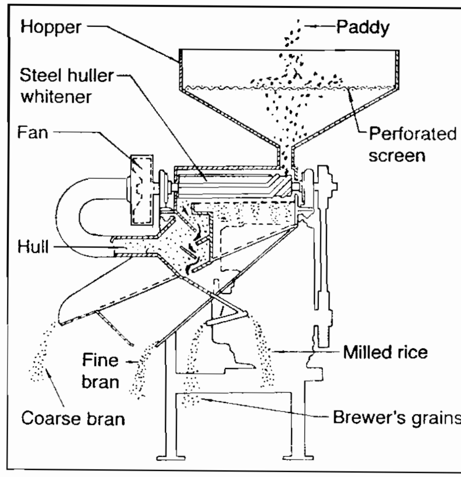

Figure 11. Schematic diagram of a typical micro-mill (IRRI).

Technology Dissemination Strategies

Being part of an international research institute with the mandate to generate knowledge and technologies, IRRI Engineering does not itself implement national extension programs. The following instruments are used to disseminate IRRI engineering technologies:

- collaboration with National Agricultural Research Systems (NARS) and other programs on technology verification and adaptation to local conditions;

Table 3. Machine specifications of two sizes of micro rice mill (IRRI).

Machine spec.	RM50	RM150
Power requirement	1 hp electric motor or 3.5 hp gasoline engine	3 hp electric motor or 7 hp gasoline engine
Capacity	< 100 kg paddy/hour	< 200 kg paddy/hour
Labour requirement	1 person	1 person
Energy consumption	1 kWh or 0.5 L/hour gasoline	3 kWh or 1 L/hour gasoline
Recoveries	70% milling recovery = f(initial paddy quality) 70% head rice recovery = f(initial quality, moisture content, and variety)	
Costs without engine	US$ 220–340	US$ 280–540

- provision of information packages and blueprints free of charge to interested parties, such as the private sector (manufacturers) and NARS;
- provision of prototypes for national and international agencies (these can be used either as market test prototypes for developmental work or in demonstrations to potential users and extension services); and
- pilot testing of prototypes in farmers' fields as mentioned earlier can initiate local dissemination. Field tests often draw a large number of spectators and, if the technology seems mature and promises to be profitable for farmers and users (farmers or farmer–contractors), can sometimes result in the placement of orders for machines.

Technology Evaluation Network (IRRI–GTZ Project)

There is a need for a systematic approach to verification of promising technologies which have been developed at IRRI, other research institutes, or by manufacturers and farmers. An engineering technology evaluation network was therefore established in 1993 at IRRI in collaboration with Hohenheim University and with support from the German Government (GTZ Project No. 92.2209.2–01.100 'Postharvest technology for rice in the humid tropics'). The network has the following objectives:

- to pilot-test selected postharvest technologies for irrigated rice under various technical and socioeconomic conditions of Southeast Asia;
- to adapt the technologies to local conditions;
- to initiate technology dissemination; and
- to strengthen technology transfer links between participating institutes.

In a participatory project planning workshop, representatives from NARS in Indonesia, Thailand, the Philippines, and Vietnam (Fig. 12) have selected the IRRI small-area stripper harvesting systems, the IRRI LT-IBDS, and an axial-flow thresher from Vietnam for evaluation and adaptation.

Project proposals for a two-year period were submitted by the NARS. Funding and implementation of

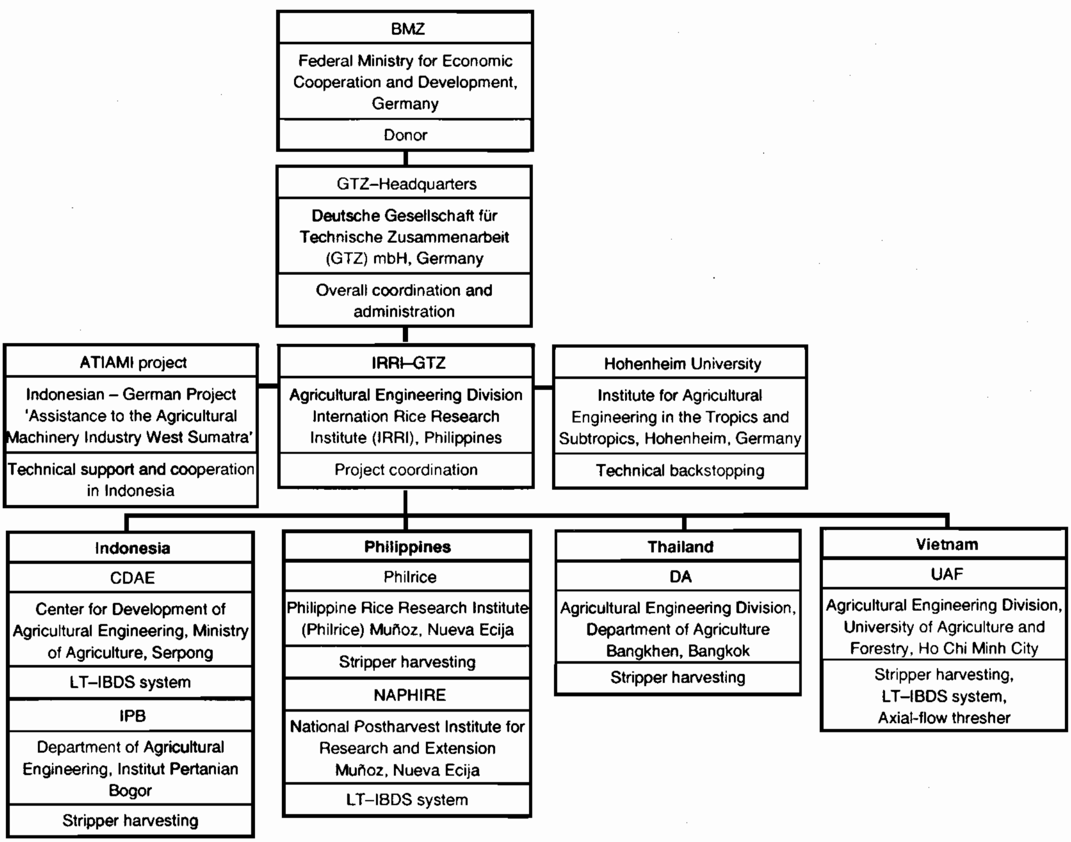

Figure 12. Organisation of the IRRI–GTZ project 'Postharvest technologies for rice in the humid tropics'.

the projects commenced in March 1994. Prototypes of the SG and the ST systems have been shipped to the Philippines, Indonesia, Thailand, and Vietnam. LT-IBDS have been constructed and tested, or are under construction, in Indonesia, the Philippines, and Vietnam. The evaluation of the first season testing, and identification of modifications needed, are currently being undertaken.

Conclusions

Since its establishment IRRI has played a key role as a catalyst in the development of the farm and contract-level operations of the rice postharvest sector by developing technologies, providing knowledge, and workable prototypes for NARS and the private sector manufacturers. Several technologies originating at IRRI are now being used all over the region.

A technology evaluation network established to verify technologies in collaboration with national counterparts is a systematic approach to evaluating promising technologies under a broad spectrum of technical and socioeconomic conditions. Because there are many institutions working with the same technologies at the same time there are also synergies expected which will further support the development of a technology.

Collaboration with other programs of institutions who work on the same or similar topics, such as in-store drying, could benefit all involved.

References

De Padua, D. 1978. Rice post production and processing: its significance to agricultural development. In: Drillion, J.D. Jr. and Sagugit, G.F., ed., Accelerated agricultural development. College, Laguna, Philippines, SEARCA.

Douthwaite, B. 1993. The stripper gatherer system for small-area rice harvesting. Agricultural Engineering Journal, 2(4), 183–194.

Hong-Sik Cheigh, Key-Sun Kim, Myung-Gon Shin, and Tai-Wan Kwon 1986. A system for small-scale farm drying and storage of paddy in Korea. In: Champ, B.R. and Highley, E., ed., Preserving grain quality by aeration and in-store drying: proceedings of an international seminar held at Kuala Lumpur, Malaysia, 9–11 October 1985. ACIAR Proceedings No. 15, 200–205.

Hossain, M. 1994. Asian population growth is overtaking rice output. International Herald Tribune, March 18, 1994.

IRRI (International Rice Research Institute) 1989. IRRI toward 2000 and beyond. Manila, Philippines, IRRI.

— 1993. IRRI rice almanac 1993–1995. Manila, Philippines, IRRI.

Lampe, K. 1994. Preparing the world's rice bowl for the next century. In: Filling the word's rice bowl. Manila, Philippines, International Rice Research Institute.

Mendoza, M.E., Rigor, A.C., Quitco, R.T. and Ilag, L.L. 1988. Grain quality deterioration in on-farm level of operation. National Postharvest Institute for Research and Extension (NAPHIRE), Philippines, Technical Bulletin No. 1.

Muhlbauer, W., Maier, G., Berggotz, T., Quick, G.R. and Mazaredo, F. 1992. Low-temperature drying of paddy under humid tropical conditions. In: Proceedings of the International Agricultural Engineering Conference, Bangkok, Thailand, 7–10 December 1992.

Nguyen Q. Loc, 1993. Self mobile thresher 'Tien Thanh' brand. Ho Chi Minh City, Vietnam, University of Agriculture and Forestry.

Paz, R.R. and Cabacungan, R. 1992. Paddy loss assessment and reduction in on-farm operations. National Postharvest Institute for Research and Extension (NAPHIRE), Philippines, Technical Bulletin No. 13.

Phan H. Hien 1991. Development of axial-flow thresher in southern Vietnam. AMA, 22(4).

Quick, G.R. 1994. Advances in rice mechanisation — small scale production and income enhancing engineering technologies. Paper presented at the Eighteenth Session of the International Rice Commission, Rome, Italy, 5–9 September 1994.

Current Research on the Postharvest Handling of Fruits and Vegetables

M. Herregods*

Abstract

The Commission on Postharvest Handling of the International Society for Horticultural Science (ISHS) seeks to disseminate the most important research findings and technological innovations presented during the many symposia presented in this field around the world.

Promising new postharvest studies in the fields of non-destructive measurement of quality, consumer quality preferences, the biochemical basis of ethylene production, fermentation and aroma ester biosynthesis, and disease resistance are reported, as is information about gene-manipulated varieties with an extended shelf life.

Cultivation and climate have specific effects. Delays in harvesting date must be avoided. Yeasts, bacteria, and fungistatic plant extracts are being investigated. Heat treatments are promising.

To attain a long storage time while preserving quality, more sophisticated refrigeration techniques with a higher relative humidity, controlled-atmosphere storage, ethylene absorption, and nitrogen flushing can be used. Also, new MAP-films with micropores or absorbent layers for ethylene and water vapour are available.

Management with intelligent dynamic control systems will be useful during refrigerated storage. For pre-cooling using forced air-cooling, an ice bank is recommended as a cold source. Temperature management during and after packing requires greater attention.

To reduce bruising during transport, less advanced fruit maturity (firmness), a minimum vibration level ($< 0.75g$) and a convenient packaging (norms for compression pressure) are important.

It is difficult to keep abreast of the promising new physiological and technological topics in the large number of symposia (20 in 4 years) organised by ISHS, IIR, ACIAR, EC Cost '94, MAICH, EC Eurofru, and other regional organisations.

Another 11 symposia have been scheduled for the next 3 years. The International Society for Horticultural Science (ISHS) Commission on Postharvest Handling is setting up a secretariat to collect news on events and activities in each country and disseminate this information to member countries. The structure of ISHS is shown in Figure 1.

Also FAO, NATO, and the European Community wish to collaborate more in scientific activities focusing on postharvest handling of horticultural products.

ISHS will try to provide a summary of the most important results of each symposium, and publish every 4 years a review and future outlook on the state of postharvest knowledge.

Some special publications can also be mentioned:

- standardised methods to determine quality of apples (EC–Eurofru)
- European colour and starch chart (EC–Eurofru)
- Small-scale and inexpensive postharvest handling practices of horticultural products (FAO).

An outline of promising areas of biological and technological research follows.

Marketing for Profit — Satisfying Consumer Preferences

Size, skin quality, freshness, colour, presence of bruises, and decay and disorders have an important influence on price. Also, preferences differ from person to person, and from area to area. Research on consumer preferences in export markets is essential.

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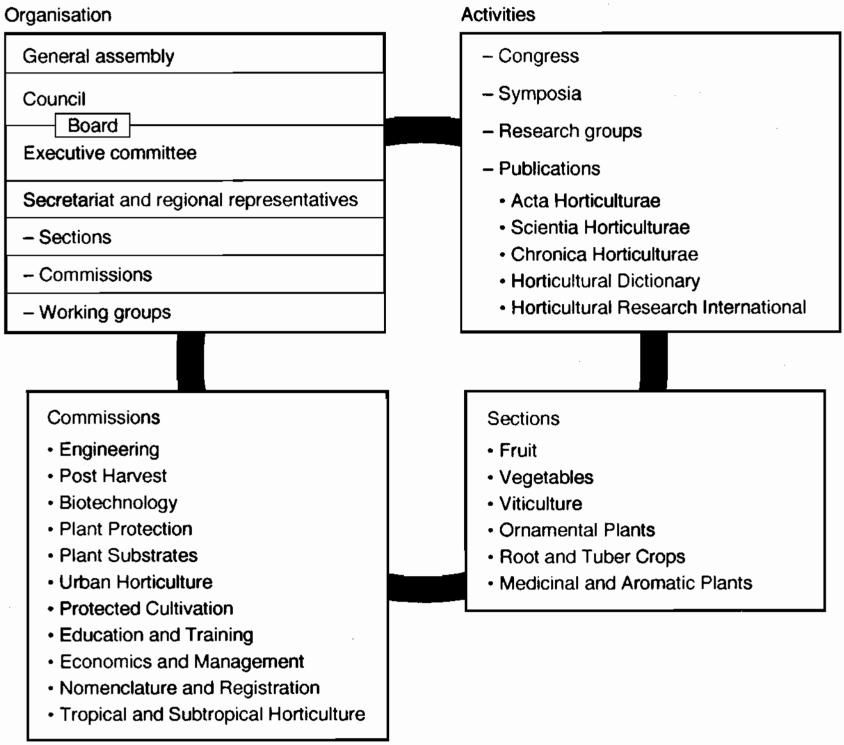

Figure 1. Structure of the International Society for Horticultural Science (ISHS).

Quality must yield profit, with returns greater than production costs. For that reason quality norms are essential. There is also a need for quick, objective, and non-destructive tests. With resonance absorption, firmness can be measured; with fluorescence, chilling injury; localised ethylene production around the product with photo-thermal deflection; bruising directly after impact with relative reflectance; sugar content with light transmission; and internal disorders with NMR.

Fundamental Research Topics

The development of new, gene-manipulated varieties is an important area of fundamental research at present. Characters being targeted include: inhibition of polygalacturonase activity and reduced ethylene production and maturity, the latter coupled with the capacity for restarting maturation by using exogenous ethylene.

There is room for improvement in manipulation of the interactions of maturity, temperature, and internal CO_2/O_2, and ethylene at levels just above the anaerobic compensation point (fermentation).

Precision treatments involving heat, very low O_2 or very high CO_2, at rates just above the levels which cause irreversible damage, have yielded promising results.

The biochemical pathways of ethylene production, ethanolic fermentation, and aroma ester biosynthesis are now understood.

More information on the morphological and chemical bases of disease resistance could help devise methods of reducing decay.

The optimum relative humidity for storage differs from commodity to commodity. For tomatoes, cucumbers, and sweet peppers high relative humidities and condensation must be avoided; for carrots and cabbages, on the other hand, very high relative humidities (96–98%) are needed to limit decay.

Cultivation and Climate Effects

There is much interest in reducing the variability in maturity and quality of the fruits on individual trees. Studies of methods of avoiding root stress (heat, drought), with its negative effects on quality, product structure, maturity, and shelf life, are also receiving attention. The stimulation of fruit colour (red or yellow colouring) separately from maturity is another new area of scientific interest.

Harvesting Date

Too late or too early harvesting has to be avoided, also the variable quality and maturity of all the fruits on the same tree reduced to avoid picking on too many dates.

Control of Postharvest Decay

The best defence methods are preharvest chemical treatments. Postharvest chemical treatments by dipping or drenching, or thermo-nebulisation, have given good results in some circumstances, but their effectiveness is influenced by cropping environment.

Cleaning, and chemical and physical treatment of the air of cool rooms or packing rooms, lowers the incidence of fungal spores. Fruit varieties differ in their resistance to fungi as regulated by antifungal compounds (phytoalexins, antifungal gum fractions after wounding, pathogenic related proteins) and morphology (calcium content, dry matter, wax layer of the skin).

Fungistatic resistance can be stimulated by U.V. irradiation (16–72 kJ/m^2).

Thymus oil, cinnamaldehyde, carvone, perrollaldehyde, salicylaldehyde, chitosan, or a mixture of unknown plant extracts or wound healing agents such as potassium phosphonate, are being evaluated. The products are not always successful, due to the lack of uniformity in the concentration of active ingredients, and the short period of effectiveness.

Yeasts (by alkalinising of the environment and competition for the substrate) and bacteria (by production of lipopeptides) are phytotoxic for some moulds. The production of effective yeasts and bacteria as commercial products has up to now been difficult and expensive.

For some commodities, heat treatment at 55°C for 2–7 minutes or 42°C for 30–60 minutes, accelerates ripening and reduces disease. Temperature–time regimes are commodity specific and there is a narrow margin between safe, effective application and fruit damage. The combination of irradiation at 75 kGy and heat treatment has some applications. The effect of lowering temperature, and optimum relative humidity, and increasing CO_2 concentration is to reduce decay.

Optimum Storage Conditions

Good storage refrigeration techniques are essential.

The outlays required for suitable refrigeration can result in substantially higher profits through reductions in weight loss and fruit disorders and decay during storage. Using the most appropriate temperature of refrigeration, the regulation of the defrosting cycle, a discontinuous but sufficiently high air circulation, improved insulation, a thermostat range that is not too narrow, and a sufficiently open stacking pattern for produce are important factors which will improve the effectiveness and reliability of refrigerated storage (Fig. 2).

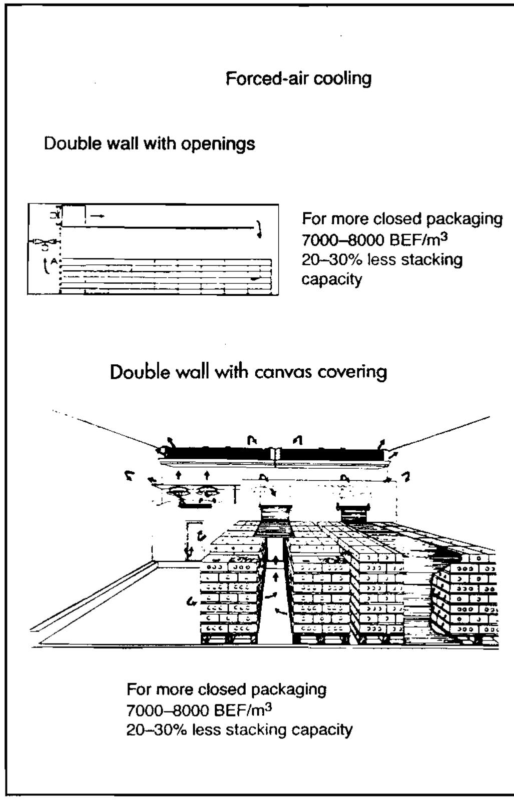

Figure 2. Principal features of forced-air cooling for horticultural produce.

For long storage periods, to preserve external appearance and intrinsic quality of the fruit, more sophisticated storage techniques such as controlled-atmosphere (CA) storage and ethylene absorption are necessary.

Nitrogen flushing without the use of scrubbers, and reducing ethylene, farnesene, and volatile components, have good prospects.

Intelligent dynamic control systems during storage using physical–mathematical models reduce risks of disorders and energy consumption.

New packaging films with micropores improve storage life, enhancing water permeability and avoiding condensation. There are also new plastic films with a fungistatic layer (sorbic acid), and impregnated with ethylene oxidants (silicon oxide) or water absorbers.

Wet, Forced-air Cooling before Transport

The current desire to market a product of higher consumer quality, to extend the shelf life in trade, and to reach more distant markets requires rapid cooling after harvest, especially for strawberries and small fruits.

As well as conventional cold rooms, precooling systems are available, including vacuum cooling, hydrovacuum cooling, hydrocooling, top-icing, package liquid-icing, and forced-air cooling. Forced-air-cooling with ice-banks as cold sources are frequently used, with many benefits.

Temperature management during and after packing is an area which needs more attention. Temperatures should be reduced before shipment. In a refrigerated trailer the cooling capacity is sufficient only to keep the product cool, not to reduce the temperature.

Reducing Bruising during Transport

Bruising during transport is affected by fruit maturity, vibration level, and packaging.

During transport in trailers, bruising occurs mostly in the middle of the upper box of a stack and in the rear part of the trailer, where vibrations at 3–4 Hz are more than 0.75*g*.

For packaging to remain stable during 800 km transportation over 2 days at 2°C and 90–97% relative humidity, the minimum compression pressure (kg) of the cardboard box must be:

$$\frac{\text{height of pallet (cm)} \times 1.5 \text{ gross weight (box)} \times 2}{\text{height of the box (cm)}}$$

Water absorption of the carton must be lower than 150 $g/m^2/30$ minutes.

Summary

Proper preservation methods are needed to reduce the very high percentage of postharvest losses of fruit and vegetables, to deliver the quality required by particular markets, to store the products for a longer period, to reach higher-priced markets further afield, and to achieve a sufficiently low temperature during transport, marketing, and selling.

Improved, cheaper, and environmentally friendly storage techniques are now available, as well as preharvest procedures that enhance subsequent storage characteristics.

The following are among the new approaches for reducing losses caused by physiological disorders, diseases, and weight reduction, and for improving postharvest quality and shelf life.

- new genetically manipulated long-life varieties
- better understanding of the biology of maturity, chilling, fermentation, and pathogenic resistance
- new data on the influence of climate, soil, fertilisation, drought, and heat stress
- new criteria for determining optimal harvesting time
- more efficient refrigerating techniques
- better management of controlled atmospheres during storage and transport
- humid forced-air precooling techniques
- optimal combination of the storage parameters maturity, temperature, relative humidity, CO_2, O_2, and ethylene, tailored to the desired storage time and the postharvest quality required
- CA storage for berries and tropical fruits
- maximum impacts on the reduction of bruising, storage disorders and decay
- new films for modified atmosphere packaging
- new techniques to optimise conditions during transport and marketing
- non-destructive methods of determining quality and maturity.

ISHS

More information about individual membership of the International Society for Horticultural Science (ISHS) can be obtained from the ISHS Secretariat, Kardinaal Mercierlaan 92, 3001 Leuven, Belgium: phone: 32 16 229427; fax: 32 16 229450.

Grain Drying

Cereal Grain Drying Problems in Vietnam

Nguyen Trong Hien*

Abstract

Paddy production in Vietnam has increased steadily over the past 10 years, and further increases are planned, centred primarily on the deltas of the Red River and the Mekong River. Lack of appropriate mechanical drying facilities is a severe impediment to maximisation of the benefits of increased production. The warm, humid climate and delays in drying of wet grain lead to problems with insects, moulds and mycotoxins, and heat damage, which are responsible for most of the problems encountered in storing, processing, and distributing grain.

Many drying systems are in use in Vietnam, relying variously on sun drying and mechanical drying. Several types of mechanical dryers have been introduced but often their running costs are high and they are not suited to small-scale farmers. Warehouse drying facilities, where they exist, cannot cope with a continuous supply of 'dripping wet' paddy during wet season harvesting.

The primary objective of grain drying research, development, and application in Vietnam is therefore to make the technology more practicable for rural areas. Low cost and simplicity of operation are key objectives. Also, research is continuing on the use, at farm level, of the more abundant and inexpensive fuels such as rice husks and coal.

THE deltas of the Red River and the Mekong River are the two most important rice-producing areas of the Socialist Republic of Vietnam, a predominantly agrarian Southeast Asian nation. In those areas, measures to intensify farming and increase paddy production are being pursued.

Annual production of food grains in Vietnam is steadily increasing (Table 1).

There are three paddy harvests in the country. The main harvest in the south is in December–January, yielding about 54% of the total production. The April–May harvest yields 34%, and the July–August harvest 12% of total production.

About 6 million ha of land are being cropped in Vietnam, where all paddy is grown in wet fields. Nearly 0.5 million ha are used in producing the additional summer–autumn crop of about 2.5 Mt.

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The warm, humid tropical weather with sudden showers or prolonged rain severely disrupts postharvest activities. The summer–autumn and the early tenth month crop in the south often given high yields, but their harvest occurs in the rainy season. In the north, on average one of every 2–3 crops is harvested on rainy days.

The warm, humid climate and delayed drying of wet grain lead to problems with insects, moulds and mycotoxins, and heat damage, which are responsible for most of the problems encountered in storing, processing, and distributing grain.

For safe storage and to prevent quantitative and qualitative losses the first priority is to reduce the excess moisture content of grain. Drying is the major postharvest operation for all crops and Vietnam makes use of various drying systems.

This paper describes general aspects of paddy drying in Vietnam, including current research work in this important area.

Methods of Paddy Drying

Many drying systems are in use in Vietnam, relying variously on sun drying and mechanical drying.

Table 1. Production of food grains in Vietnam, 1990–1994 (Mt)

Year	Rice	Maize	Root crops and other cereals (in paddy equivalent)	Total
1990	19.225	0.671	0.841	20.737
1991	19.622	0.672	0.918	21.212
1992	21.600	0.747	1.032	23.379
1993	22.277	0.830	0.875	24.082
1994	22.300	0.984	0.456	24.240

Sun drying

Natural sun drying in the open air is the most common system used in Vietnam. It is the traditional drying practice of Vietnamese farmers.

After harvesting, paddy is sun dried within 2 or 3 sunny days. In normal practice, paddy is spread out on a concrete floor for sun drying. About 0.5–1 t of paddy covers an area of 100 m^2. On sunny days the temperature of the grain in a layer 15 cm deep reaches 35–40°C.

The grain is manually turned to obtain uniform drying. Figure 1 shows the directions of movement of heat and vapour during sun drying.

Vietnamese farmers rely on their own experience to check the moisture content of food grains during sun drying. The grain is taken in when its moisture content is 13–14% wet basis or lower, which is deemed to be safe for storage.

Windrowing and sun drying are highly dependent on field conditions and weather. Natural drying is difficult or impossible during the rainy season, when grain thus becomes particularly prone to infestation by insects and moulds, leading to losses during storage.

Under the present marketing system in Vietnam, based on the food control law, because of the difficulties of drying in the wet season (summer–autumn crop), farmers now sell their surplus paddy or early crop immediately after harvest (summer–autumn crop).

The most difficult problem faced has been the great quantity of rice procured by the state that is heavily damaged by moisture and contains impurities beyond the fixed quotas. Rice harvested at this time generally has a high moisture content: it may exceed 25–26%, and be 'dripping wet'.

The moisture content of food grains delivered to government warehouses is generally about 17–18%. Spoilage of grain is unavoidable if the warehouse does not have a dryer. State warehouses have therefore become the main target for improvements in postharvest technology, particularly drying facilities.

Mechanical drying

Several types of mechanical dryers have been introduced for drying food grains in Vietnam:

- flat-bed forced air dryer;
- upright screen type forced air dryer;
- grain circulating dryer (with baffle or inverted troughs, multiple air duct type);
- continuous-flow grain dryer with tempering stage;
- crop drying in bag stacks.

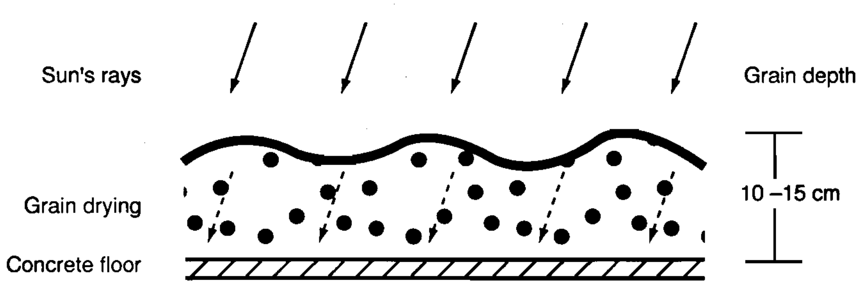

Figure 1. Directions of movement of heat and vapour during sun drying.

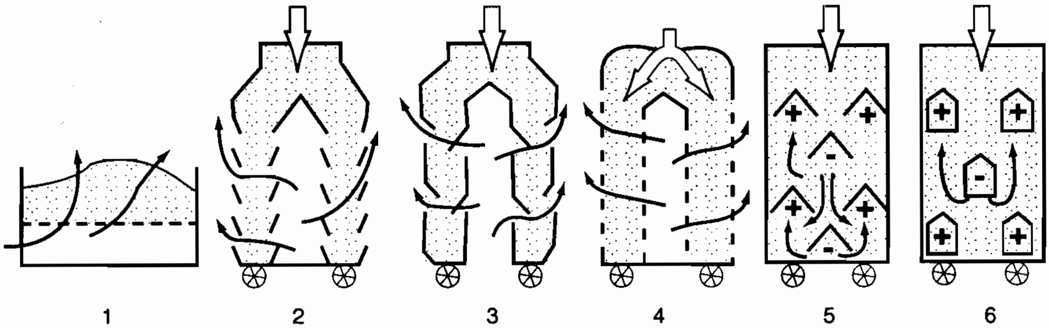

Figure 2. Modes of operation of various types of mechanical dryers: 1. flat-bed forced air; 2. shutter; 3. baffle; 4. upright screen; 5. inverted trough; 6. multiple duct.

The modes of operation of the various types of mechanical dryers used in Vietnam are show in Figure 2.

Several of the dryer types used have been imported from the developed countries, some were locally made. Despite these advances of technology, adoption of, and investment in mechanical drying in Vietnam remain very low, for the following reasons.

- Running costs are high. The liquid fuel (kerosene) used as the energy source for heating is expensive and must be imported. Also high is the initial cost of imported dryers.
- The drying facilities are generally not suited to the small-scale farmers that produce the bulk of the crop.
- Warehouse drying facilities cannot cope with a continuous supply of 'dripping wet' paddy, because of the long drying time required, the low yield of the facility, and the shortened life of the dryer.

Artificial drying will be widely used if the pattern of drying facilities in Vietnam suits social and economic conditions and there is a surplus of rice for export.

To obtain maximum returns, it is therefore essential to determine whether particular drying systems will be appropriate, based on costs, scale of operations, and type of fuel used.

Paddy and Maize Drying Research and Development in Vietnam

Grain drying is a problem common to those countries which harvest grain during a rainy season. Many types of mechanical dryers have been developed, but none has gained wide acceptance, and none is the best for all conditions. This is the main problem: to decide on the correct type and scale of dryer. Theoretically, a large-scale dryer should be the most economical, but large dryers do not always meet local requirements. Appendix 1 gives details of a selection of grain dryers in use in Vietnam.

The decision on the method of drying also depends on the climate during the harvesting season, the labour situation, the way the rice is cultivated, the kind of fuel available, and how the grain is handled, transported, and stored.

Grain drying research and development in Vietnam should aim to:

- modify existing drying facilities to use local materials for fuel, furnace construction, etc.; and
- design, develop, and fabricate mechanical dryers or manual systems appropriate to farm-level operations.

The greatest problem is how to reduce the cost of drying.

Firstly, alternative sources of energy to dry paddy, maize, and other food grains need to be investigated. At present, apart from oil there are two abundant sources of energy in Vietnam: rice husks and coal.

Rice husks, a by-product of milling, comprise about 20% of paddy by weight and have a calorific value of about 12500 kJ/kg, equivalent to around one-third that of kerosene. Rice husks are plentiful in production areas.

In northern Vietnam coal is cheap and readily available. Its energy value is in the range 15500–25000 kJ/kg, depending on quality.

Secondly, the selection of drying methods and equipment must be based on low cost, ease of manufacture by rural families or local workshops, and simplicity of operation and maintenance.

We have divided drying operations into three levels with varying scales in capacity, level of procurement, and handling.

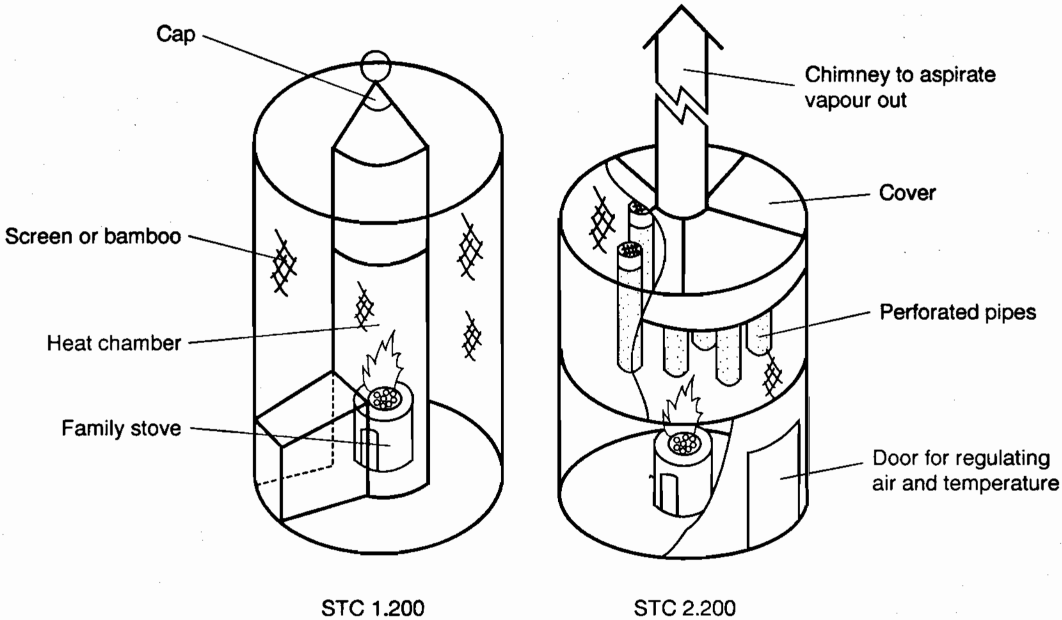

Figure 3. Manual grain dryers with a cooking stove as the heat source.

1. Small scale

The experience of many developing countries in Southeast Asia is that modern mechanised automated drying systems are not always the ideal solution.

In the socioeconomic circumstances of Vietnam we know that paddy harvested in the rainy season ideally should be dried at or near the point of harvest. Researchers need to design and supply simple dryers, based on established drying principles, that can be locally made and adopted by farmers and, where necessary, modified or improved to suit local circumstances.

Several manual drying facilities have been operated in the field with promising results. These manual dryers, built around the common family cooking stove as the heat source, may be popular among farmers by reason of their simplicity; low cost; and readily available construction materials. The dryers shown in Figure 3 can be made by farmers from bamboo, other types of wood, and other common materials.

The drying rate and quality of paddy are higher than can be achieved by natural sun drying. Moreover, losses can be prevented because the dryer is available on site during rainy periods. It is especially useful in the highlands, in wet fields, and in regions with no electricity and with transport difficulties. These advantages apply in spite of the uneven drying between the interior and exterior layer of paddy.

Other dryer types are operated as cooperative facilities by groups of farmers (see Appendixes 1 and 2).

In June–July 1993 a competition on drying facilities was organised at Can Tho city (Mekong delta) to evaluate the advantages and disadvantages of these facilities. Entries came from provincial engineering, senior college, and food departments. Some were of good construction, easy to transport, and assemble and disassemble. Some used local materials and indigenous fuel such as wood, bamboo, rice hulls, and mud coal: some were easy to install but had unsatisfactory drying costs.

In spite of these, the demonstration of rice drying was an opportunity to demonstrate various facilities and evaluate their advantages and disadvantages. It provided information of interest to those seeking to design new methods and equipment appropriate to farm-level drying.

2. Medium capacity

Some medium-scale dryers are shown in Appendix 2. Our interest centres on dryers which use burning rice husks as the heat source for drying.

Research on gasification of rice husks has been carried out in many parts of the world, and several designs of rice husk gas furnaces have been developed for drying grain. We have developed a furnace much like the HB50 Yamamoto, but almost totally locally made.

The units were installed and operated in 1990 at Cao-lanh district and Dong Thap province for paddy drying, and in 1991 at Buon Ma Thuat, a highland site, for maize drying, with the crop dried using the stack of sacks system. The drying cost is low. The fuel, rice hulls, is abundant at rice mills, and the gasification of husks yielded good energy efficiency. The investment in the drying facility was low. In 1995 we intend to use it as the heat source for grain drying in conjunction with the thermo-isolation recirculating dryer in central Vietnam.

3. High capacity

There are few large-scale dryers in Vietnam, almost all of them imported. Producers and processors seeking low drying costs and a good quality product are the main users.

In Vietnam, large-scale dryers run only for short periods during the wet season. The main reason for the low level of adoption of large-scale grain dryers is their high cost which, at a time when commodity prices are rising, places them beyond the reach of those who most need them.

Conclusions

The primary objective of grain drying research, development, and application in Vietnam is to make the technology more practicable for rural areas; low cost and simplicity of operation are the key objectives.

Finally, continued research on the use of the more abundant and inexpensive fuels such as rice husks and coal at farm level should be vigorously pursued to increase the technical and economic advantages of grain drying technology.

Acknowledgment

I would like to express my thanks to the organisers of this workshop, MAFI/ACIAR/AFHB, for giving me the opportunity to attend and present this paper.

Bibliography

Arboleda, J. 1982. Husk burning air heaters. Report of a Consultancy Mission, 27 June–13 August 1982.

FAO (Food and Agriculture Organization) 1982. Utilisation of agricultural wastes for energy conversion and product processing. Bangkok, Thailand, FAO Regional Office for Asia and the Pacific, No. 61.

Hall, D.W. 1970. Handling and storage of food grains in tropical and subtropical areas. Rome, FAO Development Paper, No. 90, 40 p.

Appendix 1. Specifications and characteristics of selected grain dryers in Vietnam.

Facilities Dryer/brand/site	Structure type	Model	Material	Type of heater	Fuel	Consumption	Capacity	Remarks (features)
A. Low capacity								
Manual drying facilities								
	Sun drying	Natural drying	Concrete floor		Sun's rays	3 sunny days	0.5–1t/100m^2	Easy to operate. No electricity required.
STC 1.200 PHTI STC 2.200 PHTI	Upright screen type with perforated pipes	Manual facilities (without electricity)	Screen or bamboo	Family stove	Mud coal	0.08 kg/hour	200 kg/batch	Portable, experimental design
Mechanical dryers								
Batch in bin 1000 PHTI	Bolted bin with shutter	IRRI design	Wood	Furnace	Mud coal	3.2 kg/batch	1000 kg/batch	Compact and portable. Experiment data.
Batch in bin 1500 PHTI	Bolted bin with shutter	IRRI design	Wood	Furnace	Mud coal	4.5 kg/hour	1500 kg/batch	Experiment on shelled maize
				Furnace	Rice husks	12 kg/hour	1500 kg/batch	Low power requirement
An Giang Mechanic Workshop	Upright screen	Circulating dryer	Metal	Burner	Kerosene	3.4 L/hour	1500 kg/batch	Portable
Can Tho University	Flat bed	Flat bed perforated	Wood brick	Furnace	Rice husks	26 kg/hour	3500 kg/batch	Fixed
Haugiang Mechanic Workshop	Perforated pipe	Silo dryer	Metal	Furnace	Rice husks	17 kg/hour	1600 kg/batch	Fixed
Long An Food Grain Dept.	Upright screen	Circulating dryer	Metal	Furnace	Charcoal or wood	3 kg/hour	900 kg/batch	Portable
Phu Lam Cooperative	Flat bed	Flat bed perforated	Brick	Furnace	Rice husks	17 kg/hour	2500 kg/batch	Fixed
Long An 1–5 Workshop	Baffle type	Column dryer	Metal	Furnace	Mud coal	3.2 kg/hour	1500 kg/batch	Portable
Long An 1–5 Workshop	Crop drying in stack	Stacks of sacks	Metal	Furnace	Wood	9 kg/hour	1200 kg/batch	Portable
Song Hau Farm	Upright screen	Circulating dryer	Metal	Furnace	Rice husks	10 kg/hour	2000 kg/batch	Portable

Appendix 1. Specifications and characteristics of selected grain dryers in Vietnam.

Facilities Dryer/brand/site	Structure type	Model	Material	Type of heater	Fuel	Consumption	Capacity	Remarks (features)
B. Medium capacity								
MST 25 VLT 1 PHTI	Crop drying in stacks of sacks	Stacks of sacks	Pallette	Gasification	Rice husks	50 kg/hour	25–35 t/batch	Efficiency of husk furnace 98 with dust collection
MST 25 VLT 2 PHTI	Flat bed with perforated pipe	Flat-bed forced air	Steel perforated	Husk furnace	Rice husks	50 kg/hour	25 t/batch	Pattern. Low cost drying
Satake MDR (Jap) 7500 M.Hai Province	Baffle with tempering bin	Circulating dryer	Steel	Burner	Kerosene	6–13 L/hour	1.2–1.5 t/hour	Fixed
Satake MDR (Jap) 30 C.Long Province	Baffle with tempering bin	Circulating dryer	Steel	Burner	Kerosene	5 L/hour	300 kg/hour	Fixed
Aeroglide (USA) HCM City	Inverted trough type	LSU circulating	Steel	Burner	Kerosene	9.5–10 L/hour	2.5 t/hour	LSU design
MST 2.5 (local) Mekong Delta	Inverted trough type	LSU circulating	Steel	Husk furnace	Rice husks	100 kg/hour	2.5 t/hour	LSU design
Extraction moisture unit (Lister. England)	Flat-bed forced air	Flat -plate perforated	Steel	Burner	Gasoil	28 L/hour	20 t/batch	Two beds
C. High capacity								
Cimbria (Denmark) Chai Thanh District	Multiple air ducts	Circulating	Steel	Husk furnace (boiled water)	Rice husks	150 kg/hour	10 t/hour	Fixed – air heated by boiling water
Cimbria (Denmark) Tra Noc District	Multiple air ducts	Circulating LD7	Steel	Husk furnace (vapour)	Rice husks	250 kg/hour	20 t/hour	Fixed – air heated by steam
(French) Tra Noc District	Baffle	Circulating	Steel	Burner	Kerosene	150 kg/hour	20 t/hour	
(French) Can Lanh District	Baffle	Continuous flow	Steel	Burner	Kerosene	240 L/hour	45 t/hour	Three units
SHL-10 (PHTI) Quy Nhon City	Inverted trough type	Recirculating dryer	Thermo-isolation	Gas husk furnace	Rice husks	120 kg/hour	10 t/hour	Will install in the centre of Vietnam

Appendix 2. Diagrams of various small- and medium-scale drying systems.

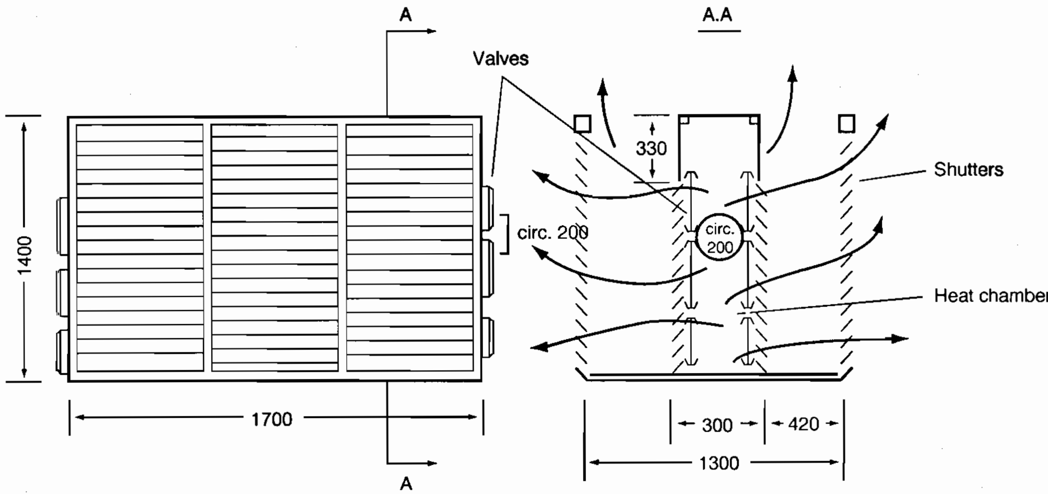

Figure A1. Small-capacity (1000 kg/batch), batch in-bin type dryer (timber, bolted, with shutters).

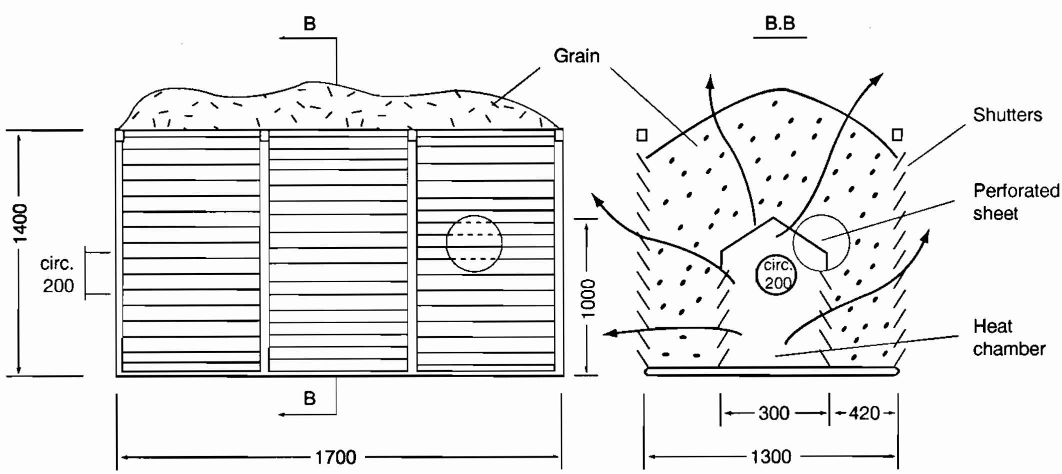

Figure A2. Batch in-bin dryer of 1500 kg/batch capacity.

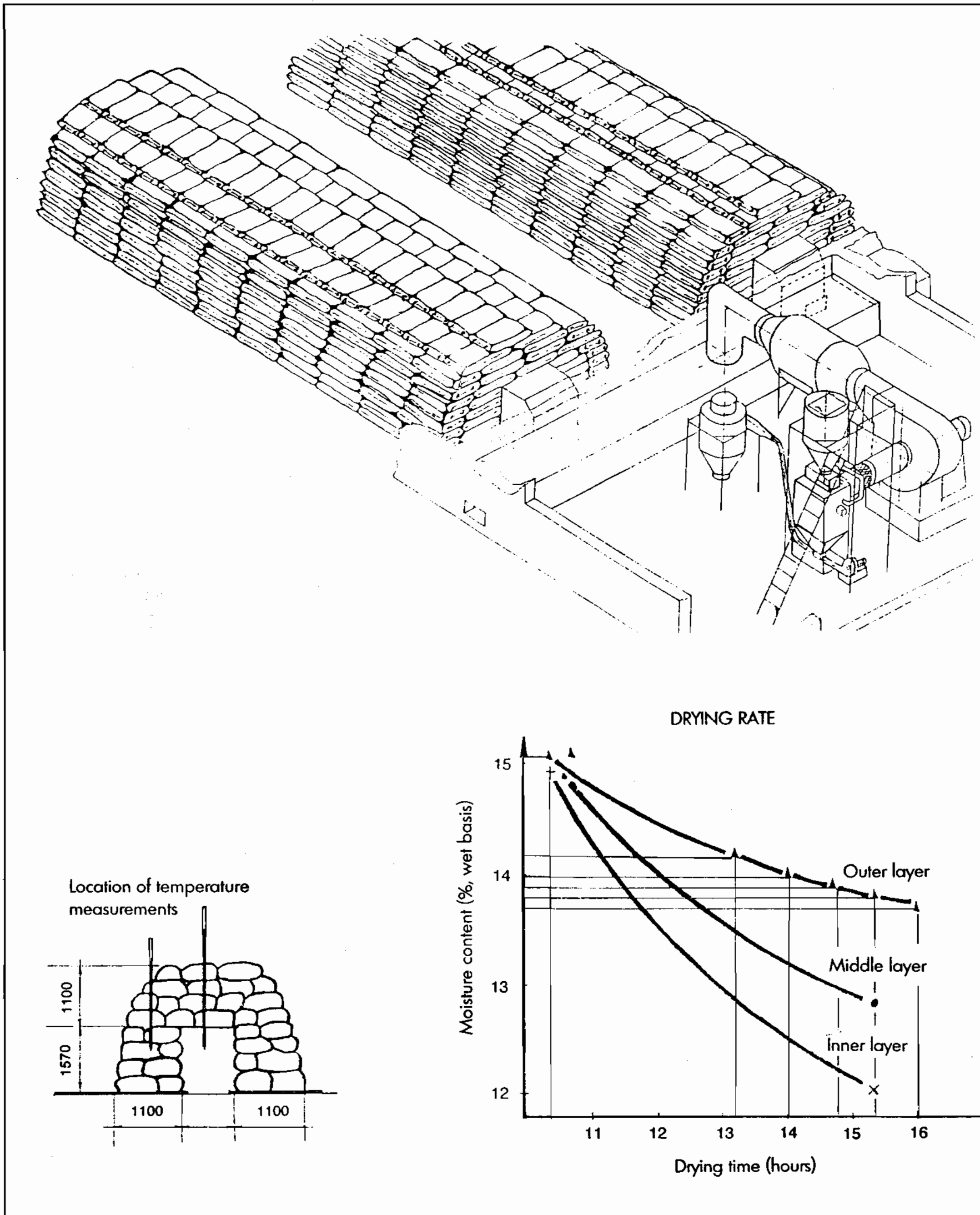

Figure A3. Drying grain in bag stacks. The capacity of the system shown, which uses burning rice husks as the heat source for drying, is 35 t/batch.

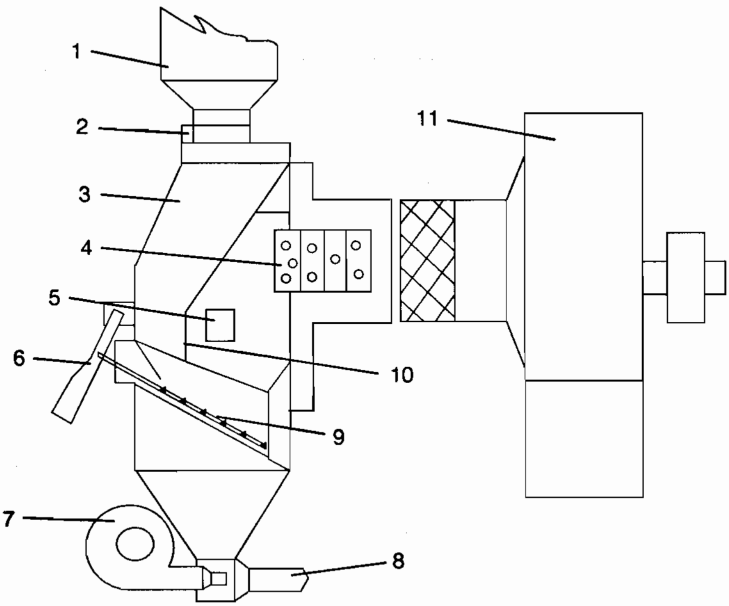

Figure A4. Schematic drawing of rice-husk furnace: 1. husk hopper; 2. husk valve; 3. main body; 4. gas combustion area; 5. inspection port; 6. discharge control device; 7. ash blower; 8. ash pipe; 9. discharger; 10. husk valve; 11. centrifugal fan.

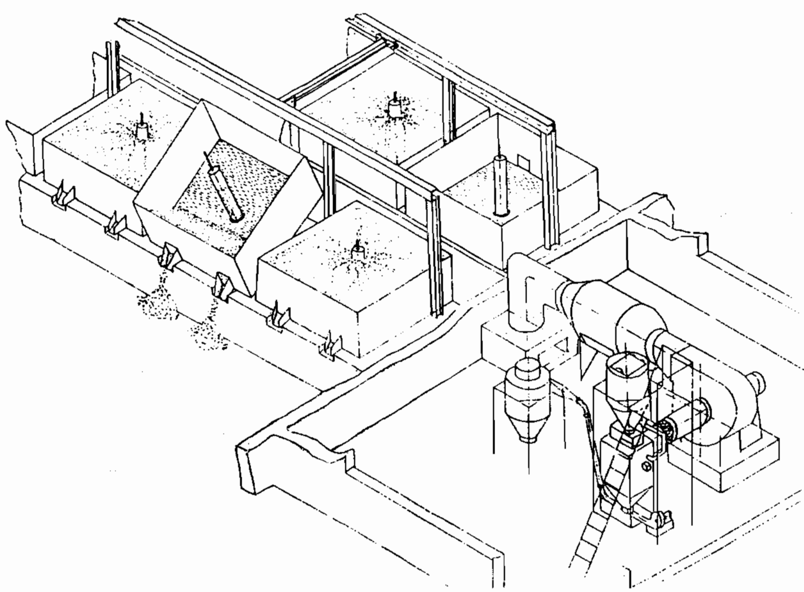

Figure A5. Flat-bed forced air drying with perforated piping system, capacity 25 t/batch.

In-store Drying and Quality Maintenance in Grain

G.S. Srzednicki and R.H. Driscoll*

Abstract

Drying is one of the conventional postharvest operations to preserve the quality of foods during storage. This paper describes the fundamentals of the drying mechanism in grain as a function of ambient process conditions, particularly those encountered in humid tropical climates. Grain quality as perceived by the industry is discussed. Two-stage drying meets industry objectives on quality maintenance by preventing discoloration of high moisture grain and reducing cracking of skin dry kernels. The mechanism of in-store drying and its effects on quality are discussed in detail. Other important considerations for adoption of in-store drying include interactions with storage and milling, and energy requirements. These are considered in the conclusions of the paper.

DRYING is one of the most efficient methods of food preservation. In earlier days, under climates with very pronounced seasons, it was probably the most efficient method of holding grain from one harvesting season to another. Transport of foods, especially during wars, also encouraged the development of different methods of drying.

The removal of moisture decreases the water activity of the product and thus decreases its susceptibility to microbial attacks. Lowering water activity also reduces chemical and biochemical activity in foods.

In brief, dehydration enhances the shelf life of the product and helps to maintain its quality.

General Principles of Food Dehydration

In this section we summarise physical and chemical phenomena occurring during dehydration. The quality of dried product depends on physical parameters of the drying process, which is why it is necessary to consider these issues. We draw heavily here on papers by Van Ardsdel et al. (1973), Sokhansanj and Jayas (1987), and Young and Wijesinghe (1994).

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Food products in their natural state, i.e. shortly after harvest, may contain significant amounts of moisture, ranging from over 80% wet basis (w.b.) for fruits and vegetables to 20–30% w.b. or more for grain. The moisture is distributed throughout the product. The surface moisture is evaporated quite rapidly and the process occurs at a constant rate for a given set of conditions. This initial phase of drying is called the 'constant rate period'. Once surface moisture has been removed, the drying rate decreases and moisture movement to the surface of the material is driven mainly by diffusion inside the material. This more advanced phase of drying is called the 'falling rate period'. The drying rates during the falling rate period are considerably lower than during the constant rate period. The transition between the constant and falling rate period is called 'critical moisture content'. For many materials, the critical moisture content is not a clear-cut limit but a gradual transition. It is a function of the *material type* and the *particle size.*

The drying material is surrounded by air at a certain temperature and relative humidity. A prolonged exposure to the ambient air will result in a state of equilibrium between the moisture in the air and in the product. This state of equilibrium, which will be characterised by absence of net transfer of moisture between the product and the air, is called 'equilibrium relative humidity' (e.r.h.). Thus, for a given temperature and relative humidity, the moisture content of the product is a function of the *material* and the *position in the cycle* (drying or wetting).

Over the past thirty years there have been several attempts to predict the mechanism of drying using mathematical modelling techniques. Among the most successful ones was the 'near equilibrium model' developed by Thompson (1972). Thompson's model predicts changes in grain temperature, moisture content, and dry matter deterioration, taking into account factors such as heat transfer through the walls of the bin, respiration of the grain mass, and conditioning of the grain through continuous aeration. The method of analysis was to construct a heat and mass balance across a single thin layer of material. A deep bed of grain was considered as multiple layers of grain, with a stream of air perpendicular to each layer.

A great advantage for the modelling of the process and development of drying simulations has been the availability of fast computers, especially during the last few years. A near equilibrium model has been developed initially for maize (corn) under the U.S. conditions and further adapted to rice by Sutherland (1984). The accuracy of predictions while using a model depends on understanding of thermophysical properties of the material. These properties can be affected to some extent by environmental factors during growth (preharvest conditions, resulting in a change in the composition of the product), varietal differences and even moisture distribution in the product.

One of the main advantages of the drying simulations is the capacity to predict the drying time for a particular batch of material. This value, as well as the throughput of a particular dryer, are determined by the drying rate of the product. The drying rate is determined by basically two factors: the *airflow rate* and the *relative humidity* of the drying air. The latter is in turn a function of the temperature and moisture content of the drying air.

When the drying process is in the 'constant rate period' at a given airflow rate, the drying rate depends mainly on the difference between the relative humidity of the drying air and the 'equilibrium relative humidity' of the product. The relative humidity of the drying air can be reduced by an increase in temperature or by dehumidification. Since evaporation of the surface moisture is the driving force at this stage of drying, an increase in temperature of the drying air will result in an increase in the drying efficiency without affecting the quality of the product (the latter being in fact cooled down).

During the 'falling rate period', the moisture movement towards the surface of the material is driven by diffusion of moisture in the product, which is a function of the *vapour pressure of water* (itself a function of moisture content and temperature), and the *structure of the material.*

While moisture moves towards the surface of the material, water soluble substances are also migrating in the same direction. This is particularly true for the larger solutes, whereas some smaller dissolved molecules tend to migrate in the opposite direction. The accumulation of significant quantities of solutes near the surface of the product will result in the creation of a hardened, less permeable outer layer, resulting in a decrease of the drying rate. The formation of such a layer is commonly called 'case hardening'. 'Case hardening' is often enhanced by high temperatures. Another undesirable effect during the 'falling rate period' is the shrinkage of the product. Finally, high temperatures during drying may lead to the loss of volatile compounds from products rich in such substances.

Principles of Two-stage Drying

Although principles described in this section may apply to various agricultural products, for the sake of simplicity, we will refer mainly to grain. Taking into account different drying rates of grain at different moisture contents, combination or two-stage systems have been developed in a number of countries.

The first stage of such systems involves high temperature, fast drying in order to reduce the moisture content from its harvest level down to a level at which the product water activity is about 0.85. This corresponds to a moisture content of about 18% (wet basis) for rice and maize. This moisture is concentrated near the surface of the grain and can be removed quite easily. After completion of the first stage of drying, grain is transferred into a storage bin, where it is tempered (cooled) and then dried using lower air temperatures. The second stage involves removal of moisture from the centre, and since it is diffusion controlled, leads to a reduced drying rate. This drying stage occurs in the 'falling rate period'.

In-store drying can also be called low-temperature in-bin drying. It may be used where grain remains in-store until milled or sold, or where drying is seen as the primary purpose of the equipment, with the grain being removed to another bin for aerated storage. The advantage of the latter is an increase in throughput resulting in reduction of capital cost per unit dried. This situation may arise at a trader's level where fast turnover of grain is required so that fresh stocks may be purchased.

The main advantages of two-stage drying are (Morey et al. 1981):

- reduced energy requirements;
- increased drying system capacity; and
- improved grain quality.

The reduced energy requirement over conventional drying technology is due to the increased air efficiency compared with continuous-flow dryers, so that less heat is lost to the atmosphere. The second advantage is related to the capacity of the first stage 'fast' dryer, since discharge of the grain at a higher moisture content before cooling will free the dryer for the next load of high moisture grain. This corresponds to the 'constant rate period' during which continuous-flow dryers are more efficient. The third point mentioned above, relates to the relaxation time given to grain during second stage drying, which allows moisture gradients within the grain to equilibrate, preventing the outer layer of the grain from being overdried and hence made brittle and susceptible to fissures and cracking. It seems that during this stage, the interior of the grain is under tensile stress, whereas the outer layer is being compressed (Fig. 1).

In-store drying was first implemented in the USA in the 1950s among maize farmers in the North Central Region and rice farmers in Texas (Do Sup Chung et al. 1986). However, this technique was used mainly on a trial-and-error basis and occasionally led to spoilage of grain due to extremely low airflow rates combined with too high drying temperatures. It was not until the early seventies after the development of Thompson's (1972) drying model that systematic research into in-store drying began in the USA, Europe and Australia (Srzednicki and Driscoll 1994). Computer simulations were run based on Thompson's model, using long-term weather data (temperature and relative humidity) from different locations of cropping areas, in order to study the drying process in each place.

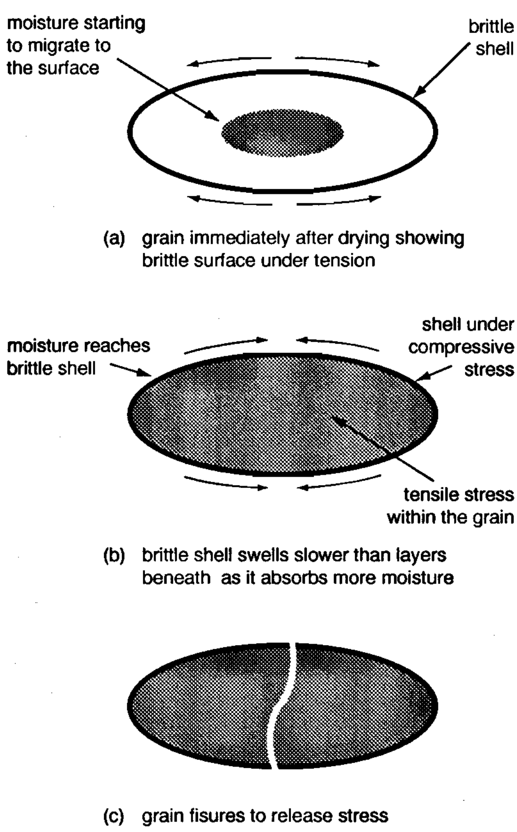


Figure 1. Concept of rice fissuring due to moisture migration within the grain (from Bulaong 1994).

In spite of the fact that weather conditions in humid tropical climates are less favourable than temperate climates for in-store drying, due to high ambient temperatures and relative humidities, research on the use of aeration in combination drying had began as early as the 1960s (Calderwood 1966). Initially, aeration was used for cooling paddy previously dried in a high temperature dryer, by aerating a mass of grain with ambient air in a holding bin. In the late 1970s researchers in a number of subtropical and tropical countries started studying conditions for successful adoption of in-store drying of paddy, later also researching its application to crops such as maize, peanuts, and soybeans. They extended the techniques initially used in temperate climates, namely optimisation by application of drying models, to tropical conditions. In order to compensate for the higher daily relative humidities, higher airflow rates and additional heat were incorporated (Adamczak et al. 1986; Driscoll and Srzednicki 1991; Driscoll et al. 1989).

A series of collaborative research projects funded by the Australian Centre for International Agricultural Research (ACIAR) was launched in the early eighties on in-store drying in the humid tropics (Srzednicki and Driscoll 1994). These projects involved research institutes in Australia and Southeast Asia: the University of New South Wales, the National Postharvest Institute for Research and Extension (NAPHIRE) in the Philippines, King Mongkut's Institute of Technology Thonburi (KMITT) in Thailand, and the Malaysian Agricultural Research and Development Institute (MARDI).

The following were the main objectives of the research.

- To determine thermophysical data for the main grain crops, with the aim of using these data to design drying systems for these crops
- To investigate first-stage drying options for areas where a two-stage drying strategy was required
- To provide appropriate technology for complete drying systems for main crops, especially paddy and maize, in the humid tropics
- To study the effects of various drying strategies on product quality.

The main outcomes of this research work, which have been published and presented at seminars, are as follows:

a) Very comprehensive weather data, covering at least ten years, have been collected from various locations in Malaysia, Thailand, Indonesia, and Australia, and to a lesser extent in the Philippines.

b) Thermophysical data comprising bulk and true density, porosity, angle of repose, coefficient of static friction, specific heat, equilibrium moisture contents at various temperatures and relative humidities, and thin-layer drying rates have been determined for a range of commercially important varieties of paddy and maize. Thermophysical data have also been collected for soybeans, peanuts, and mungbeans.

c) Baseline data regarding the structure of the grain industry in the collaborating countries in Southeast Asia have been collected. These include the geographic distribution of crops, cropping calendars, quantities procured daily by processors, and storage and milling capacities.

d) A computer drying simulation model based on the thermophysical data has been developed Driscoll (1986). The model is based on thermodynamic equilibrium between air and grain during the drying process as described by Sutherland (1984). The simulation model includes grains such as paddy (Australian and Asian varieties), maize, peanuts, soybeans, mungbeans, barley, and other products. Different strategies can be simulated for in-store drying, among them constant aeration, relative humidity control, time control, and modulated burner control. The model makes provision for options such as recirculation of air, stirring of grain, dehumidification, and heat losses through walls.

e) A great many simulations have been performed in order to assess the feasibility of in-store drying under the climatic conditions prevailing on selected sites in the main grain growing regions of the collaborating countries in Southeast Asia. As a result of the analysis of the computer simulations it has been established that two-stage drying with in-store drying as a second stage is feasible under the conditions of the humid tropics.

f) Confirmation of the computer model predictions was achieved through pilot plant studies, using 1–5 t of paddy, conducted in Australia and in Asia, followed by industrial scale experiments with up to 500 t, conducted at grain complexes belonging to government or privately owned rice mills in Southeast Asia. These experiments also demonstrated that paddy could be dried successfully during the wet season down to safe storage or milling levels within the required period of 13–23 days, depending on the chosen strategy, the initial grain condition and the bed depth.

g) Programmable controllers were added to the dryers. The most appropriate drying strategies for each location were programmed into these controllers, using parameters derived from computer simulation.

An example of the weather data for the wet season harvesting period in Thailand is shown in Figure 2.

The research work led to development of various solutions, according to the size of operations of the mill or grain handling unit. In Thailand, sheds from medium size (100 t) to large size (3000 t) are being used for in-store drying. First-stage drying is mainly performed using large capacity continuous-flow dryers. The project has developed a fluidised bed dryer of 1 t/hour capacity that is being used by a commercial mill. That unit is currently being scaled-up to 2.5 t/hour.

In the Philippines, the project team has developed a mobile flash dryer of 0.5 t/hour capacity for paddy for the first stage of drying (Fig. 3). It is equipped with a blower and a kerosene-fed heating unit. There is also a rice husk combustor option for the unit. An in-store dryer comprising six bins each of 11 t capacity (Fig. 4) matches the rate of daily receival and the capacity of the flash dryer. It also matches the capacity of the rice of the cooperative where the dryer has been installed.

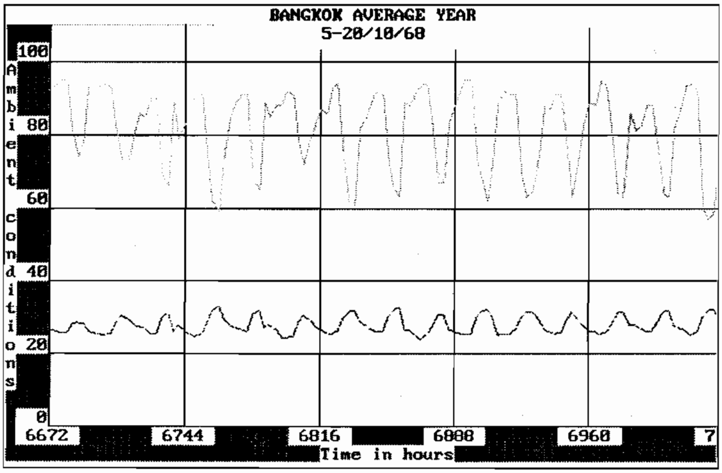
In Vietnam, a flat-bed dryer of 4–5 t capacity is being used as a first stage dryer, with an 80 t bin for in-store drying.

Effects of In-store Drying on Grain Quality

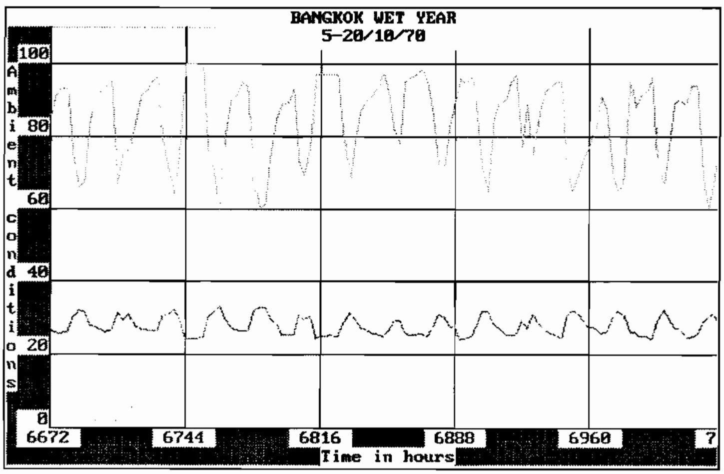
Final grain quality depends on the following factors (Brooker et al. 1992):

- environmental conditions during growth
- harvesting conditions
- early stages of postharvest operations
- drying
- storage
- conveying and transportation.

Different grain crops have different quality standards, so that it is not possible to have a general quality model. However, some quality criteria are applicable to a wide range of grains; for example, deterioration due to respiration or the action of certain microorganisms. Deterioration due to respiration is usually called dry matter loss, and can be determined by the amount of carbon dioxide produced. The extent of fungal activity can be defined in a variety of ways, including plate counts or by chemical analyses of constituents of metabolites. Some researchers (Seitz et al. 1979; Schwadorf and Muller 1989) have suggested using measurement of the amount of ergosterol present in the grain as an indicator of fungal growth. Ergosterol is a sterol found in the cell membranes of the fungi, as well as in the grain itself. Changes in the amount of ergosterol present after harvest are indications of mould activity on the grain.



A) Average year



B) Wet year

Figure 2. Weather pattern during wet season in Central Thailand.

Grain colour is a major quality criterion for rice. There are national standards that relate the number of discoloured grains to the price of grain. Experimental work done by Australian and Filipino scientists (Bason et al. 1990) has shown that the colour changes are related to chemical processes which are a function of water activity, temperature and, to a lesser extent, the oxygen concentration during storage of paddy. Fungi have also been associated with discoloration of paddy, although the mechanism of the process is not clearly understood. It can be speculated that conditions favourable to chemical discoloration (high temperature and water activity) also favour fungal growth, so that fungi are very likely to appear on grain that has already been discoloured by chemical reaction.

Another quality parameter of great commercial significance for paddy is the head rice yield, i.e. the proportion of head rice (rice which is 3/4 kernel size or larger) in the total amount of milled rice. Fissuring during postharvest handling of paddy will decrease the head rice yield. The mechanism of fissuring is associated with readsorbtion of moisture by grain that has already been dried (Kunze and Prasad 1978). Hence, the head rice yield is closely related to the drying strategy.

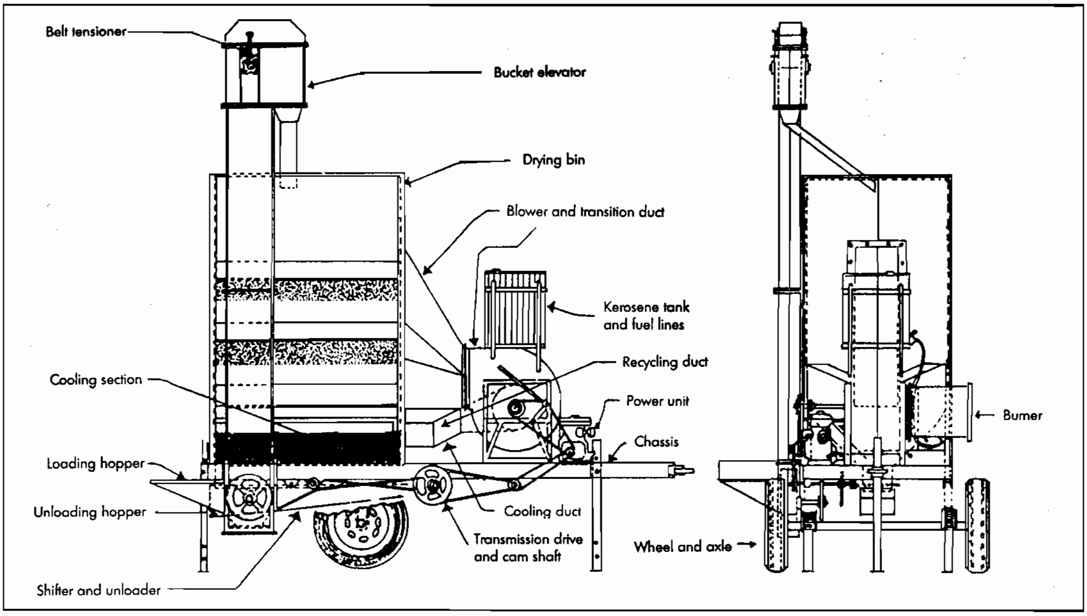


Figure 3. NAPHIRE mobile flash dryer MFD–C2 (courtesy of NAPHIRE).

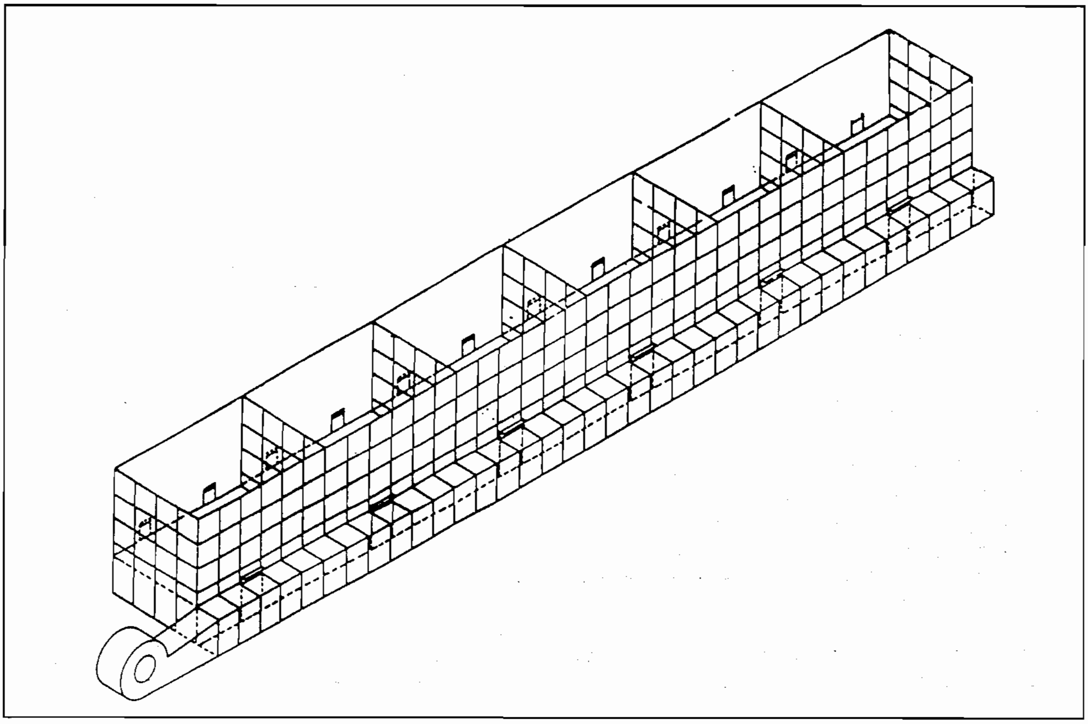


Figure 4. Schematic of a 66 t in-store dryer at the Dayap Cooperative in Calauan, Laguna Province in the Philippines (courtesy of NAPHIRE).

Although fissuring is also important to maize quality, a more significant quality parameter is the aflatoxin content. Aflatoxins are secondary metabolites formed by spoilage fungi of the genus *Aspergillus*, particularly *Aspergillus parasiticus* and *A. flavus*. They are of concern because they are human carcinogens, and cause a significant decrease in growth rate and increase mortality among poultry and pigs fed aflatoxin-contaminated feeds. Aflatoxins are produced in a range of produce, especially in maize, peanuts, copra, tree nuts, and milk.

Research on aflatoxin control in maize in the USA by Ross et al. (1979) indicated that, when using low temperature drying, grain above 17% moisture content stored at temperatures between 13–41°C should not be exposed to relative humidities above 85% for more than 48 hours. Since the equilibrium relative humidity increases with temperature for a given moisture content, any delay in drying under tropical conditions combined with an increase in temperature can result in moisture adsorbtion and increased risk of aflatoxin formation. Recent research in Thailand by Wongvirojtana et al. (1994) has shown that, with careful monitoring of the quality of incoming grain, and the choice of an appropriate drying strategy, it is possible to reduce aflatoxin build-up using in-store drying technology. However, it is feasible only for incoming grain having moisture contents below 19% and low aflatoxin levels.

In summary, a properly managed two-stage drying system can overcome the following product quality problems:

- Discoloration in paddy if there are delays in reducing moisture content from field level down to about 18% w.b. This can be overcome by a prompt start to fast drying (first stage). However, even paddy at 18% can be stored under aeration for up to about three weeks without significant deterioration. In-store drying should therefore commence as soon as possible.
- Fissuring in paddy and maize is mainly related to grain rewetting and associated with the second stage of drying. Careful monitoring of relative humidity of inlet air for aeration should provide sufficient safeguards. Automatic control systems offer a significant level of protection, provided there is a reliable power supply on the drying site, and are increasing in use in tropical countries. A properly managed in-store dryer will therefore result in an increase in head yield at a significantly lower cost than when using a high temperature dryer.
- Aflatoxins are a problem in maize at the second stage of drying. However, experimental work in Thailand has shown that, with proper monitoring of quality of grain delivered to the in-store dryer and appropriate aeration strategies, an efficient control mechanism can be implemented.

Conclusions

The following conclusions can be drawn from the results of research on in-store drying and its effects on grain quality.

- In-store drying is feasible under humid tropical conditions as a second stage of drying process, i.e. for removal of moisture from about 18% w.b. down to safe storage or milling level (14–15% w.b.).
- In-store dryers are best suited at miller and trader level, i.e. they should be incorporated into a chain of postharvest operations that includes fast drying as soon as possible after harvest, and milling or storage after in-store drying.
- The system is very flexible and can be accommodated into medium- and large-scale operations.
- There is scope for further improvement of in-store management techniques, especially automatic control systems.

References

Adamczak, T., Loo Kau Fa, Driscoll, R.H. and Mochtar, M. 1986. Preventing paddy backlogs using two stage drying. In: De Mesa, B.M., ed., Grain protection in postharvest systems. Proceedings of the Ninth ASEAN Technical Seminar on Grain Postharvest Technology, Singapore, 26–29 August 1986, 83–98.

Bason, M.L., Gras, P.W., Banks, H.J. and Esteves, L.A. 1990. A quantitative study of the influence of temperature, water activity and storage atmosphere on the yellowing of paddy endosperm. Journal of Cereal Science, 12, 193–201.

Brooker, D.B, Bakker-Arkema, F.W. and Hall, C.W. 1992. Drying and storage of grains and oilseeds. New York, Van Nostrand Reinhold, 450 p.

Bulaong, M.C. 1994. Modelling the head rice yield of high-moisture grains after high-temperature drying. MAppS Thesis, University of New South Wales, Sydney, Australia.

Calderwood, D.L. 1966. Use of aeration to aid rice drying. Transactions of the American Society of Agricultural Engineers, 9 (6), 893–895.

Do Sup Chung, Boma Kanuyoso, Erickson, L. and Chong-Ho Lee 1986. Grain aeration and in-store drying in the USA. In: Champ, B.R. and Highley, E., ed., Preserving grain quality by aeration and in-store drying: proceedings of an international seminar held at Kuala Lumpur, Malaysia, 9–11 October 1985. ACIAR Proceedings No. 15, 224–238.

Driscoll, R. H. 1986. The application of psychrometrics to grain aeration. In: Champ, B.R. and Highley, E., ed., Preserving grain quality by aeration and in-store drying: proceedings of an international seminar held at Kuala Lumpur, Malaysia, 9–11 October 1985. ACIAR Proceedings No. 15, 67–80.

Driscoll, R.H. and Srzednicki, G.S. 1991. Design of complete drying systems under Southeast Asian climates. In: Naewbanij, J.O., ed., Grain postharvest research and development: priorities for the nineties. Proceedings of the Twelfth ASEAN Seminar on Grain Postharvest Technology, Surabaya, Indonesia, 29–31 August 1989, 3–11.

Driscoll, R.H., Adamczak, T. and Samsudin, A. 1989. Control options for in-store drying. In: De Mesa, B.M., ed., Grain postharvest systems. Proceedings of the Tenth ASEAN Technical Seminar on Grain Postharvest Technology, Bangkok, Thailand, 19–21 August 1987, 44–51.

Kunze, O.R. and Prasad, S. 1978. Grain fissuring potentials in harvesting and drying of rice. Transactions of the American Society of Agricultural Engineers, 24(2), 361–366.

Morey, V.R., Gustafson, R.J. and Cloud, H.A. 1981. Combination high-temperature, ambient-air drying. Transactions of the American Society of Agricultural Engineers, 24 (2), 509–512.

Ross, I.J., Loewer, O.J. and White, G.M. 1979. Potential for aflatoxin development in low temperature drying systems. Transactions of the American Society of Agricultural Engineers, 22, 1439–1443.

Schwadorf, K. and Muller, H.M. 1989. Determination of ergosterol in cereals, mixed feed components, and mixed feeds by liquid chromatography. Journal of the Association of Official Analytical Chemists, 72, 457–462.

Seitz, L.M., Sauer, D.B., Burroughs, R. and Mohr, H.E. 1979. Ergosterol as a measure of fungal growth. Phytopathology, 69, 1202–1203.

Sokhansanj, S. and Jayas, D.S. 1987. Drying of food stuffs. In: Mujumdar, A.S., ed., Handbook of industrial drying. New York, Marcel Dekker Inc.

Srzednicki, G.S. and Driscoll, R. H. 1994. Advances in the research on in-store drying. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Stored-product protection. Proceedings of the 6th International Working Conference on Stored-product Protection, Canberra, 17–2 April 1994. Wallingford, U.K., CAB International, 351–358.

Sutherland, J.W. 1984. The design and prediction of performance of batch driers for paddy rice. International Journal for Development Technology, 2, 119–129.

Thompson, T.L. 1972. Temporary storage of high moisture shelled corn using continuous aeration. Transactions of the American Society of Agricultural Engineers, 15 (2), 333–337.

Young, G. and Wijesinghe, B. 1994. Food drying: basic principles and methods. In: Development and application of heat pump driers: proceedings of a seminar on heat pump dryers, 9 February 1994. Silverwater (Sydney), Pacific Power Energy Services.

Van Ardsdel, W. B., Copley, M.J. and Morgan, A.I. 1973. Food dehydration. Vol. 1. Drying methods and phenomena. Westport, Connecticut, AVI Publishing Co. Inc.

Wongvirojtana, P., Soponronnarit, S. and Nathakaranakule, A. 1994. Feasibility study of in-store corn drying under tropical climates. In: Naewbanij, J.O., Manilay, A.A. and Frio, A.S., ed., Increasing handling, processing and marketing efficiency in the grain postharvest system. Proceedings of the 16th ASEAN Seminar on Grain Postharvest Technology, Phuket, Thailand, 24–26 August 1993, 265–283.

Some Results of Research on Aeration of Paddy in Vietnam*

Bui Huy Thanh†

Abstract

This paper summarises the results of a series of experiments on aeration of paddy held in storage at various temperatures and moisture contents in Vietnam. The results of these experiments demonstrate the effectiveness of simple aeration strategies for grain preservation. They also indicate that existing theory relating drying rate and the equilibrium temperatures and moisture contents of air and grain applies only when the grain temperature approximates that of the ambient air, as in the case of paddy that has just entered storage. Modification to the theory is needed for grain whose temperature has risen to high levels during prolonged storage.

THE Red River delta and the Cuu-Long (Mekong) River delta are the two most important rice bowls in Vietnam. Nowadays, in those areas, people are actively introducing measures for intensive farming and multiple cropping to increase paddy production, and they have already made considerable achievements. Since 1982, many places in the Cuu-Long delta have grown three rice crops per year. The rice-growing area of the delta is nearly 40% that of the whole country and its output accounts for over 40% of total rice production. The summer–autumn crop alone (the additional crop) is grown on nearly half a million hectares and yields about 1.4 Mt of paddy.

The humid tropical weather with sudden showers or prolonged rain has caused a great deal of difficulty for postharvest activities. The summer–autumn and the early tenth-month crops in the south often bring high yields, but their harvest occurs during the rainy season. In the north, on average one of every two or three crops is harvested on rainy days.

Consequently, after harvest wet grain becomes mouldy and germinates, causing rapid qualitative deterioration and great quantitative losses. Due to the lack of drying facilities, the moisture content of paddy grain delivered to warehouses during that rainy period is often above safe levels. The storage of such high moisture grains, especially bulk grain, requires appropriate and strict handling to avoid heating, yellowing, and fungal infestation.

Many technical solutions could be adopted, such as drying, turning, hot aeration, air ventilation, etc. to deal with and improve the above-mentioned conditions. We have chosen the method of ambient air aeration because it is a simple, inexpensive method which enables lowering of the grain bulk temperature as well as the moisture content, thus maintaining grain quality during storage.

Over the last 20 years, there have been many papers published in a number of countries, reporting the findings of studies on aerated storage of paddy. Most came to the conclusion that aeration was one of the most effective measures to maintain the grain quality. At a seminar on 'Paddy deterioration in the humid tropics' held by GASGA in the Philippines in 1981, Teter (1982) used the 'deterioration index' (DI) of climate (Brooks 1950) to determine suitable climatic conditions for each type of grain and the effective timing of aeration. He determined that the purpose of aeration was to maintain grain uniformly dry at a uniform temperature, and that the rules governing aeration were that:

- heat generated must be removed
- water generated must be removed
- air with unsuitable DI cannot be used
- the deterioration at the end of the storage time should not exceed 0.85 dry matter loss.

In Vietnam farmers have long practised drying wet paddy in the air when the rain prevents them from drying threshed paddy. The wet paddy is spread out

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20–30 cm thick on the house floors to be dried by the air, and its temperature is maintained between 20–30°C, to prevent germination and yellowing. However, if they keep the paddy too long, part of the paddy stack may become discoloured and mouldy. Although this method of temporary storage is simple it is applicable to only small quantities held in individual households.

In small granaries in the countryside, people insert ported tubes made of bamboo into the grain pile to release the heat and moisture naturally. Some big warehouses are equipped with large fans to blow air into the grain bulk through ducts under the floors. However, until the past 10 years there had not been any research on paddy aeration in Vietnam, a tropical country with climatic characteristics different from those in the temperate zones. Our research has therefore had the following objectives:

- To study the factors that affect the drying and cooling abilities during aeration, such as the air temperature and humidity (in the humid tropics), and the grain temperature and moisture content, etc.
- To test the effects of aeration in order to handle wet paddy, to prevent heating, and to reduce moisture content of paddy in bulk stores in hot and cold weather.
- To determine the opportunity for suitable ventilation to get good results. This work is particularly important for the humid tropics, because if air with the wrong properties is used, the results of aeration might be the opposite to those desired.
- To assess the effectiveness of the aeration equipment tested under normal conditions of rice storage in Vietnam.

The Equipment for Aeration

Like many other countries, warehouses and the improved traditional 'godown' are popular in Vietnam, although of lower capacity, each bin holding from 100 to 250 t of paddy. Because of this, we designed a type of portable aeration equipment for experimental studies. Other reasons for designing portable equipment were that it required a lower investment, its capacity was fully used and, in particular, no modification of the existing warehouses was needed.

This equipment consisted of a suction fan and an air distribution pipe. To ventilate a bin, the duct was inserted into the bulk to about 1.6–2.0 m depth, then joined directly to the fan. The system could be easily dismantled and moved to another bin. Its technical specifications are as follows:

- aeration rate 650–700 m^3/hour
- air pressure 170–200 mm of water column
- motor speed 2850 rpm.
- power 0.7–1.0 kW

The suction pipe is 2.5 m long with a diameter of 102 mm. The pipe end, 0.8 m in length, is drilled with 14000 holes (each hole 2 mm diameter) for air release. The end of the pipe is pointed and grooved to permit easy insertion into the grain bulk.

The aeration fan can either blow or suck according to which side of the fan the aeration piping is attached.

Some Research Results

In this technical paper, only reproducible and representative results of the research are presented.

A. Aeration for protection of wet paddy

This method was used to preserve the quality of paddy which had just been threshed but could not be dried immediately because of overcast humid weather or days of steady rain.

The field experiments on wet paddy storage were carried out in the agricultural cooperatives, by the discontinuous aeration method, with grain stacks of 4.5–5.0 t, 2.0–2.2 m in height, and paddy with moisture contents in the range 20–29%.

From the results with two crops, we drew the following conclusions.

Discontinuous aeration during 49–50 hours enabled us to limit mould and germination, to avoid self-heating and yellowing of grain for up to 15 days, depending on the original moisture content of the grain.

Moisture content (%)	Time for safe storage (days)
20	15
24	6–7
29	4–5

The 50 cm surface layer accumulated heat and moisture, so the grain moisture content was not reduced and the grain temperature there was 5–6°C higher than the average temperature of the rest of the stack. Consequently, the paddy in this layer was more mouldy and germinated (with the paddy of 24% m.c., after 5 days aeration the rates of germinated and mouldy grains were 0.1% and 0.3%, respectively, and mould was mainly seen in immature grains). The grain in the middle of the paddy stack was sound.

To avoid paddy deterioration at the surface layer during aeration was a difficult problem. Some overseas researchers have solved the problem by raising the aeration rate to 500 m^3/t.hour, or by turning the grain. These solutions are expensive and complicated. Our solution was to provide additional aeration to the surface layer of the stack, or discontinuous aeration in which one-third of the time was reserved for the surface layer only. Four subsidiary suction pipes were inserted 60 cm into the pile to improve the aeration of the grain layer near the surface (Fig. 1).

The bamboo basket of paddy was a cube of side 2 m, holding 4.5 t of paddy which had been harvested and threshed for two days before being loaded in the basket for aeration. The grain moisture content was in the range 23.5–24.5%. Immature grains accounted for 20–25%.

After 6 days aeration the paddy was unloaded for sun drying. The air and grain stack temperatures, the air humidity, and aeration times are shown in Table 1.

The climate in Vietnam is usually hot and humid, so we used an aeration rate of 137 m^3/t of grain per hour, higher than that used in the experiments of some overseas. Calderwood (1966), for example, used an airflow rate of 39 m^3/t.hour.

The changes in paddy quality that occurred are shown in Table 2.

Thus, after nearly 62 hours of aeration, the grain moisture content fell by 3.5%, the germination degree rose from 32–34% to 55%, and grain quality remained constant throughout the bulk. The only deleterious change was in the colour of the grain, which became darker after aeration.

From the results of tests on three harvests, the following conclusions can be drawn:

- Aeration was an effective method of preserving wet paddy when the weather was unfavourable for drying. Aeration prevented paddy from moulding, self–heating, and germinating, which would lead to quantitative and qualitative deterioration.

Table 1. Aeration schedule.

Index	Day of aeration					
	1	2	3	4	5	6
Average air moisture content (%)	74	94	86	68	74	82
Average air temp. (°C)	28	28	30	31	33	31
Average temp. of grain (°C)	28	28–29	29–30	30–31	31–32	29–30
Total hours of aeration in the day	11	17	13.5	9.5	6	5.5
In which the hours for surface layer	3	6.5	2	4	2	2.5

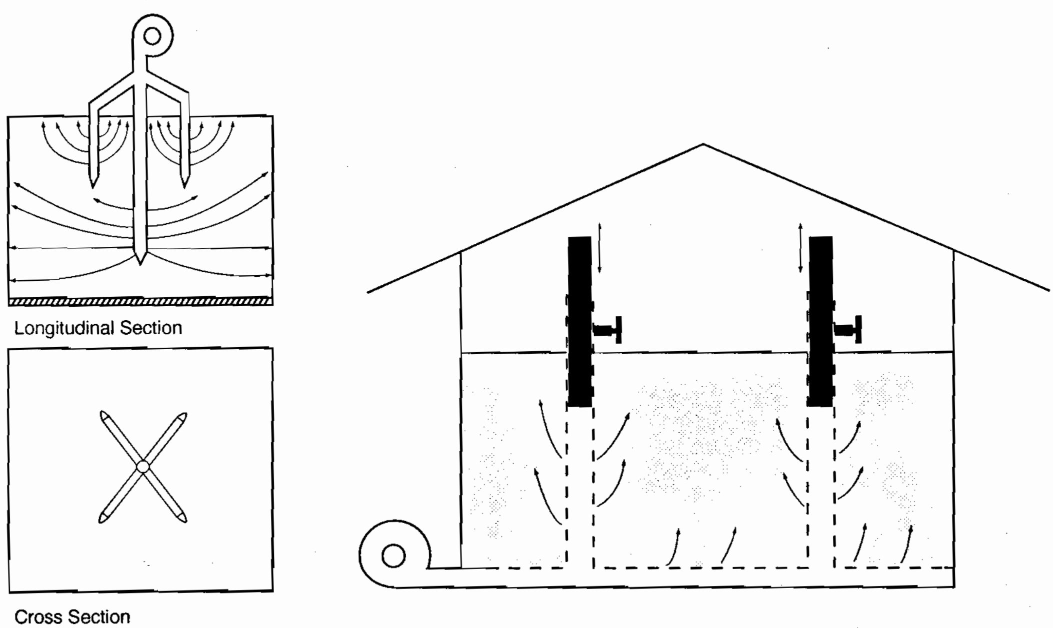


Figure 1. Aeration mode in experiment to preserve wet paddy.

- The time for safe storage depended on the original moisture content of the paddy, and the air temperature and humidity. Paddy with moisture contents above 25% could be stored for 5 days, and paddy with the moisture contents of 23% for 10–15 days in cool weather. Paddy with a moisture content of 24%, aerated discontinuously for 60–80 hours, could be safely stored for 6–10 days in hot weather.
- The aeration rate through the grain pile to accomplish the above results was between 130–140 m^3/t.hour. If the paddy was stored in larger warehouses with underfloor ducting, the aeration rate could be reduced to 100 m^3/t.hour.
- Either separate and periodic aeration of the surface layer or additional aeration for that part of the grain stack was a simple and effective measure which could preserve the paddy grains at the surface layer from moulding, germination and yellowing.

B. Aeration for cooling bulk grain stores

The aim of aeration was to prevent heating within the grain pile. The cooling rate depended upon the difference between the temperature of the grain stack and that of the air, and on the rate that air was blown through the grain.

1. *Aeration for cooling a grain stack in the cold season in a bin holding 130 t of paddy, stored for 6 months.* Four suction fans were placed, 3 m away from each other (two aspirators, two blowers), with the air volume supplied of 23m^3/t.hour (Fig. 2). The results of cooling the grain stack are shown by the data in Table 3.

2. *Aeration of a bin holding 250 t of paddy, half of which was heating.* Four suction fans were used as previously. The results are shown in Table 4.

From Tables 3 and 4 it was observed that, in the cold season, when the air temperature ranged from 16–22°C, aeration could reduce the temperature of the grain stack from 30–35°C to 24–25°C. The grain temperature fell quickly for the first 20 hours, after which the temperature reduction slowed to a marginal rate.

3. *Aeration of a grain stack of 130 t, which was heating in the hot and humid season.* Five suction fans were used, with an air volume of 28 m^3/t.hour. Temperature changes in the grain stack during aeration are shown in Table 5.

The initial temperature of the grain stack, 40–42°C, was reduced to 35–36°C, permitting safe storage. When the difference in temperature between the air and the grain reached only 5–6°C, the temperature of the grain pile was near equilibrium. The grain temperature could not be reduced by further aeration. Therefore, the effective aeration time was about 10–15 hours.

Apart from temperature reduction, aeration created a more uniform temperature distribution within the grain. This reduced the chance of moisture migration from the lower to the surface layers, and the concomitant danger of mould growth. The temperature distribution in the grain stack before and after aeration is given in Table 6. Aeration clearly reduced the differences of temperature between the layers in the grain stack.

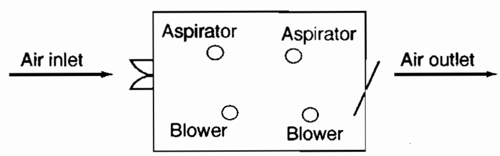


Figure 2. Aeration for grain cooling.

Table 2. Paddy quality changes during aeration.

Paddy sample	Moisture content (%)	Yellow grains (%)	Mouldy grains (%)	Germinated grains (%)	Germination degree (%)	Germination intensity (%)
Before aeration						
Sample 1	23.5	0	0	0	33	28
Sample 2	24.5	0	0	0	34	34
49 hours after aeration start (the 4th day)						
Sample near surface	24.0	0	0	0		
Sample medium	23.0	0	0	0		
Before sun drying						
Sample medium	20.5	0	0	0	55	43
Sample near surface	22.3	0	0	0	52	41
Sample in middle	18.3	0	0	0	72	50

From these data, the following main conclusions can be drawn:

- Aeration was an effective means of preventing grains from heating in both cold and hot weather.
- The effective aeration time was 20–25 hours, with an air volume of 23–30 m^3/t.hour.
- The temperature of an aerated grain stack was 5–8°C lower than unaerated grain.

C. Aeration for drying paddy

Although the effects of reducing paddy temperature and moisture content during aeration took place simultaneously, they were studied separately in order to assess the relative contribution of each to grain preservation.

Some heated grain stacks with a surface moisture content above 14% were tested to see if aeration would improve the storage characteristics of the grain.

- A bin holding 240 t of bulk baddy that had been stored over the hot season was treated. It was the cold season, but the grain stack was heating and its surface layer had begun to mould. Nine suction fans were used, including 3 aspirators and 6 blowers, with an air volume of 24 m^3/t.hour.

The results of drying and cooling the grain stack are shown in Table 7.

After 32 hours of ventilation, the average moisture content of the grain stack fell from 12.7 to 11.9%, and its temperature fell by 8%. The grain stack was free

Table 3. Results of grain cooling experiment.

Number of aeration hours	Average air temperature (°C)	Grain temperature (°C) at the depth of 1.4 m, taken at 9 different points								
		1	2	3	4	5	6	7	8	9
0	–	34.0	35.5	37.0	32.0	33.0	30.5	34.5	37.5	34.5
8	22.0	28.0	37.5	32.5	28.5	29.5	28.5	32.0	34.0	35.5
24	20.0	26.0	25.5	29.0	27.0	27.5	27.0	31.5	28.5	30.2
57	20.5	25.0	26.0	28.0	25.0	26.5	25.0	27.5	27.0	27.0

Table 4. Effect of aeration on grain temperature at various points in 250 t of bulk paddy.

Number of aeration hours	Average air temperature (°C)	Grain temperature (°C) at the depth of 1.4 m, taken at 10 different points									
		1	2	3	4	5	6	7	8	9	10
0	–	31.5	35.5	34.5	34.5	31.0	32.5	32.5	25.0	27.0	27.0
3	14.0	26.5	32.5	31.5	33.5	28.5	28.5	28.5	24.0	27.0	26.0
6	17.0	23.5	27.5	27.5	23.5	26.5	26.5	25.5	24.5	27.5	24.0
12	19.0	23.5	23.5	25.5	24.0	26.5	26.5	24.5	24.5	26.0	24.0
20	16.0	23.5	23.5	24.0	24.0	25.5	25.5	23.5	24.0	25.0	24.0
$(T_{initial} - T_{final})$°C of the grains		8.0	12.0	10.5	10.5	5.5	9.0	4.0	1.0	2.0	3.0

Table 5. Effect of aeration on grain temperature at various points in 130 t of bulk paddy.

Number of aeration hours	Average air temperature (°C)	Grain temperature (°C) measured at 6 different points					
		1	2	3	4	5	6
0	–	38.5	42.0	39.0	40.0	42.0	41.0
5.0	31.0	37.0	41.0	35.0	40.0	38.5	35.0
8.5	32.0	37.0	38.0	35.0	39.5	37.5	36.5
13.0	30.0	36.0	37.0	34.0	37.0	38.0	35.0
15.5	31.0	35.5	36.0	34.0	37.0	37.0	35.0

from humidity and mould, its porosity was better, and the paddy could be continuously stored safely.

- A grain stack had been stored for 6 months. For the last two months it had been heating, despite being turned over. Ventilation was carried out in the hot season, with an air volume of 23–24 m^3/t.hour.

The results of aeration of this stack are given in Table 8. After 18 hours aeration by air with the average temperature and moisture content shown in Table 8, with the difference of ($m.c._{grain} - m.c._{equilibrium}$) = 2.4%, the average moisture content of the grain pile decreased by 2% and its temperature fell by 6°C. The grain pile became drier and looser than before aeration.

In the literature on aeration, Koz'mina (1966, 1970) concludes that the drying of grain by aeration depends on the temperature and relative humidity of the ambient air. The tendency of the grain moisture content is to approach the equilibrium moisture content equivalent to the relative humidity of the air at a specified temperature.

Therefore, if:

- $m.c._{grain} > m.c._{equilibrium}$, aeration helps dry the grain (1)
- $m.c._{grain} < m.c._{equilibrium}$, aeration causes wetting of the grain (2)

This is why, when the air relative humidity was high, they stopped aerating the grain, or heated the air to reduce its relative humidity before aeration, so as to dry the grains effectively.

However, the results of our experiments were sometimes at variance with the second of the above conclusions. For example, when aerating a grain stack with a temperature 16°C higher than that of the ambient air, and an air relative humidity of 90%, the average moisture content of the grain could be reduced from 13.2 to 12.2%. Based on the tempera-

Table 6. Temperatures at various points and depths in bulk stored paddy before and after aeration.

Aeration status/depth		Grain temperature (°C) taken at 10 different points									
		1	2	3	4	5	6	7	8	9	10
Before aeration:											
Depth	1.6 m	34.0	35.4	37.0	32.0	32.0	30.0	34.5	37.5	34.5	33.4
	1.0 m	32.0	34.0	36.5	32.0	31.5	30.0	34.0	30.3	34.0	33.0
	0.2 m	23.5	23.5	23.0	22.0	23.5	23.0	23.0	27.5	27.0	24.0
Temperature difference between the lower and upper layers		10.5	11.9	14.0	10.0	3.5	7.0	11.5	10.0	7.5	9.4
After aeration:											
Depth	1.6 m	25.0	25.5	27.6	25.0	26.2	24.5	27.0	26.5	27.0	26.0
	1.0 m	24.4	25.2	27.5	25.0	25.0	24.8	27.0	26.0	24.5	23.0
	0.2 m	23.5	25.0	23.5	23.2	23.5	23.5	27.0	22.0	21.5	21.5
Temperature difference between the lower and upper layers		1.5	0.5	4.1	1.8	2.7	1.3	0	4.5	5.5	5.5

Table 7. Temperature and moisture content at various points in bulk stored paddy before and after aeration.

Fan hours	Average air temp. (°C)	Average air m.c. (%)	Temperature (°C) of the pile at different points						Equil. m.c. during aeration (%)	Grain m.c. (%)
			1	2	3	4	5	6		
0			26.0	30.5	32.0	31.5	32.5	28.5	9.1	Av. 12, surface layer 15.
6	14.5	86	23.0	29.5	25.0	26.0	29.0	28.5		
16	16.0	65	21	26.5	21.5	23.0	24.0	24.0	8.8–9.5	
26	18.0	55	19.5	24.5	21.0	22.5	23.0	23.5	10–10.5	
32	18.0	50	19.0	24.0	22.0	23.0	23.0	23.0	10	Av. 11.85, surface layer 14

ture and moisture content of the ambient air, the calculated equilibrium moisture content would be 17.8% higher than the grain moisture content. Thus, according to their theory, the aeration should have had no effect. Why then had it helped dry the grain?

We theorised that the air had changed in characteristics as it passed through the grain stack of higher temperature. Some experiments were needed to test this. A suction fan (see Fig. 3) was installed to aerate a grain stack. The grain temperature and ambient air temperature and relative humidity were recorded before and after blowing through the grain stack (at the outlet of the fan).

From the data in Table 9 and a series of other data, it was clear that, after passing through the grain stack, the air temperature increased to approximately that of the stack. For convenience of calculation, we considered that they had become equal.

Table 10 details the changes in aeration air characteristics after it has passed through the grain stack. It can be seen that the air temperature reaches that of the grain, while there is a marked rise in the air absolute humidity above that of the grain (meaning that the air had taken up moisture from the grains). Despite this the air relative humidity falls markedly. For example, when air with a relative humidity of 92% and a temperature of 28°C passed through a grain stack having a temperature of 39°C its temperature rose to 39°C. If the air had not taken up moisture from the grain, its relative humidity would have been 51%. This air would be very dry and so would take up moisture from the grain (1 m^3 of air could take

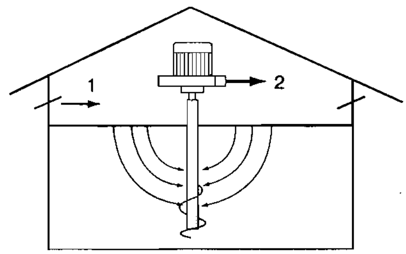


Figure 3. Experimental set-up to determine change in characteristics of air used for aeration (see text for explanation): 1. air inlet; 2. air outlet.

1. $m.c._{equilibrium} = f(T_{air}, r.h._{air}, T_{grain})$

in which $m.c._{equilibrium}$ = equilibrium moisture content of the grain

T_{air} = the air temperature

$r.h._{air}$ = the air relative humidity

T_{grain} = the grain temperature.

2. If:

- $(m.c._{grain} - m.c._{equilibrium}) \geq 3$, aeration helps dry grains well and quickly, reducing ≥ 1.5% m.c.
- $2 \leq (m.c._{grain} - m.c._{equilibrium}) \leq 3$, aeration helps dry grains at a moderate rate, reducing about 1% grain m.c.
- $1 \leq (m.c._{grain} - m.c._{equilibrium}) \leq 2$, aeration dries grains slowly and little, below 1% grain m.c.

3. If: $(m.c._{grain} - m.c._{equilibrium}) < 0$, aeration is ineffective.

Table 8. Changes in air and grain temperatures and moisture contents during aeration.

Aeration hours	Average air temp (°C)	Average air r.h. (%)	Average temp. of grain stack (°C)	Equilibrium moisture content during aeration (%)	Grain moisture content (%)
0			43		Average 12.8–13.0
					Surface layer 14.2
10	28.0	90.0	41–42	10.6	
13	29.0	85.0	39	10.8	
18	30.0	70.5	36–37	10.3	Average 11.0
					Surface layer 12.6

approximately 8 g of vapour). The relative humidity of the air was, in reality, 88%.

The air temperature was nearly equal to that of the grain because when passing through the grain stack the air was in contact with many millions of grains, presenting a substantial heat exchange surface. There was therefore rapid heat transfer.

A self-recording moisture meter was inserted in the grain stack at a depth of 50 cm. Its chart showed that, during hours of aeration, the temperature of the air blowing through the grain stack increased, so that its relative humidity went down. When the fan stopped working, the air relative humidity remained almost unchanged.

These experimental results led to the conclusion that it was the equilibrium moisture content corresponding to the conditions of the air with its temperature increased to almost that of the average temperature of the grain stack, and with the supposition that the grain moisture had not yet been taken up, that determined the ability to dry the grains by aerating.

Hence, besides the two factors of temperature and humidity of the ambient air, the equilibrium moisture content also depended on a third factor, namely the average temperature of the grain pile.

All the abovementioned conclusions can be generalised as shown in the box below, whose rules are incorporated in the chart in Appendix 1.

In Vietnam, for a large part of the year the air has an average humidity of approximately 85% and there is lack of good technical facilities for bulk storage. Therefore, the grain temperature in warehouses is often 5–15°C higher than that of the ambient air. So it is possible to dry and cool the paddy by aeration.

We can thus say that the conclusion of Koz'mina (1966, 1970) and Teter (1982), that the equilibrium moisture or the deterioration index (DI) of the grain is dependent on the temperature of the air and its relative humidity, applies only when the grain temperature approximates that of the ambient air, as in the case of paddy that has just entered storage.

Table 9. Variation of the air temperature during aeration.

Warehouse	Time	Air temp. before aeration (°C)	Average temp. of grain stack around the fan (°C)	Air temp. after aeration (°C)	(T_{air} — T_{grain}) (°C)
A	10.30 pm	13.0	26.0	31.5	5.5
	12.00 pm	13.0	27.5	30.5	3
	3.00 am	12.0	26.7	28.0	1
	10.30 am	19.0	25.0	26.0	1
B	12.00 am	29.0	38.7	37.0	−1.7
	4.00 am	27.2	37.2	37.5	0.3
	8.00 am	32.0	37.2	27.0	−0.2
	6.00 pm	31.5	36.0	36.0	0

Table 10. Changes to ambient air temperature and moisture content following transit through bulk paddy.

Warehouse	Measurement time	Ambient air			Grain average temperature (°C)	Air passing grain pile		
		Temp. (°C)	r.h. (%)	a.h. (g/m^3)		Temp. (°C)	r.h. (%)[a]	a.h.[b] (g/m^3)
C	1st time	20.4	84	14.8	36	36.0	57	23.6
	2nd Time	23.5	72	15.5	35	35.0	65	25.3
	3rd Time	20.4	81	14.3	33.5	33.5	55	20.0
D	1st time	29.0	88	25.0	42	42.0	100	55.6
	2nd Time	28.0	92	24.7	39	39.0	68	32.8

[a] Relative humidity corresponded to the conditions in which the air had exchanged moisture with the grains and its temperature had been raised.
[b] Absolute humidity.

D. Influences of other factors on aeration

In addition to the factor

$$\text{m.c.} = (\text{m.c.}_{\text{grain}} - \text{m.c.}_{\text{equilibrium}})$$

that determined the drying ability as mentioned above, the air volume supplied and the grain temperature also exerted important influences on the results and speed of drying.

The results of experiments on the grain stack with a temperature over 38°C showed that the optimum air volume supplied was 25 m^3/t.hour. If the air volume was smaller the drying rate would be slow. If a higher rate was used the grain pile would be cooled quickly, but the grain would remain wet..

The higher the grain temperature, the more rapidly the grain dried. If we consider that the grain stack was a uniform and isotropic volume, the drying rate equation is as follows:

$$dM/dT = -k(\text{m.c.} - \text{m.c.}_{\text{equilibrium}})$$

in which m.c. = the grain moisture content at the start of aeration; T = the aeration time; $\text{m.c.}_{\text{equilibrium}}$ = the equilibrium moisture content; k = a constant, the drying rate coefficient, depending on aeration conditions.

To solve this equation, we get

$$\frac{\text{m.c.} - \text{m.c.}_{\text{equilibrium}}}{\text{m.c.}_0 - \text{m.c.}_{\text{equilibrium}}} = e^{-kT}$$

m.c._0 = the grain moisture content before aeration; k could be determined by experiments, as shown in Table 11.

k is influenced most by grain temperature. The higher the grain temperature, the larger is k and therefore the higher the drying rate.

k is also directly related to the rate of air supply.

Time for Aeration

This section outlines design techniques for aeration.

To aerate a bulk grain store, firstly we should determine:

- the moisture content of a sample representing the whole grain store;
- the temperature of the grain store (taken at a depth of 1.4–1.6 m at various points); and
- the temperature and relative humidity of the ambient air.

Appendix 1 and the paddy equilibrium moisture content table (Table 12) are then used to determine the equilibrium moisture content corresponding to the conditions of the air passing the grain stack with its temperature raised to that of the grain, with the air assumed to have not as yet taken up any grain moisture.

The time suitable for ventilation was as follows:

- For first 10 hours: $(\text{m.c.}_{\text{grain}} - \text{m.c.}_{\text{equilibrium}}) > 2$, the air relative humidity ≤ 85%, no rain.
- For subsequent hours: $(\text{m.c.}_{\text{grain}} - \text{m.c.}_{\text{equilibrium}}) > 1$, the air humidity ≤ 85%, no rain.

Table 11. Determination of drying rate constant, k.

Experiment	Aeration hours	Air volume supplied (m^3/t.hour)	Grain temperature (°C)	Equilibrium moisture content (%)	k value
No. 1	32	23.0	32–34	9.8	0.0230
No. 2	29	23.0	29–33	10.2	0.0197
No. 3	12	17.0	38–43	10.0	0.0598
No. 4	18	32.6	37–43	10.3	0.0730
No. 5	18	26.0	35–42	10.3	0.0696

Table 12. Equilibrium moisture content of paddy at different temperatures and relative humidities.

Temperature (°C)	Relative humidity of air (%)							
	20	30	40	50	60	70	80	90
30	7.1	8.5	10.0	10.9	11.9	13.1	14.7	17.1
25	7.4	8.8	10.2	11.2	12.2	13.4	14.9	17.3
20	7.5	9.1	10.4	11.4	12.5	13.7	15.2	17.6
15	7.8	9.3	10.5	11.6	12.7	13.9	15.6	18.0

Table 13. Influence of equilibrium moisture on the results of grain drying by aeration.

Parameters	Hours of aeration						
	0		7		10		17
Average air r.h. (%)		100.0		75.0		85.0	
Average air temp. (°C)		13.0		14.0		19.0	
Average temp (°C) of grain stack		25.0		25.0		25.0	
W1[a] (%)		11.0				12.2	
W2[b] (%)		19.3		14.1			
Deterioration index		10.2				5.9	
Moisture content (%) of grain stack	12.2				11.5		12.1

[a] W1: Equilibrium moisture content of grain relating to the conditions of air passing through the grain stack. The air temperature has risen to equal the grain temperature, but the air has not yet exchanged moisture with the grain.
[b] W2: Equilibrium moisture content of grain corresponding to the temperature and the percentage relative humidity of the air.

During ventilation, determine the equilibrium moisture content every four hours. The moment the conditions become unsuitable, stop ventilating. Therefore, aeration is carried out discontinuously, normally for 8–17 hours a day (Table 13).

The total effective length of each period of aeration is normally 20–30 hours, which might reduce the grain moisture content by 1–2%.

Benefits of the Use of the Suction Fan

This equipment had the advantages of being simple, inexpensive, and convenient to install.

Each set consisted of 4–5 units, capable of treating stores holding 130–150 t of paddy, and of handling 4500–5000 t of paddy per year.

The results of aeration of tens of thousands of tons of paddy in the Red River and Cuu–Long River deltas in recent times support the findings outlined in this paper. Handling paddy by ventilation not only met the technical demands but also cost less than redrying by sunlight or dryers because it needed less fuel and equipment, and fewer personnel.

Bibliography

Brooks, C.E.P. 1950. Climate in everyday life. London, Ernest Benn Ltd, 314 p.

Bui huy Thanh and Vu Kim Dung 1973. Paddy storage. Review of Food and Foodstuff, 2.

Calderwood, D.L. 1966. Use of aeration to aid rice drying. Transactions of the American Society of Agricultural Engineers, 16, 525–527, 532.

Golik, M. 1971. Experiments on forced aeration for paddy, Mukomolnoelevatornaja i Kombikormovaja promushlennosch, No. 8, 1971.

Hall, D.W. 1970. Handling and storage of foodgrains in tropical and subtropical areas. Rome, FAO Development Paper, No. 90, 40 p.

Koz'mina, E.P. 1966. Rice storage and processing. Moscow, Kolos.

Koz'mina, E.P. 1970. Rice procurement and storage. Moscow, Kolos.

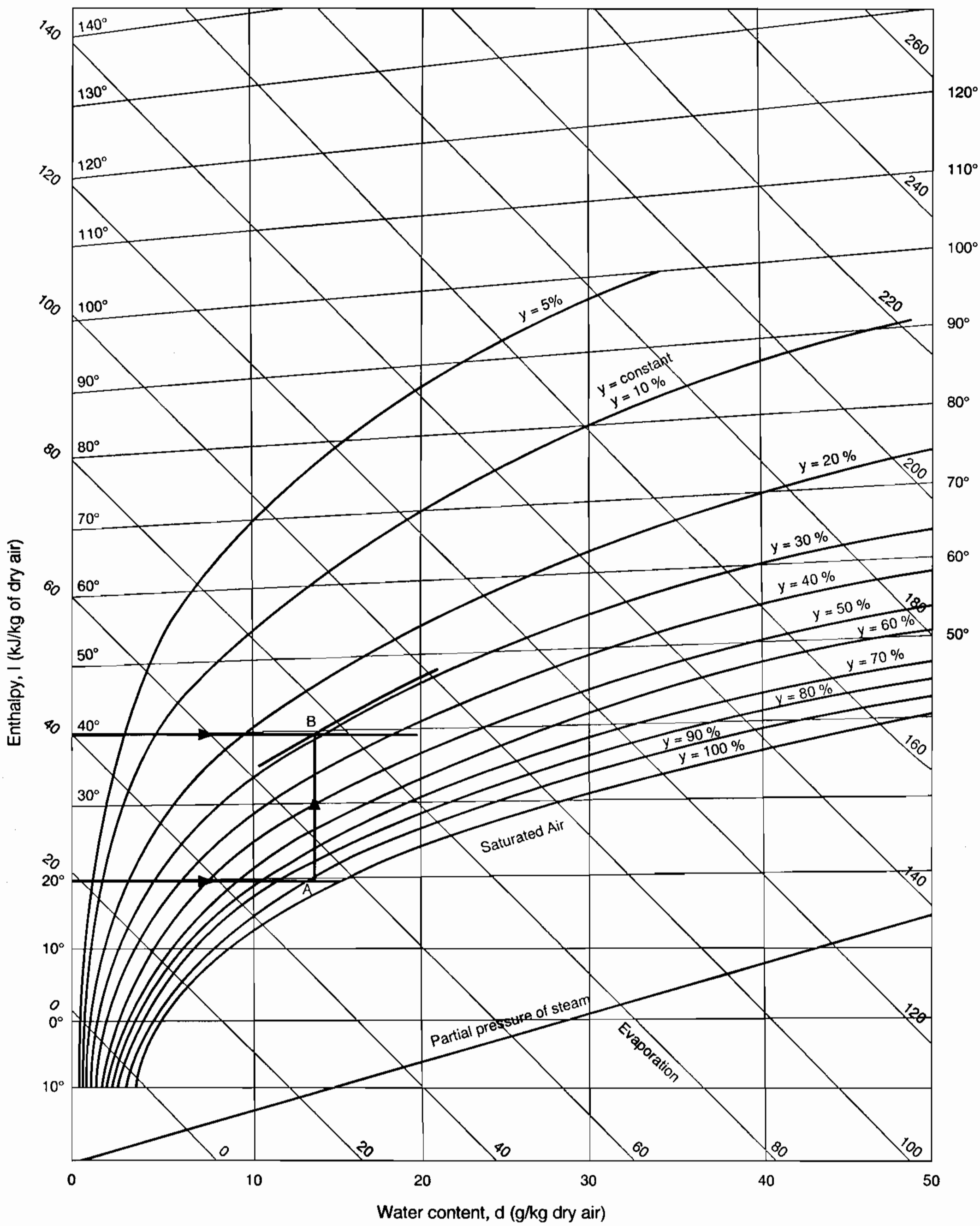
Mel'nik, B.E. 1970. Ventilation for grain. Moscow, Kolos, 183 p.

Sinha, R.N.and Muir, W.E., ed. 1973. Grain storage: part of a system. Westport, Connecticut, AVI Publishing Co., 481 p.

Sorenson, J.W. 1964. Engineering developments in crop processing, drying and storage. Rice Journal, 10, 67.

Teter, N.C. 1982. Aeration of grain. In: Paddy deterioration in the humid tropics. Proceedings of a GASGA seminar, Philippines, 1981. Eschborn, Germany, GTZ, 142–153.

Appendix 1. Diagram for calculating drying and cooling of grain in a cabinet dryer.



Drying of Paddy and Maize in Thailand

Somchart Soponronnarit*

Abstract

Grains such as paddy and maize (corn) are important agricultural products that must be dried for safe storage. This paper describes strategies appropriate for drying paddy and maize in hot and humid climates.

In-store drying is a method that has already been shown to be feasible under such conditions. The advantages of in-store drying are that it yields a high quality product, has low operating costs, and enables safe storage of wet grain for longer periods. The technique had been tested in a private rice mill with a total capacity of 5500 t. The paper provides design charts for in-store drying of both paddy and maize. These permit selection of appropriate airflow rates and bed depths of grain for in-store drying.

It is recommended that grain with a moisture content higher than 20% wet basis be rapidly pre-dried to 19% before in-store drying commences. For this rapid drying phase, continuous-flow column dryers are generally used. Fluidised-bed drying has potential as an alternative to column dryers. The paper describes tests of a 1 t/hour fluidised-bed dryer installed in a paddy merchant's mill and used to dry more than 300 t of paddy during the past season.

DRYING is one of the oldest technologies for preserving agricultural products. Paddy and maize (corn) are the most important grains produced in Thailand. Moisture content at harvesting is approximately 18–25% wet-basis. The products have to be rapidly dried to 14% in order to prevent them from spoilage. Yellowing and broken grain are serious quality problems with paddy, while fungi and aflatoxins are critical in maize, especially in the feed industry.

This paper will describe research, development, and demonstration of drying of some agricultural products such as paddy and maize. Some technology has already been adopted by private sector.

In-store Drying

The simplest method for decreasing grain moisture content is direct sun drying. However, this may not be available during the cloudy and rainy climate of the wet season. Wet grain may be dried rapidly by mechanical dryers using hot air. Product quality after drying may not be very impressive, in particular for paddy. The drying cost is also high. Slow, in-store drying using ambient air is an alternative.

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In-store drying has been employed for many years in temperate climates. Grain will be dried and stored in the same structure, with usually no movement of grain during or after drying. The system comprises an air duct and fan. Ambient air is forced into the grain bulk, preferably during the daytime. Drying takes place over several weeks. It has been proven that in-store drying is also efficient in hot and humid climates such as are experienced in Thailand (Soponronnarit 1988; Soponronnarit and Chinsakolthanakorn 1990).

In-store drying of paddy has already been accepted by a private rice mill in Thailand (Soponronnarit 1994; Soponronnarit et al. 1994a). Total stored capacity at the mill is 5500 t. It has also been demonstrated in two agricultural cooperatives, one for maize and the other for paddy. It can be applied to any grain and some other kinds of agricultural products.

The advantages of in-store drying are:

- prolonging the safe storage period for wet grain, usually more than double that for non-ventilated;
- good quality, such as no yellowing of grain and low percentage of broken rice; and
- low cost.

In the case of maize, aeration of wet grain can eliminate high temperatures in the grain bulk and thus reduce unwanted sour odours.

The operating cost of in-store paddy drying in a private rice mill was found to be very low. Specific

Figure 1. Air ducts in elevated wooden shed.

electricity consumption was approximately 6 kWh/t of paddy dried from approximately 20% to 14% wet-basis (Soponronnarit 1994). This is cheaper than columnar hot air dryers.

In-store drying systems can be designed for both old and new sheds. In Thailand, there are many elevated wooden sheds, each of total capacity of 500 t. The air duct for these should be made from perforated steel sheet rolled in a semicircular section (Fig. 1). Centrifugal fans with backward curved blades are recommended. The specific airflow rate suggested is 0.5–1.0 m^3/minute/m^3 of grain. Design charts are available in Figures 2 and 3 (Soponronnarit et al. 1994b,c). The initial moisture content should not be higher than 20% wet-basis. For concrete floor sheds, it is suggested that an in-floor air duct be constructed as a part of the concrete floor. This can be achieved in both new and existing sheds.

It is recommended that the store be ventilated during the daytime, for 8–14 hours/day. The fan should be turned off during rain.

During long-term storage, the grain bulk can accumulate heat produced by respiration. Ventilation for 1–2 hours once a week is recommended to remove this.

Fluidised-bed Drying

For grain with a moisture content higher than 20% wet-basis, rapid drying to about 19% is recommended. This can be achieved by column continuous dryers which are now becoming more and more accepted in rice mills. An alternative is to use a fluidised-bed dryer. Its advantages are firstly, uniform product moisture content, as a result, very high air temperatures can be employed; and secondly, high drying capacity due to high ratio of air mass to mass of product and high drying air temperature.

Soponronnarit and Prachayawarakorn (1995) review some research and development work on fluidised-bed drying of grain. Little progress was observed during the past few years, especially for drying paddy. Soponronnarit and Prachayawarakorn (1995) also conducted both experimental and simulation work on fluidised-bed paddy drying. A batch process was used. Results showed that maximum drying air temperature had to be limited to 115°C and final moisture content of paddy to 24–25% dry-basis if product quality in terms of head yield and colour was to be maintained. To maximise drying capacity and minimise energy consumption, an air velocity of 4.4 m/second and a bed thickness of 9.5 cm (corresponding to a specific airflow rate of 0.1 kg/second/kg dry matter of paddy) should be used, and 80% of the drying air recycled. Specific energy consumption in terms of primary energy was reported at approximately 7.5 MJ/kg water evaporated. An economic analysis showed that total drying cost was approximately US$0.08/kg water evaporated. This energy consumption and total cost are relatively attractive for Thai conditions.

Batch drying with a fluidisation technique is operationally inconvenient. Continuous-flow drying would remove this problem. A laboratory-scale cross-flow fluidised bed paddy dryer was developed and tested (S. Soponronnarit, S. Prachayawarakorn, and O. Sripawatakul, unpublished data). Similar results were obtained except that air velocity should be 2.3 m/second. At higher velocities, feeding in paddy was more difficult.

Figure 4 is a schematic diagram of an experimental fluidised bed dryer. It comprises a drying section, a 3.7 kW fan, and a 4 × 4 kW electric heater. The bed length, width, and height of the drying section are 0.8, 0.15, and 0.5 m, respectively. Paddy bed depth is controlled by a weir. Paddy is fed by a rotary feeder. In operation, hot air is blown into the drying section in which the direction of the air and grain flow is perpendicular. A small percentage of exhausted air is delivered to the atmosphere and the major portion is recycled, mixed with ambient air, and reheated to the desired temperature. Feed rate of paddy can be varied from 50–200 kg/hour.

Experimental results showed that decreasing moisture content of paddy from 0.29 to 0.21 dry-basis could be achieved in 2–3 minutes. Drying air temperature was 115°C. Final moisture content should not be lower than 0.22 dry-basis if grain quality in terms of head yield and whiteness is to be maintained.

For optimum drying strategy, the following operating parameters were recommended: air speed of 2.3 m/second, bed thickness of 10 cm, fraction of air recycled of 80%, and drying air temperature of 115°C.

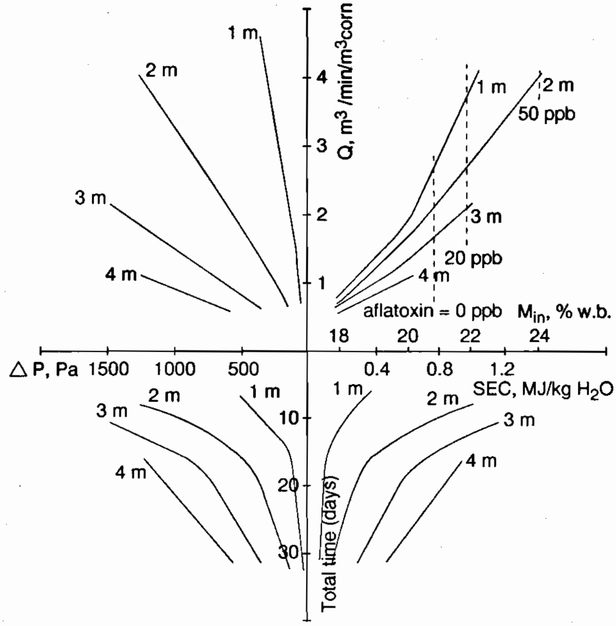

Figure 2. Design chart for in-store paddy drying (intermittent ventilation), inlet relative humidity below 75%, ambient mean temperature 28.4°C, ambient relative humidity 77.8%, dry matter loss 0.5%., M_{in} = initial moisture content, Q = air flow rate for 0.5% dry matter loss, ΔP = total pressure drop, SEC = specific energy consumption.

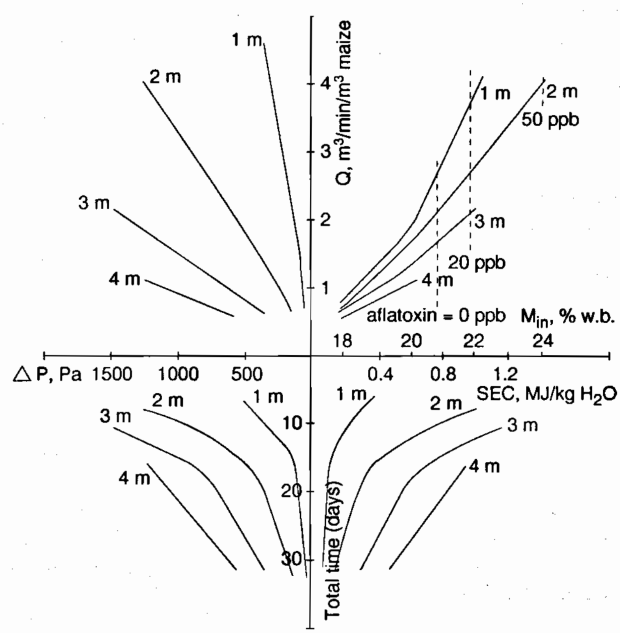

Figure 3. Design chart for in-store maize drying (intermittent ventilation), inlet relative humidity below 75%, ambient mean temperature 28.4°C, ambient relative humidity 77.8%, dry matter loss 0.5%., M_{in} = initial moisture content, Q = air flow rate for 0.5% dry matter loss, ΔP = total pressure drop, SEC = specific energy consumption.

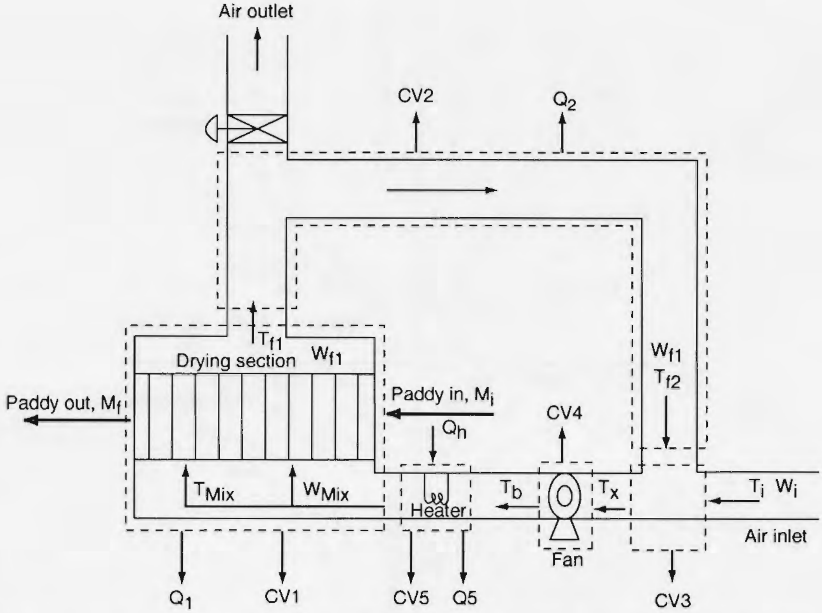

Figure 4. Control volumes of continuous cross-flow fluidised-bed drying system: T, temperature; W, humidity ratio; M, grain moisture content; Q, heat; CV, control volume; arrows give directions of air and grain flow.

Because of the benefits of fluidised-bed paddy drying, i.e. fast drying rate, uniform product moisture content, and reasonable energy consumption compared with most column continuous dryers, it was decided to scale-up the fluidised bed dryer to 1 t/hour, a size appropriate to most of the medium rice mills in Thailand. The width and length of the reactor were 0.3 and 1.7 m, respectively. Diesel oil, the fuel usually used in conventional paddy dryers, was selected for heating the air. The machine (Fig. 5) was constructed and installed by King Mongkut's Institute of Technology Thonburi and the Rice Engineering

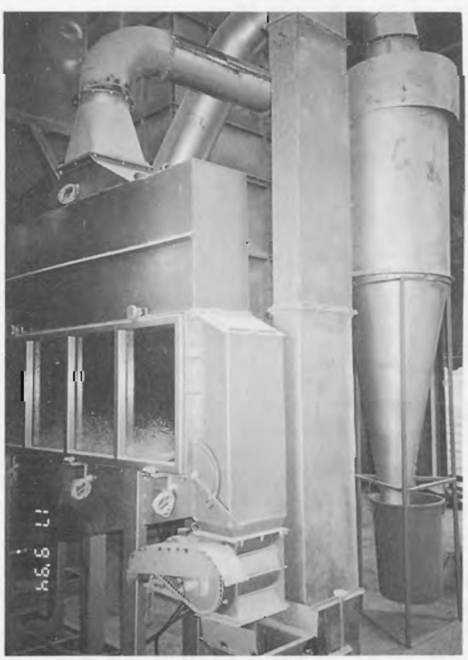

Figure 5. Prototype fluidised-bed paddy dryer: left, complete unit; below, paddy bed.

Supply Co. Ltd at a paddy merchant's site. During almost the whole 1994 harvesting season the unit was used in preference to the existing two column continuous dryers. The unit was operated for approximately 10 hours/day, with good results. More than 300 t of paddy have been dried to date.

Conclusion

In-store drying is applicable to paddy and maize under hot and humid climates. Its advantages are that it yields a high quality product, is of low cost, and gives a longer safe storage period for wet grain. The technique has been used in a private rice mill with a total capacity of 5500 t. Design charts for both in-store drying of paddy and maize are provided. These help select appropriate airflow rate and bed depth of grain.

For grains with moisture contents higher than 20% wet-basis, it is recommended that the moisture content be rapidly reduced to 19%, followed by in-store drying. Fluidised-bed drying is an alternative to column continuous drying for rapid drying. A prototype with a capacity of 1 t/hour was tested at a paddy merchant's site for almost a full harvesting season, with good results.

Acknowledgments

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References

Soponronnarit, S. 1988. Energy model of grain drying system. ASEAN Journal on Science and Technology for Development, 5(2), 43–68.

Soponronnarit, S. 1994. Application of in-store drying in grain industry in Thailand. ACIAR progress report for the period of 1 January–30 June 1994. Bangkok, Thailand, King Mongkut's Institute of Technology Thonburi.

Soponronnarit, S. and Chinsakolthanakorn, S. 1990. Effects of heat and water from respiration on the drying rate and energy consumption. ASEAN Journal on Science and Technology for Department, 7(2), 65–83.

Soponronnarit, S., Nathakaranakule, A., Prachayawarakorn, S. and Inchan, S. 1994a. Design and testing of paddy drying and storage (2nd phase)—a final report. Bangkok, Thailand, King Mongkut's Institute of Technology Thonburi, 79 p.

Soponronnarit, S., Wongvirojtana, P. and Nathakaranakule, A. 1994b. Design chart for in-store maize drying under tropical climates. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Stored product protection: proceedings of the 6th International Working Conference on Stored-product Protection, 17–23 April 1994, Canberra, Australia. Wallingford, U.K., CAB International, 346–350.

Soponronnarit, S., Wongvirojtana, P., Nathakaranakule, A. and Chinsakolthanakorn, S. 1994c. Maintaining paddy quality by appropriate ventilation under tropical climates. Presented at the 9th International Drying Symposium, Gold Coast, Australia, 1994.

Soponronnarit, S. and Prachayawarakorn, S. 1995. Optimum strategy for fluidised bed paddy drying. Drying Technology, in press.

Application of Two-stage In-store Drying Technology in Southern Vietnam

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Abstract

Drying is still the most important operation to maintain grain quality in Vietnam, especially in the rainy season.

This paper reports on investigations of the application of two-stage drying technology to paddy, with in-store drying as the second stage. Existing flat-bed dryers were used for first-stage drying: at a drying temperature of about 50°C and a bed depth of 20 cm it took 4.3 hours of fan running time to reduce the moisture content of the paddy from around 27% wet basis (w.b.) to 19% w.b.

For the second stage, two in-store paddy dryers of 4 and 80 t capacity have been fabricated and installed at Song Hau State Farm, Can-Tho. Using the 4 t facility, paddy of 18–21% moisture content (w.b.) was dried to below 15% w.b. in 84–127 hours, depending on the weather and bed depth, which in these experiments was in the range 1.4–1.9 m. Using a drying temperature of 29–30°C and an air velocity of 9.6–10.8 m/minute, total specific energy for fan and heater was about 5.25 MJ/kg water (evaporated). Tests with the 80 t dryer at 4.4 m/minute air velocity and the same temperature resulted in lower energy consumption, about 4.93 MJ/kg water, but the drying time was longer. The milling quality and appearance of samples of paddy dried in-store were very satisfactory.

In a preliminary test with maize, only a low percentage of aflatoxin was found in samples of maize cobs dried in-store, even though the grain was not dried until four days after harvest.

DRYING grains during rainy seasons in the Mekong Delta provinces of Vietnam is still the most important operation to improve grain quality. For example, freshly harvested paddy with a moisture content as high as 29% or even more gets downgraded or starts sprouting after just 24 hours. Much effort has therefore been made to introduce appropriate drying technology into these regions. In large grain-processing complexes, some modern continuous dryers with capacities ranging from 5 to 10 t/hour have been installed to serve the incoming high moisture content grains sold to the processing centres. The large majority of grain is sun dried on concrete floors or highways, or is dried in flat-bed dryers. In the summer–autumn season of 1994, according to our survey, sun drying in one State farm during unfavourable weather resulted in yellowing of 60% of paddy grains. Flat-bed drying gives acceptable grain quality as long as adequate airflow rates are maintained. Furthermore, operators need to be well trained to mix the whole bed at appropriate times and maintain the plenum temperature at or below 43°C (Hien 1993). Soponronnarit and Preechakul, as quoted by Soponronnarit and Nathakaranakule (1992), also confirmed this temperature ensures a good germination rate. They also suggested that 50°C is the maximum temperature if a high percentage yield of head rice is desired.

In-store drying has long been applied in temperate climate regions since it reduces drying costs and improves grain quality. Under Korean weather conditions, a 1.2 m thick layer of paddy could be dried in 15 days to safe storage conditions using ambient air

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(Kim et al. 1989). This drying technology is also applicable in humid tropical countries such as Vietnam if careful consideration is given to local climatic conditions.

Paddy could be in-store dried directly from moisture contents up to 27.5% wet basis (w.b.) in the Philippines. However, a 2 m maximum depth was recommended, and layered-drying with layer thicknesses around 30 cm was proposed if moisture content was higher than 22% w.b. (Gummert and Arturo 1994). An alternative strategy is two-stage drying. In the first stage, freshly harvested grain is quickly dried to about 18% w.b. by sun drying, flat-bed drying, continuous drying, rapid fluidised-bed drying (Sutherland and Ghaly 1992), or spouted bed drying (Srzednicki and Driscoll 1993). During the second stage, grain is in-store dried down to 14–15% w.b. in a gentle manner using near ambient temperatures and a low airflow rate. This drying strategy was recommended for large-scale drying in Thailand, since it resulted in low operating costs and high quality grain (Soponronnarit 1986). Two-stage drying can also reduce drying time and avoid high moisture content grain turning yellow during a long drying period.

Application of two-stage drying with in-store drying as the second stage for maize with an initial moisture content less than 15% w.b. was also effective in controlling the build up of aflatoxin B1, even though the length of the drying process was 10–14 days (Srzednicki et al. 1993).

Experiments on in-store drying in humid climates have been conducted for about 10 years in other countries, but few on a large scale. The applicability of in-store drying in Vietnam needs to be shown in terms of technical feasibility and acceptability to users through firstly, demonstration of pilot drying, even during extremely unfavourable weather, and secondly, performance of a scale-up in-store dryer with adequate capacity for large-scale application.

Flat-bed drying has been applied in the Mekong Delta for 15 years. Although its recognition by users varies from province to province, it is now the most popular mechanical drying technology in the region. It was estimated that there were more than 300 flat bed dryers working in Soc Trang Province during the most recent autumn–summer season.

The objectives of the study reported here were:

- to use existing flat-bed dryers for first-stage drying, i.e. drying freshly harvested paddy down to 18–19% w.b.;
- to apply in-store drying for the second stage, bringing grain moisture content down to below 15% w.b.; and
- to conduct preliminary tests on controlling aflatoxin contamination in maize using in-store drying technology.

Materials and Methods

First-stage drying with flat-bed dryer

A flat-bed dryer made from galvanised sheets on a wooden frame was used for first-stage drying. Heat energy for drying was provided by combustion of paddy husks, and a diesel engine was used to power the dryer fan. Temperature was monitored by mercury thermometers inserted into the grain bed. Diesel oil and rice husk consumption were recorded to evaluate total energy expenditure.

Pilot in-store dryer

A detachable container — 2 m wide, 2 m long, and 2.5 m high — was built from plywood on a timber frame. The false floor was made of perforated galvanised sheets and located 0.5 m from the bottom, which made an 8 m^3 volume available for grain above the false floor. The walls were covered inside by 2 mm-thick plastic sheeting to prevent heat loss and water penetration; and the walls in the plenum chamber by galvanised sheets to increase bin life.

A heater was constructed from six 600 W resistances which were wired into four stages. Depending on drying procedure and directed by relays, they would be on or off, stage by stage to maintain the required temperature in the plenum chamber. A centrifugal fan was used to supply airflow. The whole system was monitored by a control panel connected to a micro computer. This panel provided both automatic and manual control modes. In case of failure of the computer or the interface cards, the system could still function in manual mode. To measure power consumption, a 1 kWh meter was installed for the fan, and one for the heater. Safety devices were also incorporated including a pressure switch and an overheating protecting sensor.

Due to a failure of circuits in automatic mode, temperature in the plenum chamber was no longer monitored by the computer. The system was shifted to manual mode where a digital thermostat and T-type thermocouple were used to control temperature. Ambient air temperature and relative humidity were recorded by a hygro-thermometer (Testo 610). Airflow rates were measured via static pressure in the plenum chamber and fan curve.

The water removed was determined by weighing grain before and after drying. Paddy moisture content was measured by a resistance-type Kett moisture meter. Samples were taken at different heights along the bin walls using a double concentric tube sampling device. Shade-dried samples were used as control treatment in comparisons of milling quality between different drying methods. All samples were coded before being sent for examination at the Grain Quality Laboratory of the Farming System Center, Can-Tho University.

One drying test with maize cobs was also conducted as a preliminary test of the capacity of this method in controlling aflatoxin content in maize harvested in the rainy season. Moisture content was determined by air oven drying method. Control treatments were threshed grain and maize cobs put in shadow to compare the development of aflatoxin with that in in-store dried maize cobs. Samples were sent to the Food and Commodities Control Center, Ho-Chi-Minh City, to detect aflatoxin contamination by thin-layer chromatography.

Scaled-up dryer

The results of two pilot tests (tests 1 and 2) encouraged the Directorate Board of the Song Hau State Farm to agree on building an 80 t capacity in-store dryer. This was considered as a prototype to test large-scale drying and to confirm the result. The upper part was 6 m wide, 12 m long, and 2.5 m deep from the perforated-sheet false floor. This part was made of detachable plywood-on-wooden frames, covered inside by 3 mm-thick galvanised sheets. The 0.2 m high plenum chamber was built from bricks and mortar. A conduit ran close to one wall, and drying air from a centrifugal fan, driven by a 11 kW electric motor, moved sidewards into the plenum chamber and upwards across the grain bed. A diesel oil burner was used to supply heat, and temperature in the plenum chamber was maintained by a digital thermostat and T-type thermocouple. Oil and electricity consumption were recorded to evaluate total energy expenditure.

Results and Discussion

First-stage drying using flat-bed dryer

Paddy with an initial moisture content of about 27% w.b. was dried to 19% w.b. after 4.23 hours of fan running time at about 20 cm bed height. Including mixing, loading, and unloading time, it would take 5.1 hours per batch, giving the ability to handle 3–4 batches per day if the dryer were operated continuously. Energy consumption by the fan was 1.2 L/hour; and for raising air temperature to around 50°C, it took 28.3 kg paddy husk per hour (Table 1).

In-store drying of paddy

Pilot drying

Figure 1 graphs the reduction of moisture content with time. The maximum differences of moisture content between top and bottom layers were in the range 0.91–1.7%. These differences, however, occurred mainly by the top layer. In tests 2 and 3, where the differences were greatest, the differences between the layers next to the top one and the bottom one were around 0.5%. This suggests that a mixing of the top layer, say 20–30 cm, with the next one would help to ensure an even distribution of moisture content in the grain mass.

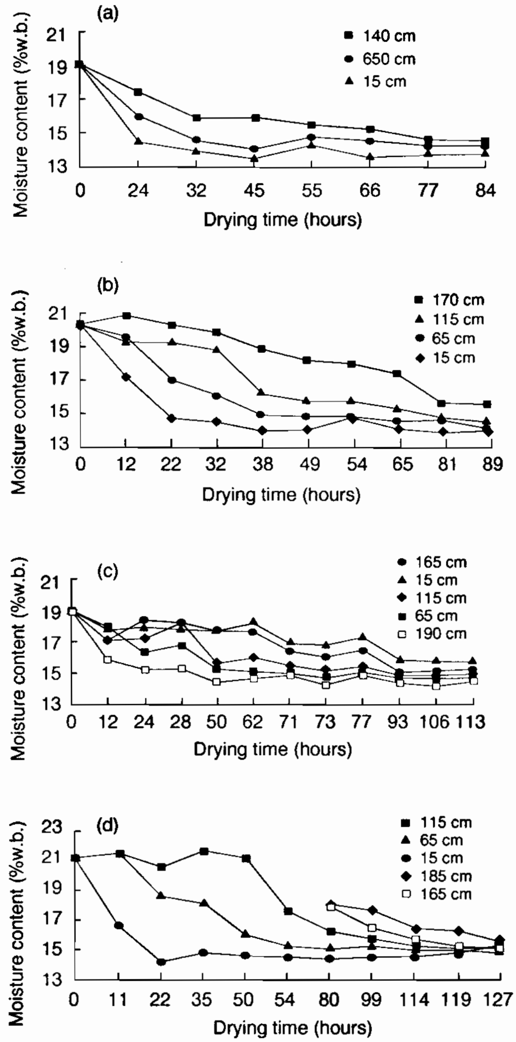

Figure 1. Moisture reduction with time: (a) Test 1; (b) Test 2; (c) Test 3; (d) Test 4.

Depending on the bed height and weather conditions, it took 84–127 hours to reduce moisture content from 18–21% w.b. to 14.3–15.2% w.b. At air velocities from 9.6 to 10.8 m/minute and 29–30°C temperature, the specific energy consumption was between 4.17 and 7.77 MJ/kg water (evaporated), using an electric burner. During the autumn–summer season, with average ambient temperature around 27°C, and average ambient relative humidity around 87% (Table 2), it was necessary to raise ambient air temperature 2–3°C.

Table 1. Results of first -stage drying using flat-bed dryer.

Expt. no.	Initial wt. (t)	Bed height (mm)	Initial m.c. (%w.b.)	Final m.c. (%w.b.)	Drying time (hours)		Energy consumption				Labour	Paddy temp. (°C)
					Total	Fan running	Diesel		Paddy husk			
							Total (L)	Rate (L/hour)	Total (kg)	Rate (kg/hour)		
1	3.6	200	28.5	19.40	8.00	6.00	8.8	1.5	161	26.8	2	47–50
2	3.2	180	27.7	18.60	6.00	3.35	4.6	1.4	120	35.8	2	45–50
3	3.8	220	26.0	18.52	6.00	4.00	5.5	1.4	125	31.3	2	48–50
4	2.6	na	27.0	19.40	5.20	3.30	3.0	0.9	61	18.5	2	50–55
5	3.9	na	25.5	19.54	5.40	4.50	4.5	1.0	130	28.9	2	45–50
Average	3.4		26.9	19.09	6.12	4.23	5.3	1.2	101	28.3		

The method of controlling temperature in the plenum chamber proved to be effective. The system was reliable, easy to run by an unskilled operator, relatively cheap and easily repaired in case of breakdown. This seemed to be quite suitable for medium scale in-store dryer. For application on a larger scale, other drying management strategies such as relative humidity control, could offer a more economic option. The cost of the system then, however, will increase and a skilled operator is required to monitor it.

Before turning into a storage facility after the drying period, an in-store dryer could also function as a normal dryer. To maximise its drying capacity, two levels of temperature could be applied. From the beginning of drying processes, a relative high temperature was used until the bottom layer reached 15% w.b. Then, second level of temperature, 29°C, in tests 3 and 4, was applied for the remaining drying time. This method was strongly recommended when drying relative wet paddy, say more than 19% w.b., and in grain beds deeper than 2 m, to prevent yellowing of grain due to long drying period.

Milling quality in terms of head rice was compared between in-store drying and shade drying (Tables 3 and 4). Except for test no. 1, head rice recovery of in-store dried samples appeared to be higher than those of shade-dried ones. This could be due to wet weather during those days. It took a long time for samples put in shadow to reach equilibrium conditions and some spoilage could occur.

Scale-up drying

Moisture reduction with time is plotted in Figure 2. Air velocity in these experiments was around 4.4 m/minute. Total drying time was prolonged: 96 hours and 127 hours for 1.1 and 1.8 m bed depths, respectively; but specific energy consumption was somewhat lower, about 4.93 MJ/kg water evaporated (Table 5). It should be noted that if heater efficiency

Table 2. Results of pilot in-store drying of paddy at Song Hau State Farm in 1994.

Measurement	Test number			
	1	2	3	4
Drying period	16–21 June	25–30 June	07–14 July	20–27 July
Weight (kg)				
Initial	3277.0	4144.3	4500.0	3440 & 1010[a]
Final	3039.9	3784.7	4300.2	4121
Water removed	237.1	359.6	199.8	329
Moisture content (% w.b.)				
Initial	19.04	20.34	18.9	21.12 & 17.9[a]
Final	14.25	14.38	15.06	14.94
Height of drying bed (m)	1.4	1.7	1.9	1.40 &1 .45[a]
Total drying time (hour)	84	89.5	113.5	127
Total energy consumption				
Fan (kWh)	109.2	116.3	152	164
Resistance heater (kWh)	198.2	321	279	218
Specific energy consumption (MJ/kg water evap.)				
Fan	1.66	1.16	2.74	1.79
Resistance heater	3.01	3.21	5.03	2.38
Total	4.67	4.37	7.77	4.17
Set temperature (°C)	30	30	32 & 29[b]	32 & 29[b]
Air velocity (m/minute)	10.8	na	9.6	9.4
Avg. amb. temperature (°C)	27.87	27.58	27.58	26.43
Avg. relative humidity (%)	84.03	87.36	87.36	89.28

Notes: [a] In batch no. 4, paddy was loaded two layers into the bin, the figures indicate two loadings
[b] Two temperatures were applied: 32°C from starting until the bottom layer reached about 15% w.b; 29°C: during the remaining drying time.

was taken into account, scale-up tests consumed even less energy for each unit of product since efficiency of a diesel oil burner is lower than that of electric one. The differences between top and bottom layers were 1.13% and 0.85% for tests 5 and 6, respectively. Average head rice recovery of shade and in-store dried samples is presented in Table 4. It was also observed in all tests that the appearance of rice dried in-store was quite acceptable to quality control officers of Song Hau State Farm.

Table 3. Average head rice recovery (%) of control and in-store samples of pilot tests.

Method of drying	Test no. 1	Test no. 2	Test no. 3	Test no. 4
Shade drying	51.2	55.8	51.7	48.8
In-store drying position of layer				
15 cm	52.2	58.8	55.5	50.8
65 cm	50.5	59.3	57.3	54.2
115 cm	47.7	57.3	57.2	52.0
165 cm	---	---	55.0	53.3
surface	51.0	57.5	54.0	50.5

In-store drying of maize cobs

Table 6 gives the results of the in-store drying test for maize cobs. Using drying air at 30°C, it took 176 hours to reduce moisture content of maize cobs from

Table 4. Average head rice recovery (%) of control and in-store samples of scale-up tests.

Method of drying	Test no. 5	Test no. 6
Shade drying	na	45.4
In-store drying position of layer		
20 cm	na	46.2
120 cm	na	48.8
180 cm	na	47.3

Table 5. Results of scale-up drying of paddy at Song Hau State Farm in 1994.

Measurement	Test number 5	Test number 6
Drying period	11–18 August	02–09 Sep.
Weight (kg)		
Initial	49732	72100
Final	47340	68641
Water removed	2392	3459
Moisture content (% w.b.)		
Initial	18.64	18.41
Final	14.53	14.51
Height of drying bed (m)	1.1	1.8
Total drying time (hours)	96	157
Total energy consumption		
Fan (kWh)	960	1570
Diesel oil (L)	212	345
Specific energy consumption (MJ/kg water evap.)		
Fan	1.45	1.63
Diesel oil	3.19	3.59
Total	4.64	5.22
Set temperature (°C)	32 & 29[a]	32 & 29[a]
Air velocity (m/minute)	na	4.4

[a] Two temperatures were applied: 32°C: from starting until the bottom layer reached about 15% w.b.; 29°C: during the remaining drying time.

29.35 to 15.25% w.b. Although it was dried four days after harvest, aflatoxin contamination of in-store dried samples was less than in the two control treatments.

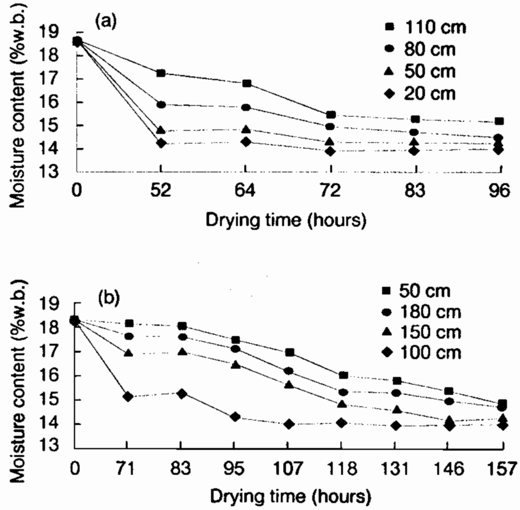

Figure 2. Moisture reduction with time: (a) Test 5; (b) Test 6.

Conclusions

Two-stage drying technology with in-store drying as the second stage was applied for the first time in southern Vietnam. It was tested in the wettest season in the Mekong Delta. The results of paddy drying showed, nevertheless, that this method is technically feasible for reducing grain moisture content to safe levels. In addition, quality of grain was improved in terms of increased head rice recovery and no adverse effect on grain colour. This is of great importance at a time of great potential for expansion of production of high quality and fragrant rice in the Mekong Delta. In-store drying could also become an appropriate technique in the rainy season to control aflatoxin contamination of maize.

The following activities are planned to fully evaluate the technique under Vietnamese conditions:

- Application of two-stage drying during the next winter–spring harvest season
- Collection of further data bearing on the economic feasibility of the method.
- Intensive experiments on maize drying, especially in the rainy season, to confirm the ability of this method to control aflatoxin development.

Table 6. Experimental conditions and results of in-store drying test on maize cobs.

Maize variety		DK-888
Planting location		Dong Nai province
Date of harvest		18 September, 1994
Date of drying beginning		22 September, 1994
Weight (maize cobs) (kg)	initial	4232
	final	3354
Moisture content (% w.b.)		
Threshed grain	initial	29.35
	final	15.25
Cobs	initial	46.51
	final	18.55
Total drying time (hours)		176
Drying temperature (°C)		30
Ambient temperature (°C)		26–32
Ambient relative humidity (%)		65–95
Air velocity (m/minute)		na
Result of aflatoxin determination		

	Moisture content (% w.b.)	Aflatoxin (ppb)
Shade drying threshed grain	14.9	750
In-store drying maize cobs	14.7	40
Shade drying maize cobs	18.4	80

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References

Gummert, M. and Arturo, B.T. 1994. Designing a low-temperature in-bin drying and storage system. Technical handbook, IRRI–GTZ Project P.N.92.2209.2–01.110, 4–15 (unpublished).

Hien, P.H. 1993. Using batch grain dryers for summer–autumn crops in south Vietnam. Proceedings of the 14th ASEAN seminar on grain postharvest technology, Manila, Philippines, 5–8 November 1991. Bangkok, Thailand, AGPP, 129–135.

Kim, K.S., Slim, M.G., Kim, B.C., Rhim, J.H., Cheigh, H.S., Muhlbauer, W. and Kwon, T.W. 1989. An ambient-air in-storage paddy drying system for Korean farms. AMMA, 20(2), 23–29.

Soponronnarit, S. 1986. Paddy drying in Thailand. In: Champ, B.R. and Highley, E.. ed., Preserving grain quality by aeration and in-store drying. Proceedings of an international seminar held at Kuala Lumpur, Malaysia, 9–11 October, 1985. Canberra, ACIAR Proceedings No. 15, 192–199.

Soponronnarit, S. and Nathakaranakule, A. 1992. Field experiment of in-store drying of paddy under tropical climates. Proceedings of the 13th ASEAN Seminar on Grain Postharvest Technology, Brunei Darussalam, 4–7 September 1990. Bangkok, Thailand, AGPP, 184–189.

Srzednicki, G.R. and Driscoll, R.H. 1993. High moisture grain drying with spouted bed dryer. Proceedings of the 14th ASEAN Seminar on Grain Postharvest Technology, Manila, Philippines, 5–8 November 1991. Bangkok, Thailand, AGPP, 113–128.

Srzednicki, G.R., Driscoll, R.H. and Soponronnarit, S. 1993. Studies on drying strategies for aflatoxin control in corn. Proceedings of the 15th ASEAN Seminar on Grain Postharvest Technology, Singapore, 8–11 September 1992. Bangkok, Thailand, AGPP, 165–183.

Sutherland, J.W. and Ghaly, T.F. 1992. Rapid fluid bed drying of paddy rice in the humid tropics. Proceedings of the 13th ASEAN Seminar on Grain Postharvest Technology, Brunei, Darussalam, 4–7 September 1990. Bangkok, Thailand, AGPP, 168–177.

Quality Management in Stored Grain

Pest Management in Stored Grain

M. Bengston*

Abstract

Losses due to pest infestation in stored grain vary widely. They are greatest in warm countries, but probably average 10% worldwide. Good storage practices — grain hygiene, and reduction in grain temperature and grain moisture — are fundamental to pest control.

In Australia, around 70% of grain is fumigated, chiefly with phosphine either in sealed storages which permit prolonged exposures to lethal concentrations (1 week minimum) or in a continuous application system which also permits prolonged exposures. Methyl bromide and carbon dioxide are used to a lesser extent. Around 30% of the grain is treated with grain protectant insecticides, currently chlorpyrifos-methyl plus methoprene.

LOSSES due to pests in stored grain vary widely but are more serious in tropical climates and probably average around 10% worldwide. Specific estimates of losses include: maize 11% after 8 months storage and paddy 5% after 7 months in the Philippines (Caliboso et al. 1986); milled rice 0.5–2.0% after 6 months in Indonesia (Sidik et al. 1986); paddy 3–6.8% after 3–12 months, milled rice 5–14.2% in Malaysia (Muda 1986). A higher standard of pest control is generally applied in grain traded internationally than in grain for local consumption.

In Australia, grain production is around 25 Mt per year and comprises chiefly wheat, barley, oats, sorghum, and maize. The grain is handled in bulk and 70% is exported. The standard of pest control is very high so that actual losses are negligible and government regulations impose a nil tolerance for live insects in export grain.

Grain Hygiene

Grain hygiene, which aims to minimise the insect pest population at the commencement of storage, remains a fundamental aspect of pest control. Grain stores should be emptied and physically cleaned using grain handling machinery followed by use of shovels, brooms, etc. supplemented as appropriate by the use of air-blowers and vacuum. One practical aspect which is often overlooked is the prompt destruction or disposal of residues away from the storage site.

The cleaned empty store is then treated with structural treatments. The treatments most commonly used in Australia are listed in Table 1.

Table 1. Store fabric treatments currently used in Australia.

Treatment	Application rate
fenitrothion 1% plus carbaryl 1%	5 L/100 m^2
or	
azamethiphos 0.5%	5 L/100 m^2
or	
activated amorphous silica, dry	200 g/100 m^2
activated amorphous silica, slurry	600 g/100 m^2

The spray combination of fenitrothion plus carbaryl is the cheapest treatment and is used in areas where insect resistance is not severe. Azamethiphos is currently effective against resistant insects and is persistent on concrete, but is more expensive. The activated amorphous silica is produced by treating diatomaceous earth with silica aerogels. It may be

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applied as a dust, but in larger stores is conveniently sprayed as a slurry. It has a major advantage in being unlikely to produce cross-resistance to protectants or fumigants and is thus a useful tool in use in resistance-management strategies.

Grain Temperature

Lowering grain temperature reduces the rate at which insect pest populations increase. Concrete structures have better insulating properties than metal ones and in many situations result in lower grain temperatures, especially in the peripheral region of the storage. Painting metal storages white reduces temperatures in the grain headspace by around 10°C.

Grain aeration using ambient air lowers grain temperatures but the results clearly depend on ambient conditions. The objective is to lower temperature to 15°C, at which insect population growth is negligible. More recently it has been recognised that wet-bulb temperature is linearly related to population growth rate, so that for dry grain (wheat at 9%) a dry bulb of 27°C is equivalent to a wet-bulb temperature of 14°C (Desmarchelier 1988).

In Australia, grain aeration alone will not completely control insects and it has typically been used in combination with the application of grain protectants. The number of insect generations per year, and hence the rate of selection for insect resistance, are reduced. In addition, the rate of decay of residual pesticides is reduced (Desmarchelier et al. 1979) so that the rate of application and hence the cost are also reduced.

Grain aeration using refrigerated air has been successfully tested on an experimental basis (Elder et al. 1975, 1984) but is used on only a very small scale because the costs of the insulation needed for storages are high.

Cool storage at temperatures below 10°C is highly effective for insect pest control. However, the costs are such that it is used only where it is required for other purposes, such as maintenance of buffer stocks of shelled peanuts or in the preservation of germination of high value seeds.

Disinfestation of grain at high temperatures has been successfully tested on an experimental basis (Clafin et al. 1986; Sutherland et al. 1989). Grain is heated briefly, e.g. an air temperature of 80°C for 4 minutes giving a surface temperature on wheat of 65°C, and then cooled rapidly so that quality is unaffected. A continuous-flow, fluidised bed has been used at rates up to 180 t/hour.

Grain Moisture

Lowering grain moisture reduces the rate of increase of insect pests but the upper limit for prolonged storage, i.e. an equilibrium relative humidity of 70%, is set by the need to prevent spoilage by mites or fungi. Most Australian grain is harvested at a low grain moisture content, and only 10% requires artificial drying. The maximum grain moisture limit for wheat entering central storage is 12%. Other grains such as sorghum and rice, when harvested in the Australian autumn generally require artificial drying.

Studies have shown that the potency of grain protectants is significantly reduced when they are applied to moist grain (Samson et al. 1987). In practice it is important that grain be dried before treatment with grain protectants.

Fumigation

Fumigation is the major technique used for pest control in stored grain in Australia, with an estimated 70% of grain currently being fumigated. Phosphine is the major fumigant and most is generated from aluminium phosphide. Major emphasis is now placed on ensuring that storages are gastight, and preferably this is verified using a pressure decay test. Phosphine is much more effective with long exposure times than short ones and recent recommendations specify a minimum of 7 days (Table 2).

Table 2. Application rates for phosphine (g/m^3) for commodities with low sorption held in sealed storages at temperatures above 20°C.

Storage capacity	Exposure period in days				
	7	10	14	21	28
< 1000 t	2.0	1.0	0.75	–	–
> 1000 t	na	2.5	2.0	1.5	1.5

In addition the application rate must be increased for commodities with high sorption. For those with moderate sorption, i.e. oats, soybeans, faba beans, triticale, canola, safflower, and field peas, the doses are increased by a factor of 2. For those with high sorption, i.e. paddy rice, sunflower, grain legumes-in-shell, peanuts, and peanuts-in-shell, the doses are increased by a factor of 3.

In storages with a lesser degree of gastightness a continuous application system for phosphine (e.g. SIROFLO®) may be used (Winks 1993; Winks and Russell 1994a,b). Gas is released slowly from cylinders containing 2% phosphine in carbon dioxide and is pushed along with external air into the storage so that all leaks are outwards. The minimum phosphine concentrations are 0.05 g/m^3 for 14 days or 0.02 g/m^3 for 28 days.

A low level of phosphine resistance is now widespread in Australia (White and Lambkin 1990) but is not sufficiently serious to cause failure of fumigation under good conditions. Much higher levels of phosphine resistance have been recorded in Asia (Tyler et al. 1983; Liang 1994). Urgent steps are necessary to delay its further development.

Methyl bromide is used for rapid disinfestation of grain with an application rate of 24–32 g/m^3 for 24 hours at temperatures above 15°C. These rates may be revised downwards. Use of methyl bromide is expected to be phased out by the year 2000 in view of its implication in ozone depletion of the atmosphere.

Carbon dioxide is used as a fumigant in only a few specialised situations, such as the treatment of grain destined for the 'organic' food market. The application rate must attain a minimum concentration of 35% after 2 weeks.

Grain Protectants

Around 30% of grain in Australia is treated by spraying with grain protectant insecticides during intake to storage. Widespread use of grain protectants commenced in the 1960s following the recognition that malathion had properties suitable for this purpose (Strong and Sbur 1960, 1961; Floyd 1961; Bang and Floyd 1962). Many workers in many countries contributed to its development. In Australia it was used to protect virtually all grain and was highly successful in reducing overall infestation levels. Dichlorvos was developed and introduced soon after and has many properties complementary to malathion. It has a short residual life and, when incorporated into the grain stream, it is useful for disinfesting grain without producing high residues (Godavaribai et al. 1960; Green and Tyler 1966; Champ et al. 1969; Desmarchelier et al. 1977). It is particularly effective against species of Lepidoptera and for that purpose may conveniently be applied as slow-release strips (Conway 1966; La Hue 1969; McFarlane 1970) or aerosols (Bengston 1976).

By the 1970s malathion resistance developed in many countries (Champ and Dyte 1976). The severity of the resistance was related to the extent of its use. In Australia, where use had been almost universal, malathion was totally ineffective for the purposes of practical control. In China, where malathion was not readily available for widespread use, it is currently still effective in many situations.

With the development of malathion resistance in Australia no single compound provided control of the resistant strains, and combinations of pesticides were introduced. Most species were controlled by chlorpyrifos-methyl (Bengston et al. 1975; Morallo Rejesus and Carino 1976a,b; La Hue 1977a,b; Quinlan et al. 1979), fenitrothion (Champ et al. 1969; Bengston et al. 1980), or pirimiphos-methyl (Bengston et al. 1975; La Hue 1975, 1977b; McDonald and Gillenwater 1976; Quinlan et al. 1980). These were widely used in Australia and many other countries. The significant exception to effective control was *Rhyzopertha dominica*. Either natural pyrethrins or a synthetic pyrethroid, bioresmethrin (Bengston et al. 1975, 1980, 1983a), or deltamethrin (Bengston et al. 1983b, 1984), or fenvalerate (Bengston et al. 1983a, 1984), or IR-phenothrin (Bengston et al. 1983b, 1984), or the carbamate carbaryl (Bengston et al. 1980, 1983a; Davies and Desmarchelier 1981), must be used. All the synthetic pyrethroid materials are synergised by the addition of piperonyl butoxide (Bengston 1979). In some areas in Australia resistance has developed in *Rhyzopertha dominica* to the synthetic pyrethroid insecticides and methoprene has proved effective (Amos and Williams 1977; Bengston and Strange 1994).

Resistance to each of these insecticides except methoprene is now present in some regions. To delay its further development the use of particular insecticides is changed each two years. The use in Queensland for most grains in 1994–95 is chlorpyrifos-methyl 10 mg/kg plus methoprene 1.0 mg/kg for 3–9 months storage and half this rate for up to 3 months storage.

Future Developments

The major threat to current pest control technologies is the development of resistance, which will make the particular technology more expensive or else ineffective. Of particular significance is resistance to fumigants which constitute the most practicable means of pest control in many situations. Clearly, we need to understand how this occurs and then to implement measures to delay the further development of resistance.

In addition, as pest control measures become more complex and the need for integration into the storage management system more evident we can use microcomputer technology to develop computer-based decision-support systems which will make available expert advice to personnel implementing the pest control measures.

References

Amos, T.G. and Williams, P. 1977. Insect growth regulators. Some effects of methoprene and hydroprene on productivity of several stored grain insects. Australian Journal of Zoology, 25, 201–206.

Bang, U.H. and Floyd, E.G. 1962. Effectiveness of malathion in protecting stored polished rice from damage by several species of stored-grain insects. Journal of Economic Entomology, 55, 188–190.

Bengston, M. 1976. Timed daily emission of dichlorvos for control of *Ephestia cautella* (Walker) infesting stored wheat. Journal of Stored Products Research, 12, 157–164.

— 1979. Potential for pyrethroids as grain protectants. In: Evans, D.E., ed., Australian Contributions to the Sympo-

sium on the Protection of Grain against Insects, Moscow 1978. Canberra, CSIRO Division of Entomology, 88–91.
Bengston, M., Connell, M., Davies, R.A.H., Desmarchelier, J.M., Phillips, M.P., Snelson, J.T. and Sticka, R. 1980. Fenitrothion plus (IR)-phenothrin and pirimiphos-methyl plus carbaryl as grain protectant combinations for wheat. Pesticide Science, 11, 471–482.
Bengston, M., Cooper, L.M. and Grant-Taylor, F.J. 1975. A comparison of bioresmethrin, chlorpyifos-methyl and pirimiphos-methyl as grain protectants against malathion-resistant insects in wheat. Queensland Journal of Agriculture and Animal Science, 32, 51–78.
Bengston, M., Cooper, L.M., Davies, R.A.H., Desmarchelier, J.M., Hart, R.H. and Phillips, M.P. 1983a. Grain protectants for the control of malathion-resistant insects in stored sorghum. Pesticide Science, 14, 385–398.
Bengston, M., Davies, R.A.H., Desmarchelier, J.M., Henning, R., Murray, W., Simpson, B.W., Snelson, J.T., Sticka, R. and Wallbank, B.E. 1983b. Organophosphates and synergised synthetic pyrethroids as grain protectants in bulk wheat. Pesticide Science, 15, 500–508.
Bengston, M., Davies, R.A.H., Desmarchelier, J.M., Phillips, M.P. and Simpson, B.W. 1984. Organophosphorus and synergised synthetic pyrethroid insecticides as grain protectants for stored sorghum. Pesticide Science, 15, 500–508.
Bengston, M. and Strange, A.C. 1994. Recent developments in grain protectants for use in Australia. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Stored-product protection. Proceedings of the 6th International Working Conference on Stored-product Protection, Canberra, April 1994. Wallingford, U.K., CAB International, 751–754.
Caliboso, F.M., Sayaboc, P.D. and Amoranto, M.R. 1986. Pest problems and the use of pesticides in grain storage in the Philippines. In: Champ, B.R., and Highley, E., ed., Pesticides and humid tropical grain storage systems: proceedings of an international seminar, Manila, Philippines, 27–30 May 1985. Canberra, ACIAR Proceedings No. 14, 17–29.
Champ, B.R. and Dyte, C.E. 1976. Report of the FAO global survey of pesticide susceptibility of stored grain pests. Rome, FAO Plant Production Protection Service No. 5.
Champ, B.R., Steels, R.W., Genn, B.G. and Elms, K.D. 1969. A comparison of malathion, diazinon, fenitrothion and dichlorvos for control of *Sitophilus oryzae* (Linnaeus) and *Rhyzopertha dominica* (Fabricius) in wheat. Journal of Stored Products Research, 5, 21–48.
Clafin, J.K., Evans, D.E., Fane, A.G. and Hill, R.J. 1986. The thermal disinfestation of wheat in a spouted bed. Journal of Stored Products Research, 22, 153–161.
Conway, J. 1966. The control of *Anagasta kuehniella* (Zeller) (Lepidoptera, Phycitidae) in metal bins using dichlorvos slow release poly-vinyl chloride strips. Journal of Stored Products Research, 1, 381–383.
Davis, R.A.H. and Desmarchelier, J.M. 1981. Combinations of pirimiphos-methyl and carbaryl for stored grain protection. Pesticide Science, 12, 365–374.
Desmarchelier, J.M. 1988. The relationship between wet-bulb temperature and the intrinsic rate of increase of eight species of stored-product Coleoptera. Journal of Stored Products Research, 24, 107–113.
Desmarchelier, J.M., Bengston, M., Evans, D.E., Heather, N.W. and White, G.G. 1979. Combining temperature and moisture manipulation with the use of grain protectants. In: Evans. D.E., ed., Australian Contributions to the Symposium on the Protection of Grain against Insect Damage during Storage, Moscow, Canberra. 1978. CSIRO Division of Entomology. 61–73.
Desmarchelier, J.M., Dans, H.J., Williams, P. and Minnet, W. 1977. Toxicity of dichlorvos vapour to insects in aerated and unaerated wheat and comparison of the vapour action of dichlorvos and malathion. Journal of Stored Products Research, 13, 1–13.
Elder, W.B., Ghaly, T.F. and Thorpe, G.R. 1984. Grain refrigeration trials in Australia. In: Ripp, B.E., ed., Controlled atmosphere and fumigation in grain storages. Amsterdam, Elsevier, 623–643.
Elder, W.B., Hunter, A.J. and Griffiths, H.J. 1975. Refrigeration of bulk wheat in a thermally insulated silo for the control of insect infestations. Australasian Refrigeration, Air Conditioning and Heating, 29, 38–46.
Floyd, E.H. 1961. Effectiveness of malathion dust as a protectant for farm-stored corn in Louisiana. Journal of Economic Entomology, 54, 900–904.
Godavaribai, S., Krishnamurthy, K. and Majumder, S.K. 1960. Studies on malathion for stored product insect control. Pest Technology Supplement to Public Health Sanitation (London), 2, 12–15.
Green, A.A. and Tyler, P.S. 1966. A field comparison of malathion, dichlorvos and fenitrothion for the control of *Oryzaephilus surinamensis* (Linnaeus) (Coleoptera, Silvanidae) infesting stored barley. Journal of Stored Products Research, 1, 273–285.
La Hue, D.W. 1969. Control of malathion-resistant Indian meal moths, *Plodia interpunctella* (Hübner) (Lepidoptera, Pyralidae) with dichlorvos resin strips. Proceedings of North Central Branch of Entomological Society of America, 24, 117–119.
— 1975. Pirimiphos-methyl as a short-term protectant of grain against stored product insects. Journal of Economic Entomology, 68, 235–236.
— 1977a. Chlorpyrifos-methyl: doses that protect hard winter wheat against attack by stored grain insects. Journal of Economic Entomology, 68, 235–236.
— 1977b. Pirimiphos-methyl: effect on populations of *Tribolium confusum* and *Tribolium castaneum* in wheat. Journal of Economic Entomology, 70, 135–137.
Liang Quan 1994. Meet the challenge of insect resistance to phosphine. Grain Storage, 23.
McDonald, J.L. and Gillenwater, H.B. 1976. Toxicity of pirimiphos-methyl and Bay SRA 7660 to six species of stored product insects. Journal of the Georgia Entomological Society, 11, 110–114.
McFarlane, J.A. 1970. Treatment of large grains stored in Kenya with dichlorvos slow-release strips for control of *Cadra cautella*. Journal of Economic Entomology, 63, 288–292.
Morallo Rejesus, B. and Carino, F.O. 1976a. The residual toxicity of five insecticides on three varieties of corn and sorghum. Philippines Journal of Agriculture, 60, 96–104.
— 1976b. Evaluation of five contact insecticides as protectants against insects of stored corn. Philippines Journal of Agriculture, 60, 105–111.

Muda, A.R. 1986. Pest problems and the use of pesticides in grain storage in Malaysia. In: Champ, B.R., and Highley, E., ed., Pesticides and humid tropical grain storage systems. Proceedings of an international seminar, Manila, Philippines, 27–30 May 1985. Canberra, ACIAR Proceedings No. 14, 11–16.

Quinlan, J.K., White, G.D., Wilson, J.L., Davidson, L.I. and Henricks, L.H. 1979. Effectiveness of chlorpyrifos-methyl and malathion as protectants for high moisture stored wheat. Journal of Economic Entomology, 72, 90–93.

Quinlan, J.K., Wilson, J.L. and Davidson, L.I. 1980. Pirimiphos-methyl as a protectant for high moisture stored wheat (in controlling insects). Journal of the Kansas Entomological Society, 53, 825–832.

Samson, P.R., Bengston, M., Parker, R.J. and Keating, J.A. 1987. The effect of grain moisture on the biological activity of fenitrothion residues on maize in storage. Pesticide Science, 19, 135–144.

Sidik, M., Halid, H. and Pranata, R.I. 1986. Pest problems and the use of pesticides in grain storage in Indonesia. In: Champ, B.R., and Highley, E., ed., Pesticides and humid tropical grain storage systems: proceedings of an international seminar, Manila, Philippines, 27–30 May 1985. Canberra, ACIAR Proceedings No. 14, 37–43.

Strong, R.G. and Sbur, D.E. 1960. Influence of grain mositure and storage temperature on the effectiveness of malathion as a grain protectant. Journal of Economic Entomology, 53, 341–349.

— 1961. Evaluation of insecticides as protectants against pests of stored grain and seeds. Journal of Economic Entomology, 54, 235–238.

Sutherland, J.W., Fricke, P.W. and Hill, R.J. 1989. The entomological and thermodynamic performance of a pneumatic conveyor wheat disinfestor using heated air. Journal of Agricultural Engineering Research, 44, 113–124.

Tyler, P.S., Taylor, R.W. and Rees, D.P. 1983. Insect resistance to phosphine fumigation in food warehouses in Bangladesh. International Pest Control, 25, 10–31, 21.

White, G.G. and Lambkin, T.A. 1990. Baseline responses to phosphine and resistance status of stored-grain beetle pests in Queensland, Australia. Journal of Economic Entomology, 83(5), 1738–1744.

Winks, R.G. 1993. The development of SIROFLO® in Australia. In: Navarro, S. and Donahaye, E., ed., Proceedings of an international conference on controlled atmosphere and fumigation in grain, Winnipeg, Canada, 11–13 June 1992. Bet Dagan, Israel, Agricultural Research Orgnization, 399–410.

Winks, R.G. and Russell, G.F. 1994a. Effectiveness of SIROFLO® in horizontal storages. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Stored product protection. Proceedings of the 6th International Working Conference on Stored-product Protection, Canberra, April 1994. Wallingford, U.K., CAB International, 1238–1244.

— 1994b. Effectiveness of SIROFLO® in vertical silos. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Stored product protection. Proceedings of the 6th International Working Conference on Stored-product Protection, Canberra, April 1994. Wallingford, U.K., CAB International, 1245–1249.

Research and Development on Pest Management in Stored Food Grains in Vietnam

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Abstract

This paper summarises the main features of grain storage pest management in Vietnam and current research directions in pest management in the Post Harvest Technology Institute. The latter include studies on pesticide resistance, application of *Bacillus thuringiensis*, rodent control, and use of ultra high frequency for pest control in small-scale storage.

VIETNAM'S Post Harvest Technology Institute originated in the Vietnam Food-Grains Storage Branch, established in 1954 as a successor to the Central Food Warehouse. The branch subsequently became the Bureau of Food-Grains Storage, part of the Department of Food. Some of its staff were trained in China.

From 1960 to 1965, the Bureau of Food-Grains Storage managed research and technical operations in this field throughout Vietnam. In 1970, the Food Research Institute was established, with a research function only. It was renamed the Post Harvest Technology Institute (PHTI) in 1989.

Pests occurring in warehouses in Vietnam include microorganisms, stored-products insects, termites, and rodents. This paper focuses on the last three groups.

Survey of Insect Pests in Food Grain Storages

Before 1954, the French colonial administration had conducted some preliminary surveys on insect pests in food grain storages. However, it was not until 1961–1972 for the north and 1982–1984 for the whole country, that extensive surveys on insect pests in food grain storages were carried out. Consequently, 43 species have been discovered: Coleoptera, 28 species; Lepidoptera, 9; Acarina, 4; and Blattodea, 2.

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Pest Management Techniques for Food Grain Storage

Techniques used for pest management for food grain storage in Vietnam are similar to those used in developed countries.

From 1954–1960 the strategy was pest prevention through disinfestation.

In 1970 an integrated pest management (IPM) approach was adopted.

Regulations covering food grain storages were introduced in 1972. They emphasise pest prevention and disinfestation for food grain storages as follows:

- Paddy for storage in warehouses must be dry, mature, and free from pest insects and foreign materials
- Three days before loading, warehouses must be cleaned and treated with pesticide
- During storage, if the density of insect pests (*Sitophilus*, *Sitotroga*, *Rhyzopertha* etc.) reaches 10 individuals/kg paddy disinfestation techniques must be applied.

Chemical pesticides

Chemical pesticides continue to play a major role in pest prevention and disinfestation in food grain storages in Vietnam. The main chemical protectants used before 1960 included DDT and BHC. Use of DDT was banned in 1961, and application of BHC to stored food grains was not permitted after 1964. Use of methyl parathion, introduced in 1965, was banned in 1970.

Before 1964, trichloronitrile (CCl_3NO_2) and methyl bromide (CH_3Br) were widely used as fumigants for stored paddy, rice, maize, and wheat flour. CCl_3NO_2 was withdrawn from use on wheat flour and rice in 1965. CH_3Br has not been used since 1970, though it remains available.

Phosphine (PH_3) has been the most popular fumigant for food grains in Vietnam since 1965, generally generated from aluminium phosphide (AlP) formulations made in China, Germany, or Vietnam. Research by PHTI indicates that if high quantities of AlP made in China or Vietnam are to be used it should be done in combination with carbon dioxide (CO_2) and in airtight storages to avoid combustion of PH_3.

Natural pesticides

Natural pesticides from the plant kingdom have been used in food grain storage. There has been considerable research on, for example, use of tobacco and beadtree leaves. However, these materials are practical for food grain storage at family household level only.

Quarantine pests

The quarantine pest *Trogoderma granarium* has, up to now, not been found in Vietnam. In 1979–1981, the Plant Protection Department discovered *T. granarium* in food grain warehouses in Sihanouk-Port, Phnom-Penh, Cambodia. Vietnamese and Cambodian authorities worked together to deal with the problem. Mr Vu Huy Tien and Mr Hoang Ho were stationed in Phnom-Penh for several months to eliminate *T. granarium* from infested food grains. They had to apply a dosage of PH_3 1.5–2 times higher than for other insect pests in order to eliminate the infestation.

Protection by rice husks

Another IPM method, unique to Vietnam, has been developed by Bui Huy Thanh and Hoang Ho (1970–1980). They used rice husks to cover the surface of paddy in bulk storage to prevent insect contamination. This method proved very effective, but is economically impractical due to high labour costs.

Bacillus thuringiensis

PHTI is currently researching production of the biopesticide *Bacillus thuringiensis* (BT) for use in food grains storage. BT has been applied to 300 t paddy for testing. Preliminary results show that it is effective against the moth *Sitotroga cerealella*.

Rodent Prevention and Elimination

The most common rodents occurring in food grain warehouses in Vietnam are *Rattus norvegicus*, *R. flavipectus*, and *Mus muculus*.

Both zinc phosphide and Warfarin have been used as rodenticides. The bio-rodenticide Samocumarin (made in Cuba) was tested in Vietnam in 1993.

The prevention of rodents in warehouses has been given much attention, especially in the National Food Storage System.

Termite Prevention and Elimination

About 80% of warehouses in Vietnam have been infested by *Coptotermes* termites. In an FAO-supported project (TCP/VIE/6658, 1987) termite prevention and elimination studies were conducted by various institutions including PHTI. The main findings of the PHTI research were:

- *Coptotermes* nests may be up to 2 m above the ground (in the roof or the 2nd floor)
- *Coptotermes* nests found in Vietnam are smaller than those found elsewhere.
- In the Red River Delta, *Coptotermes* nests are no more than 0.5 m from the surface.

Current Research at the PHTI

Major food grain pest management research topics in PHTI are:

- pesticide resistance of insect pests;
- application of BT (made by PHTI) for food grain storage throughout the country;
- domestic production of Samocumanin for rodent elimination; and
- research on UHF (ultra high frequency) for pest prevention and elimination in small capacity warehouses.

The Mycotoxin Problem and Its Management in Grain in Vietnam

Le Van To and Tran Van An*

Abstract

The warm, humid climate of Vietnam is conducive to the rapid development of fungi in stored commodities, especially in the rainy season.

Research by the Food and Commodities Control Center on the fungi found on cereal grains in Vietnam has identified *Aspergillus* species as the most common, followed by *Penicillium* species. Among nine strains of *A. flavus* isolated from fungal-contaminated grain, four were found to be producing aflatoxins to varying degrees. Four strains of *A. parasiticus* were also producing aflatoxins.

High levels of aflatoxins have been found in some samples of cereal-based foods and animal feeds. The aflatoxin content of maize varies with season and length of storage, whereas levels of aflatoxin in groundnut cake are always high. Practical measures for protection of grain and detoxification of groundnut cake are being sought.

Simple procedures for the determination of water activity in agricultural products, and for field analysis of aflatoxin (e.g. BGYF and mini column tests) are being promoted in warehouses and on farms by agricultural extension.

MORE than 11 Mt of cereals are produced each year in the Mekong Delta of Vietnam. This figure represents about half of the country's cereal production. State warehouses can accommodate only 20% of production and almost all are located in the cities. This means that about 80% of cereal production is stored in primitive warehouses.

The hot, humid climate and shortage of appropriate storage techniques has led to significant postharvest losses.

We look first in this paper at the characteristics of climate and cultivation practices on the southern plain to identify the causes of postharvest problems in southern Vietnam.

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Climate and Cereal Production in Southern Vietnam

Unlike northern Vietnam, the southern plain has two distinct seasons: dry and rainy. The rainy season begins in mid May and runs to the middle of November, but is wettest in June–October when there are more than 15 days a month when the rainfall is 200–270 mm. It does not rain continuously every day but intermittently (Fig. 1).

Air humidity is highest (>84%) from June to October. An analysis of daily variation in air humidity reveals that the humidity of the air is generally lowest (<70%) from 1000 to 1700 h and highest (up to 100%) between 2200 and 0600 h. Temperatures are lowest between midnight and dawn.

Many kinds of cereals are harvested during the rainy season (Fig. 2): rice, 4 Mt; maize, 280 kt; soybeans, 30 kt; groundnuts , 72 kt; and green beans.

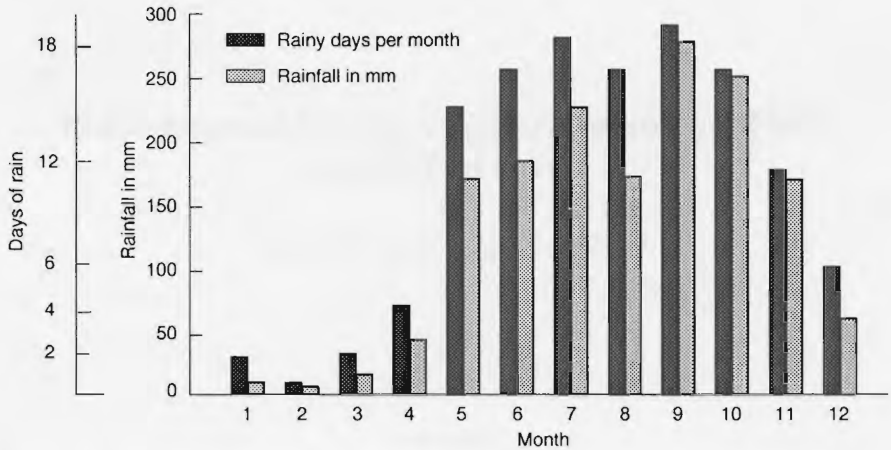

Figure 1. Annual distribution of rainfall in southern Vietnam.

According to 1993 statistics, up to 78% of Vietnamese farmer households had average monthly incomes of only US$5–10/person. Ordinary farmers therefore cannot afford dryers, so cereal drying depends mainly on sun drying.

There are about 450 flat-bed dryers, some of them large, as in Tra Noc, Cai Rang (Can-Tho), and Satake factory (HCMC), but they meet only a small part of cereal-drying needs in the Mekong Delta.

To reduce postharvest losses, especially in the rainy season, Vietnamese farmers have implemented the following measures.

- Roofed, multistorey drying yards that are covered by nylon sheets during rainy periods.
- During periods of high air humidity at night, the doors of warehouses are closed tightly to avoid water vapour penetrating the grain mass. From 1000–1600 h, when it is sunny and air humidity is low, the doors are kept open.
- Ventilation or hot-air ventilation is applied to dry grains in bags.

Through the interconnected system of rivers and canals, agricultural produce is transported mainly by boat, barge, and lighter. It is therefore necessary to locate small dryers along the banks of the rivers and canals, or to manufacture mobile dryers on trucks or barges to provide drying services.

Grain Mycoflora and Mycotoxins in Vietnam

As a result of tropical climatic conditions, harvesting in the rainy season, and shortage of warehouses and appropriate means for drying, the postharvest losses in Vietnam, especially in the rainy season, are high. Moulding is responsible for a relatively high proportion of these losses.

There have been many incidences of poisoning of domestic livestock in Vietnam in recent years as a result of consumption of feeds contaminated by moulds. The problem of moulds and their toxins is particularly serious and, following a symposium on animal feeds in southern provinces in 1991, the subject of aflatoxin in feeds is drawing official concern. For example, the Ho-Chi-Minh City Agriculture Department has prohibited inclusion of groundnut oil cake in animal feeds.

In Vietnam since the 1960s there have been various studies of mycoflora developing on agricultural produce. Some of the results obtained are given in the sections to follow.

Mycoflora on paddy

Table 1 lists the species of fungi isolated from 500 samples of paddy rice examined.

The genera *Aspergillus*, *Penicillium*, and *Mucorales* have usually appeared on 80–100% of samples examined. In addition, there have also been less frequent occurrences of species of *Fusarium*, *Sporotrichum*, *Trichoderma*, and other genera.

Mycoflora on milled rice

Table 2 lists the species commonly found on milled rice in Vietnam.

As on paddy, *Aspergillus* species are the most important on rice, followed by species of *Penicillium* and *Mucor*. These fungi have been observed on 60–100% of samples examined.

Among Aspergilli, *A. flavus* accounted for 20–30%, *A. candidus* 35–45%, and *A. nidulans* 10–15% of species isolated. Interestingly, during our research aflatoxin has not been found on well-milled, stored rice.

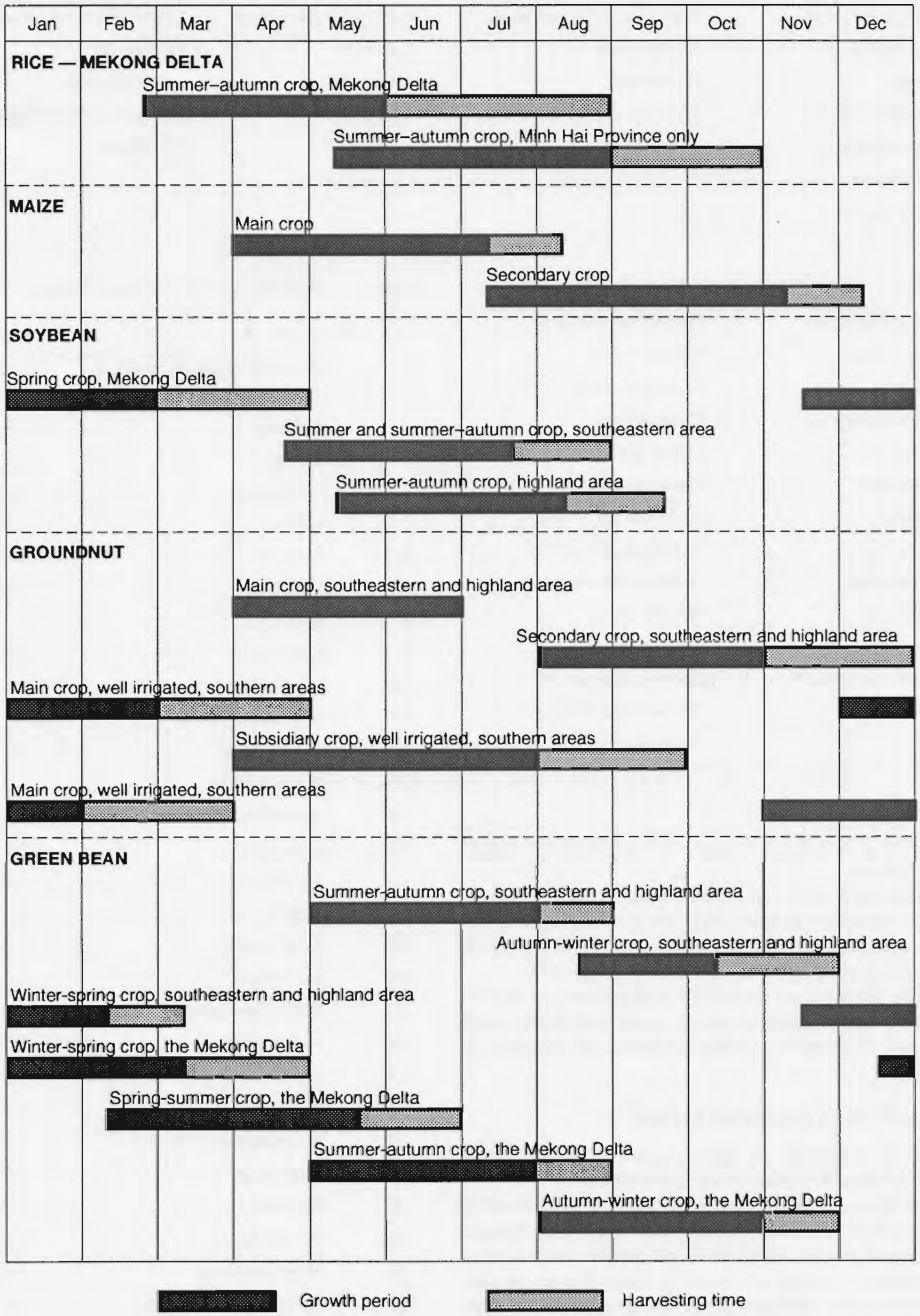

Figure 2. Seasonal pattern of crop production and harvesting in southern Vietnam.

Table 1. Mycoflora of Vietnamese paddy.

Aspergillus flavus	*Penicillium chrysogenum*
A. candidus	*P. rugulosum*
A niger	*P. citrinum*
A. ochraceus	*Rhizopus nigricans*
A. fumigatus	*Mucor* spp.
A. nidulans	
A. versicolor	

Table 2. Mycoflora of Vietnamese milled rice.

Aspergillus flavus	*Penicillium citrinum*
A. candidus	*P. frequentans*
A. niger	*P. chrysogenum*
A. fumigatus	*P. rugulosum*
A. clavatus	*Mucor* spp.
A. nidulans	*Cladosporium* sp.
A. ustus	*Fusarium* sp.
A. versicolor	*Helminthosporium* sp.
A. restrictus	*Hormodendrum* sp.
A. tamarii	*Monilia* sp.
A. rubruni	*Sporotrichum* sp.
A. glaucus group	*Syncephalastrum* sp.
A. wentii	*Trichoderma* sp.
	Trichothecium sp.

Mycoflora on maize

Table 3 lists the fungal species isolated from maize in Vietnam.

The most common were Aspergilli and Penicillia. It is noteworthy that the proportion of *Aspergillus flavus* contamination on dry maize was 9–13%; but on poorly-stored, wet maize, it was up to 25–30%.

The research has revealed a high proportion of aflatoxin contamination in maize, especially in the rainy season. *Aspergillus wentii* produces the mycotoxin, emodin.

Mycoflora on groundnut kernels

Table 4 lists the 32 species isolated from 120 samples of mould-contaminated groundnuts.

Table 4 shows that Aspergilli were dominant on the groundnut samples examined. The 20 species occurred in just over 88% of mould-contaminated samples. Penicillia occurred in about 8% of samples and the four remaining species in only about 3%. Considering Aspergilli separately, the *A. glaucus* group occurred in about 47% of samples, with *A. flavus* taking second place.

Table 3. Mycoflora of Vietnamese maize.

Aspergillus parasiticus	*Penicillium cyclopium*
A. flavus	*P. rubrum*
A. wentii	*P. viridicafum*
A. candidus	*Fusarium graminearum*
	F. roseum

Table 4. Mycoflora of Vietnamese groundnuts.

No.	Species	Ratio (%)
1	*Aspergillus glaucus* group: *A. chevalieri, A. amstelodami*	46.5
2	*A. flavus*	7.5
3	*A. niger*	5.0
4	*A. candidus*	4.0
5	*A. wentii*	4.0
6	*A. orizae*	4.0
7	*A. sydowi*	2.5
8	*A. tamarii*	1.5
9	*A. terricola*	1.5
10	*A. asperescens*	1.5
11	*A. awamorii*	1.5
12	*A. aculeatum*	1.0
13	*A. echinulatus*	1.0
14	*A. flavipes*	1.0
15	*A. nidulans*	1.0
16	*A. sulfureus*	1.0
17	*A. ustus*	1.0
18	*A. versicolor*	1.0
19	*A. vinaceus*	1.0
20	*Penicillium corylophilum*	1.0
21	*P. decumbens*	1.5
22	*P. charlesii*	1.5
23	*P. citrinum*	1.0
24	*P. frequentans*	1.0
25	*P. piscarum*	1.0
26	*P. steckii*	1.0
27	*P. velutinum*	1.0
28	*Mycelia sterilia*	1.0
29	*Scopulariopsis* sp.	1.0
30	*Spicaria* sp.	1.0
31	*Trichoderma lignorum*	1.0

Aflatoxin content

It was shown that Aspergilli are the predominant species of fungi occurring on all stored products examined in Vietnam: paddy, rice, maize, and groundnuts. This agrees with findings from elsewhere. Aspergilli develop well in tropical climates, whereas in temperate climates Penicillia predominate.

The presence of *Aspergillus flavus* does not necessarily mean that aflatoxins are produced. In our research, in 9 varieties of *A. flavus* isolated, 6 produced aflatoxin at various levels, while the remaining 3 did not (Table 5). On the other hand, all varieties of *A. parasiticus* isolated produced aflatoxin.

The aflatoxin content of maize varied with the duration of mould contamination and the extent of weevil infestation (Table 6). A strong interrelationship was noted between moisture content, and degree of moulding and insect infestation.

Table 5. Production of aflatoxins by various strains of *Aspergillus flavus* Link et Fies isolated.

Number of strain	Production of aflatoxin (mg/100 mL medium)
IVP	6.5
IP	6.85
P.13-75	5.42
AC.10	3.7
AF.3.74	1.6
AZ.1	2.3
AP.19	0
AC.5	0
AC.10	0

Table 6. Aflatoxin content produced by *Aspergillus flavus* in maize.

Storage duration (months)	Degree of contamination	
	Aflatoxin (ppb)	Weevily (%)
0	15	0
2	25	8
4	85	27
6	135	42

Table 7 gives average concentrations of aflatoxins found in agricultural products in southern Vietnam. The aflatoxin content in materials for animal feeds varies with the season. The rainy season is conducive to the development of mould, and aflatoxin content increases markedly (Table 8).

Table 7. Aflatoxin content in some agricultural products in South Vietnam (average of 10–15 samples).

No.	Agricultural produce	Average (ppb)
01	Groundnut oil cake	1140
02	Yellow maize (for animal feed)	255
03	Mixed animal feed	105
04	Coconut oil cake	55
05	Rice bran	30
06	Fish powder (for animal feed)	35
07	Sesame oil cake	10
08	Refined groundnut oil	05
09	Soy bean	25
10	Soya oil cake	10
11	White rice	05
12	Broken rice	20
13	Cashew kernel	15
14	Wheat flour	05

Table 8. Seasonal variation in aflatoxin content of animal feeds.

Season and commodity	Number of samples	Average (ppb)	Maximum (ppb)
Rainy season			
Groundnut oil cake	17	1520	5000
Yellow maize (for animal feed)	16	290	750
Dry season			
Groundnut oil cake	18	525	1160
Yellow maize (for animal feed)	15	120	450

There is no measurable difference among three aflatoxin-analysing methods: TLKC, mini-column, and BGYF (Bright Green Yellow Fluorescence test). Because of their simplicity and cheapness, we have publicised the mini-column and BGYF methods, and the water activity test (a_w) to farmers and breeding farms.

Protective Measures

Measures for protecting agricultural produce from moulds and mycotoxins in rural Vietnam include the following:

- Storage under carbon dioxide in a plastic enclosure

- Use of simple water absorbers such as quicklime
- Storage of produce in warehouses made from clay mixed with rice husk and straw.

To protect fresh maize which is not dried in time, we experimented with a mould-preventing chemical substance ('Mycox') available in Vietnam, with promising results (Table 9).

Table 9. Aflatoxin content in maize at various times after treatment with a mould-inhibiting chemical. Using this treatment, maize colour remained unchanged after 40 days, and the grain could be dried for animal feed. The treatment costs about US$15/t.

Duration of preservation (days)	Aflatoxin content (ppb)		
	0% 'Mycox'	2% 'Mycox'	3% 'Mycox'
7	800	20	20
14	1100	20	20
21	1400	35	40

Eliminating Aflatoxin from Groundnut Oil Cake

To decontaminate groundnut oil cake containing high levels of aflatoxin, we have experimented with ammonia treatment at normal temperature and pressure. Table 10 gives the primary results after 15 days of such treatment.

Table 10. Aflatoxin content in groundnut oil cake before and after treatment.

Sample	Mass (kg)	Aflatoxin content (ppb)	
		Before treatment	After treatment
1	20	400	<100
2	20	3000	<100
3	30	1500	<100
4	10	1000	<100
5	25	1800	<100

Conclusions

Like many other tropical countries, the climate in Vietnam is hot and humid, particularly in the rainy season, and is very favourable for moulds and insects developing, causing large postharvest loss.

Investigations of the mycoflora of stored products have shown that there are various common fungal contaminants, of which the Aspergilli are generally predominant.

Moulds invading food and feedstuffs produce a range of toxins, the most siginificant of which are aflatoxins. Aflatoxin content in some kinds of grain and animal feeds in Vietnam is very high. The best measure to prevent fungal invasion is drying to a safe moisture content. Solution of the mycotoxin problem therefore requires implementation of grain drying policies and practices appropriate to farm-level application in Vietnam.

Bibliography

Anon. 1990. Thin layer chromatography for quantitative analysis of aflatoxin in corn and peanut. In: Official Methods of Analysis of the AOAC, 15th ed. Washington, D.C., Association of Official Analytical Chemists.

Dang Hong Mien 1975. Studies on prevention of mould growth in groundnut kernels (in Vietnamese). Science and Technology, 103, 15–32.

Duong Thanh Liem and Tran Van An 1992. Effect of high level aflatoxin feed on laying hen (Rate of hatching of egg) (in Vietnamese). Ho-Chi-Minh City University of Agriculture and Forestry Science and Technology Workshop — April 1992.

Goldblatt, L.A. and Dollear, F.G. 1977. Review of prevention, elimination and detoxification of aflatoxin. Pure and Applied Chemistry, 49, 1759–1764.

Kawashima, K. 1991. Mechanism of aflatoxin infection of Thai maize and preventative measures. Farming Japan, 25, 42–46.

Le Van To 1984. A fungal metabolite and the effects of emodin on the growth of some soil microorganisms. Acta Agraria et Silvestria, 23, 235–242.

Le Van To, ed. 1991. Post-harvest practices for rice in the south of Vietnam. Vietnam, Ho-Chi-Minh City, 121 p.

Le Van To and Bui Huy Thanh 1986. Studies on paddy stored in Cuu Long River Delta and related aspects. In: Warehouse management of bag storage of grains. India, New Delhi, 272–281.

Naewbanij, J.O. and Frio, A.S. 1993. Grain storage warehouse control technology. Bangkok, Thailand.

Park K.L. et al. 1988. Review of the decontamination of aflatoxins by ammoniation: current status and regulation. Journal of the Association of Official Analytical Chemists, 71, 685–703.

Smyk, B. and Le Van To 1978. The influence of biologically active toxic substances of fungal origin on the growth of some soil microorganisms. Presented at XII International Congress of Microbiology, Munich, Germany, 1978.

Tran Van An 1995. Application of the three methods of aflatoxin analysis (BGYF test, minicolumn test, thin layer chromatography) in Vietnam. Preliminary data on aflatoxin level in agricultural commodities in the south of Vietnam. Agricultural Science and Technology Journal, in press.

Quality Maintenance in Fruit and Vegetables

Fruit and Vegetable Postharvest Handling Practices in Vietnam

Nguyen Cong Hoan*

Abstract

This paper gives an overview of postharvest handling practices for fruit and vegetables in Vietnam and related aspects of production and consumption. Specific postharvest topics are: management; growing and harvesting times; maturity and ripening; harvesting; packing house operations; and storage and shelf life.

FRUIT and vegetables rank second only to rice in Vietnam in terms of production area and domestic food consumption. They therefore play a very important role in Vietnamese life and society.

Vietnam stretches almost 2000 km from north to south, embracing climatic regions from tropical in the south, to subtropical in the north, and temperate in the highlands. The range of fruit and vegetables that can be grown in Vietnam reflects this. Tropical fruits grown are pineapple, banana, mango, durian, rambutan, and papaya. Citrus, lychee, longan, and jujube are grown in subtropical areas, and plums, apricots, peaches, and pears in the temperate zone. Important tropical vegetables include *Ipomoea aquatica* ('spinach'), while cabbage, kohlrabi, tomato, and cauliflower are prominent among temperate vegetable crops.

Fruit and Vegetable Production and Consumption

Most fruits and vegetables are eaten fresh in Vietnam, so there is little domestic demand for processed products. Indeed, some fruits and vegetables have medicinal uses in which instances freshness becomes even more important.

The fruit and vegetable processing industry in Vietnam is geared to exports. There is also a network of trading companies exporting fresh fruit and vegetables. These activities are expected to expand with Vietnam's new free market economic policies.

The horticultural industry in Vietnam started in the early 1960s. If we take the annual average production of vegetables and fruits during 1960–1962 as a base, production doubled during 1963–1967, and trebled during 1968–1974. Vietnam was reunified in 1975 and if we take the figure of average annual horticultural production in 1975 as a base, production increased 1.5 times during 1976–1980 and doubled during 1981–1991.

Rice is the main agricultural commodity in Vietnam and its production has increased rapidly over the past decade. The horticultural production industry has also grown, maintaining an output ratio of approximately 1: 4, fruits and vegetables: rice (Table 1).

About 1% of fruit and vegetable production is exported (Table 1).

The government plans to markedly increase fruit and vegetable production over the next few years. This will necessitate the introduction and adoption of new postharvest technologies for the processing industry and growers.

Postharvest Management/Handling in Vietnam

Natural conditions of high temperature, high rainfall, heavy infestation of insect pests, etc. in Vietnam are detrimental for the prolonged shelf life of vegetables and fruits. Leafy vegetables must usually be eaten within a day. Some soft-skin fruits such as banana and lychee can be kept fresh for only a few days. Poor facilities and technical information affect the application of modern technologies to postharvest handling. Many vegetables and fruits are grown in isolated regions far from the national main roads. There are thus difficulties in transporting products from the growing areas to the centres of population. Bad roads also make the bruising percentage high (up to 100% in certain cases).

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Table 1. Comparison between quantity of exported vegetable and fruit products and annual production (E/P), and between vegetable and fruit production and rice production (VF/R).

	North Vietnam				All Vietnam			
	1960	1963	1968	1973	1980	1984	1988	1990
E/P (%)	1.0	1.3	0.45	1.0	0.64	1.0	0.84	0.55
VF/R(%)	14.0	25.0	36.0	39.0	28.0	26.0	25.0	24.0

Growing and Ripening

Most fruits are harvested in summer and autumn, starting with apricots, plums, and finally oranges. A number of fruits, such as pineapple, can be harvested for 8–9 months of the year thanks to artificial fruit-ripening using acetylene. Banana is another fruit which can be harvested all year round. Tropical vegetables are grown and harvested in the summer–autumn, and temperate vegetables during the winter–spring.

Due to the difference in latitude between the north and south of the country, vegetable and fruit crop growing times differ between the two regions. Oranges are harvested continuously for 9 months in southern Vietnam whereas they are available only in the autumn in the north. The situation is similar for pomelo and guava.

During the summer, several vegetables that cannot be grown in the coastal delta areas, can be cultivated in the cooler mountainous and highland regions (such as Da Lat in the south and Sa Pa in the north of Vietnam).

Determining Maturity

Vietnamese growers have long known how to determine the maturity status of fruit and therefore the proper time for harvest. Numerous climacteric fruits, such as banana, mango, and papaya, are harvested green. It is also well known that fruits such as banana and papaya ripened on the trees are not as tasty as when they are harvested green and later incubated for ripening. A banana-ripening technique has long been available. It is traditional practice to put a piece of wood on the top of the jackfruit to make it ripen more quickly. The early (green) harvesting of banana, papaya, jackfruit, and mango reduces damage during transport and it has become a harvesting technique for fruit to be transported long distances.

There are many ways to determine the maturity of fruit for harvesting, but the most common practice is to observe their colour (bright green) or to check they are fully developed, e.g. it is harvesting time for banana when it is full round–shaped and for the pineapple when the fruit's 'eye' opens.

For processing plants, fruit can be purchased at a maturity stage that will facilitate transportation and it is then ripened on a large scale. A number of processing plants have ripening capacities of 20 t/day. Ripening agents are joss sticks (for small scale operations) or acetylene. After this incubation procedure, the fruit will be degreened or put in a cool chamber if the weather is hot.

Harvesting

Generally speaking, farmers do not practice fruit-wrapping on trees except in special cases. Longan, for example, can be placed in bamboo baskets for protection from bats, but this method is rarely used.

Most fruit harvesting is done by hand. While of lower productivity than machine harvesting, picking by hand should result in a smaller percentage of bruised fruit. However, due to shortage of knowledge on harvesting techniques, particularly about poor handling methods, fruit is often bruised. This situation has improved recently with the development of the market economy. Stronger commercial linkages have developed between urban and rural dwellers. Business and technical people are visiting fruit–growing areas to buy products and to give fruit growers suitable harvesting and handling techniques that will improve fruit quality.

Because of poor roads, there are many problems in transport of fruit to the packing houses. The fruit–growing areas are scattered among villages and distances from the orchards to the packing houses are usually long. Bamboo baskets and bicycles are the main means of conveying fruit to the packing houses. Packages specially designed to carry harvested vegetables and fruits are usually not available, or when they are they are often not strong enough to protect their contents from bruising. These problems affect the quality and storage characteristics of vegetables and fruits.

Packing House Operations

Packing house operations are the major fruit and vegetable postharvest activity in Vietnam. There are very few packing houses with a range of modern facilities. This is because fruit-growing areas are still dispersed and technical expertise is sparse.

In some places, temporary packing houses without cool storage facilities or mechanised grading lines have been established at the fruit and vegetable collection stations of foreign trade units or cooperative farms.

Postharvest handling is entirely manual. For bananas, for example, the bunch is cut from the banana tree and then each hand is cut and removed from the bunch. A piece of stem is left on top in order to restrict microorganism infection. The stem also makes it easier for customers to handle the banana hands.

Bananas for export have to be cut by Equador knife to make their packing easier and to reduce excessive weight during transportation. Banana packing is a technical procedure, as it has to ensure the tightness of the packed bananas in order to prevent them from being shaken, bruised, or otherwise damaged, and to ensure specified net weight.

Harvested oranges have to be cut close to their conical top, avoiding rupture of essence sacs in the skin. They are then waxed or wrapped in soft paper tissue. Paraffin wax is currently imported and research to produce it locally is still at an early stage. Waxing machines are available in certain places.

Lychees are packed in bundles or in bags of 1 kg net weight containing single fruit. These bags are packed in carton boxes of 5–10 kg.

Packages used for fresh vegetables and fruits are usually made of bamboo in Vietnam as this material is readily available and the production cost of bamboo baskets is quite low. There are several types of bamboo baskets, with capacities of either 50–100 or 30–50 kg. They are usually round with either round or square-shaped bottoms. Recently, square bamboo baskets of 20–30 kg capacity have become available. This improvement saves transport volume and the packages are aesthetically more pleasing. In addition to this, other wooden and hard plastic packages or large bags (sacks) and small bags made of PE, PVC, PP are also available but not commonly used.

The types of packages currently used are generally not durable and have to contain heavy commodities. Therefore, they provide very poor protection for fruit and vegetables during transportation. Little attention is given to the packaging used for vegetable and fruit commodities in terms of either protection, presentation, or advertising and promotion.

Export fruit is packaged in ventilated waxed cartons, but there has been little research to determine the best type of packaging. Customers usually provide packaging specifications which are followed by sellers for each individual consignment.

Use of cartons is steadily increasing, but the use of packaging appropriate to each type of vegetable and fruit, and mechanised cleaning and transport of vegetables and fruits to the packing houses are not available in Vietnam, except in some of the export-orientated establishments.

Storage and Shelf Life

The storage of vegetables and fruits largely depends on technical matters such as equipment, store houses, and energy. At present, only large trading companies can provide investment for storage facilities used for fresh vegetables and fruits.

Cold storage is the most commonly used technique. Cold storages are available in large cities but are not of large capacity. Usage of these is still low because of their relatively high cost. Ambient temperatures in Vietnam are high, particularly in the summer–autumn seasons (the fruit-ripening season). Therefore, vegetable and fruit commodities destined for export must be cold stored. Storage temperatures depend on the type of vegetables and fruits (e.g. 8–10°C for leafy vegetables, 13–14°C for banana, 10–12°C for orange, and 2–5°C for lychee). Cold storage is also a way of aggregating appropriate size batches of export commodities for shipping.

Chemicals are used for the control of diseases for vegetables and fruits during storage, usually in combination with cold storage techniques. As a result, it is possible to prolong the storage duration of certain products for several months, long enough to permit prolonged sea transport of tropical fruits and vegetables to distant markets. The chemicals used in fruit and vegetable storage are Topsin–M and Benlate. Topsin–M was the first to be used. Both appear effective for disease control in stored oranges and a number of other fruits. Several other chemicals are being used on a trial basis. Two locally made natural compounds — 'TN' and an extract of prawn cuticle — have been found effective in vegetable and fruit storage, but they are not used on a large scale.

The waxing technique, which has been introduced into Vietnam over the last 10 years, has enhanced storage of oranges. Fumigation has been found useful in storage of lychee.

Various research institutes are investigating techniques other than cold storage. As mentioned above, cold-storage costs are quite high, the network of cold storage houses is very small, and there are few cold-storage transportation facilities, particularly by rail. Transportation distances are long: over 1000 km (from the south of Vietnam to Hanoi) for mango, grape, and mandarin, and similar distance for longan and lychee to be transported south to Ho Chi Minh City. It often takes 3 days for the train to carry vegetables and fruits between Ho Chi Minh City and Hanoi. The required storage duration for fresh fruits is therefore at least 3 days. At present, lychee and longan have to be domestically transported by air at very high cost. Initial research shows that it will be possible to achieve the storage duration required.

Storage techniques such as CA (controlled atmosphere), MA (modified atmosphere), and SA (sub–

atmospheric storage) are not currently used in Vietnam, mainly due to lack of equipment and investment inputs. The economic returns from such investment may not be high in a country with an abundance of fruits and vegetables in all seasons.

Generally speaking, the standard of postharvest management in Vietnam is low. Vietnam has good sources of vegetable and fruit raw materials. The production and trading of vegetables and fruits are well organised, with an existing contingent of good postharvest technicians who are dedicated and hardworking. It is hoped that in the near future the horticultural industry of Vietnam will be further developed with the support provided by the international associations and the Government of Vietnam in order to meet society's demands on vegetables and fruits.

Quality Maintenance of Fruit and Vegetables with Modified Atmosphere Packaging

C.M.C. Yuen*

Abstract

The science and technology of gas preservation of food is not new. However, increasing consumer demand for fresh and minimally processed fruit and vegetables with 'fresh-like' qualities and extended shelf life has accelerated the development of innovative modified atmosphere packaging (MAP) techniques. In order to realise the full potential of MAP, it is essential that food scientists understand the various aspects of this promising technology. It is not possible to retain all the original natural freshness, nutrients, and organoleptic qualities of fruit and vegetables with MAP, but with systematic research development, MAP can become an important supplement to other postharvest technologies for the quality maintenance of fruit and vegetables in both the developed and developing countries.

FRUIT and vegetables are important food commodities. They provide variety and taste in the diet, and essential nutrients which the body cannot synthesise. In terms of commerce, billions of dollars worth of fruit and vegetables are produced and consumed each day worldwide. There is a huge investment of resources in transportation, packaging, storage, and marketing facilities, and technologies to ensure a continuous supply of fruit and vegetables within and across international boundaries.

In general, quantitative and qualitative postharvest losses of fruit and vegetables are very high, even in developed countries. There are no official figures as to the postharvest losses of individual fruit and vegetables in different countries, but postharvest technologists generally agree that, in developed countries, up to 25% of fruit and vegetables are lost each year before they reach the consumer. For developing countries such as Vietnam, losses of up to 50% are estimated, depending on the particular commodity.

Losses of fruit and vegetables after harvest are particularly significant in economic terms because the value of these commodities can increase many times after harvest. Losses impact on not only producers and consumers but also postharvest handlers, distributors, and marketers.

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There is therefore an urgent need for improved postharvest management and technologies for fruit and vegetables, particularly in developing countries where there is a general move from farming cereals to farming fruit and vegetables, because of the perceived higher value of these commodities in both the domestic and international markets. However, improving postharvest management and technologies as a means of reducing postharvest losses, and hence increasing food availability, is still a relatively new concept in many developing countries. There is a general lack of appreciation that complex management procedures and technologies are required to maintain the quantity, quality, safety, nutrition, and value of fruit and vegetables after harvest, especially if the products are intended for long-term storage and/or distant markets. One of the technologies that has attracted the attention of many postharvest specialists in recent times is modified atmosphere packaging (MAP).

Modified Atmosphere Packaging (MAP)

Our food comes in packages of all shapes and sizes, made from a range of materials, and in just about every colour of the rainbow: boxes, cartons, bottles, etc. are made from paper, cardboard, glass, plastic, and so forth. Packaging plays an important role not only in carrying the product to the consumer, for identification, convenience, and safety, but also is designed to extend the shelf life of the packaged food.

The concept of modifying the atmosphere surrounding the food in order to extend its shelf life is quite a simple one. MAP is defined as the use of a packaging in which the gas composition, or atmosphere, is changed from that of air. This normally implies a decrease in oxygen and/or ethylene, and an increase in carbon dioxide and/or nitrogen. This can be achieved by either gas flushing, or through the normal respiration of living things such as fruit and vegetables.

MAP can be considered as a less stringent form of controlled atmosphere (CA) storage. In CA storage, the composition of the atmosphere is monitored and precisely controlled once it has been established, but CA systems are very expensive to install and maintain.

Application of MAP

The principles and applications of MAP of fresh fruit and vegetables are quite different from MAP for food products such as processed meat, dairy foods, seafood, and cereal products. Unlike many processed foods, fresh fruit and vegetables are living things which continue respiratory and other metabolic activities after harvest. They can also be injured during handling and become 'ill' when exposed to disease microorganisms and/or adverse environmental conditions, much like humans.

No matter to what fruit or vegetable MAP is applied, the technique should be used only as a supplement to good postharvest practices such as the selection of good quality products of optimum maturity, avoidance of mechanical injury and disease microorganisms, and maintenance of optimum temperature, humidity, and other conditions.

Principles of MAP

Because fruits and vegetables differ one from the other in physical and biochemical attributes, they respond differently to MAP. There are two main factors which must be considered when designing MAP for individual fruits or vegetables.

Firstly, there are physiological factors which must be considered. These include: the diffusion resistance of the product to O_2, CO_2, C_2H_4, and H_2O; respiration and ethylene production rates; sensitivity to C_2H_4; optimum storage temperature and relative humidity; and product tolerance to O_2 and CO_2.

Secondly, environmental conditions such as temperature, relative humidity, concentrations of CO_2, O_2, and C_2H_4 in the storage atmosphere, light, and sanitation must be taken into account.

Recent innovations have generated much excitement in the area of MAP research. One of these is the development of new films that provide postharvest technologists with greater flexibility in controlling the atmosphere inside packages. Advanced low-density polyethylene, PVC, polypropylene, and polystyrene films which have average permeabilities to carbon dioxide that are 3–5 times that of oxygen are now commonly used as MAP materials for fresh produce. Relatively impermeable membranes, such as polyester films, can be used on produce with low rates of respiration.

The latest innovation in MAP is the development of gas absorbent/adsorbent films and sachets which can actively modify O_2, CO_2, C_2H_4, and H_2O and other volatiles within the package. The application of gas modification films and materials is called *active packaging*. This technology has been used commercially to package individual fruits such as oranges, bunches of bananas, retail units of strawberries, boxes of cauliflower, pallet loads of Chinese gooseberries, and container loads of avocadoes. Under optimal conditions MAP can double the shelf life of many fruit and vegetables.

Conclusion and Recommendations

Due to its low cost and simplicity, MAP technology is potentially a very useful one for developing countries such as Vietnam. Nevertheless, it is quite clear that the Vietnamese horticultural industry currently lacks the critical mass in administration, marketing, transport and distribution infrastructure, the relevant postharvest technologies, the marketing skills and information, and the government support needed to take full advantage of MAP technology and the immense domestic and global opportunities available to the fruit and vegetable industry.

It is therefore proposed that the Vietnamese Government take a leading role and work closely with the fruit and vegetable industry and the various postharvest organisations to gather the following information seen as essential to the development of the horticultural industry.

1. Develop a thorough understanding of the postharvest management and handling system for fresh fruit and vegetables.
2. Document the various fruit and vegetables produced in Vietnam with respect to their importance to the national economy in terms of dietary significance, nutritional value, and their ability to earn foreign exchange, and the quantities, values, and varieties produced.
3. Collect detailed information on target markets — both domestic and international — with regard to consumer and market preferences, market trends, supply and demand patterns, etc.

4. Identify and describe the principal factors affecting losses in each product postharvest system with a view to establish priorities for action.
5. Catalogue and quantify existing practices, and postharvest equipment, facilities, and technologies available.
6. Establish realistic, far-reaching, sustainable, and coordinated national and regional research and development priorities and strategies.

Bibliography

Ben-Yehoshua, S. 1985. Individual seal-packaging of fruit and vegetables in plastic film — a postharvest technique. HortScience, 20(1), 32.

Ben-Yehoshua, S., Fishman, S., Fang, D. and Rodov, V. 1994. New developments in modified atmosphere packaging and surface coating for fruits. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruits. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 250–260.

Brecht, P.E. 1980. Use of controlled atmospheres to retard deterioration of produce. Food Technology, 34(3), 45.

Burton, W.I.G. 1978. Biochemical and physiological effects of modified atmospheres and their role in quality maintenance. In: Hultin, H.O. and Milner, M., ed., Postharvest biology and technology. Westport, Connecticut, Food and Nutrition Press, 97.

Cameron, A.C. and Reid, M.S. 1982. Diffusive resistance: importance and measurement in controlled atmosphere storage. In: Richardson, D.G. and Meheruik, M., ed., Controlled atmospheres for the storage and transport of perishable agricultural commodities. Beaverton, Oregon, Timber Press, 171.

Deily, K.R. and Rizvi, S.S.H. 1981. Optimisation of parameters for packaging of fresh peaches in polymeric films. Journal of Food Processing, 5(1), 23.

Dewey, D.H. 1983. Controlled atmosphere storage of fruits and vegetables. In: Thorne, S., ed., Developments in food preservation, 2nd ed. London, Applied Science Publishers.

Dilley, D.R. 1983. Manipulation of the postharvest atmosphere for preservation of food crops. In: Lieberman, M., ed., Postharvest physiology and crop preservation. New York, Plenum Publishing Corporation, 383.

El-Goorani, M.A. and Sommer, N.F. 1981. Effects of modified atmospheres on postharvest pathogens of fruits and vegetables. Horticultural Review, 3, 412.

Hayakawa, K., Henig, Y.S. and Gilbert, S.G. 1975. Formulae for predicting gas exchange of fresh produce in polymeric film package. Journal of Food Science, 40, 186.

Henig, Y.S. and Gilbert, S.G. 1975. Computer analysis of the variables affecting respiration and quality of produce packaged in polymeric films. Journal of Food Science, 40, 1033.

Hintlian, C.B. and Hotchkiss, J.H. 1986. The safety of modified atmosphere packaging: a review. Food Technology, 40(12), 70.

Isenberg, M.F.R. 1979. Controlled atmosphere storage of vegetables. Horticultural Review, 1, 337.

Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Technology, 40(5), 99.

— 1994. Modified and controlled atmosphere storage of tropical fruits. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruits. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 239–249.

Lipton, W.J. 1975. Controlled atmospheres for fresh vegetables and fruits — why and when. In: Haard, N.F. and Salunkhe, D.K., ed., Postharvest biology and handling of fruits and vegetables. Westport, Connecticut, AVI, 130.

Smock, R.M. 1979. Controlled atmosphere storage of fruits. Horticultural Review, 1, 301.

Tomkins, R.G. 1965. An assessment of the suitability of plastic films used for the prepackaging of fruits and vegetables. Institute of Packaging Journal, November, 1.

Veeraju, P. and Karel, M. 1966. Controlling atmosphere in a fresh-fruit package. Modern Packaging, 40(2), 168.

Wills R.B.H., McGlasson, W.B., Graham, D., Lee, T.H. and Hall, E.G., ed. 1989. Postharvest — an introduction to the physiology and handling of fruit and vegetables. Sydney, University of New South Wales Press.

Wolfe, S.K. 1980. Use of CO- and CO_2-enriched atmospheres for meats, fish, and produce. Food Technology, 34(3), 55.

Zagory, D. and Kader, A.A. 1988. Modified atmosphere packaging of fresh produce. Food Technology, 42(9), 70-77.

Quality Maintenance of Fruits and Vegetables in Vietnam

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Abstract

This paper outlines postharvest handling practices for maintenance of quality in bananas, oranges, lychees, pineapples, and vegetables. The results of recent studies on the use of radiation for extending shelf life are summarised.

WHILE Southern Vietnam is located in a region of tropical climate, the climate in the north of the country is subtropical, with both summer (hot) and winter (cold) seasons. Therefore, a diverse range of vegetables and fruits can be grown, consisting of products of tropical, subtropical, and even temperate origin, as follows:

- Tropical fruits: pineapple, banana, papaya, guava, mangosteen, pomelo, rambutan, durian, mango, annona, star apple, dragon fruit, coconut.
- Subtropical fruits: citrus, lychee, longan, avocado.
- Temperate fruits: pear, apricot, plum, peach.

Major vegetables are *Ipomoea aquatica* ('spinach'), potato, tomato, cucumber, kohlrabi, cabbage, cauliflower, ball onion, champignon de Paris (French mushroom), and straw mushroom.

The general status of horticultural postharvest technology is covered by Mr Nguyen Cong Hoan in his report 'Fruit and vegetable postharvest handling practices in Vietnam' in these proceedings. This report describes postharvest management technologies used in quality maintenance of some important fruits and vegetables.

Bananas

The major banana variety grown in Vietnam is Cavendish, which is called 'Tieu' banana in the local language. In southern Vietnam, another variety — *Musa spientum* or 'Bom' — is also grown.

Banana is used as a fresh fruit in local family households. The fruit is not usually left on the tree to ripen naturally. Rather, it is harvested when the fruit is at 85–90% maturity as indicated to the experienced observer by:

- Dark green skin.
- Round angle of the fruit.
- Thick latex is obtained when the fruit is broken in two pieces and the latex exudate can be formed into a thread.
- The fruit flesh turns light yellow.

It is also possible to identify appropriate maturity for harvest from duration of growth (115–120 days after bunch formation).

After the mature bunch is cut from the tree, all hands on the bunch are removed and left for 1–2 hours for the latex to dry. They are then placed in mud pots/containers. Joss sticks are burnt to increase the temperature in the pots to 19–20°C.

Bananas are held in mud pots for 3–4 days. The fruit is considered ripe when its skin turns yellow and the fruit flesh becomes soft and has a sweet taste and smell. Traditional experience is that bananas treated as above have a strong, ripe flavour and no bitter taste, whereas bananas naturally ripened on the tree have less flavour and a slightly bitter taste.

The above treatment method is used at household level, and to treat larger, export quantities of bananas, in non-mechanised packing houses.

Bananas for export are harvested at a maturity less advanced than fruit for local consumption: 90–95 days after bunch formation. Banana is exported in two ways: in bunches and in hands.

Bananas for the former Soviet Union were exported in bunches. The bunches were removed from the trees, collected, then left for 1–2 hours for the latex to dry, before washing with water. A 0.1% Topsin–M (prochloraz) solution was spread over the bunches, which were later wrapped in polyethylene (P.E.) bags before delivery to the shipper. The banana bunches were then vertically packed with their cut stems kept at the bottom of the cartons or wooden boxes during transportation, delivery, and storage. Exported banana

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was shipped by sea in cool storage at a temperature of 13±1°C and relative humidity of 85–90%.

Fresh bananas for export in hands were removed from the bunch and left for 1–2 hours for the latex to dry. Paper tissue could be used to clean off the latex. The hands were then washed using water and pieces of soft cloth to remove dirt and insects clinging to the fruit skin, before being dipped in Topsin–M solution (0.1%) for 1 minute. The treated banana would be left to dry, wrapped in P.E. bags, and packed in cartons of 12 kg.

Oranges

The main citrus variety grown in Vietnam is *Citrus sinensis* which is consumed domestically and exported in large quantities.

For family consumption, oranges are harvested when they begin to ripen. The fruit stem is cut close to the skin without breaking the conical top of the orange and without bruising the fruit.

After harvesting, the fruit is left for 12–14 hours before being stored. The simplest method of storage is to leave the fruit on a clean, cool floor and put $Ca(OH)_2$ (slaked lime) on the conical top of the oranges to prevent fungal invasion.

In many localities, sand is used for orange storage. The procedure is as follows. A layer of clean, dry sand is spread on a clean, cool floor. A layer of oranges is placed on the sand, and covered with a layer of sand 5 cm thick. This procedure is repeated until there are 10 layers of oranges, the final layer of sand being 30 cm thick. Bricks are used for the surrounds of such storages. The technique can also be used in mudpots/containers and will keep oranges for 3–4 months.

Export oranges are treated as follows. Harvested oranges are inspected to remove all fruit which are not of export standard, then graded, washed with water, cleaned with pieces of soft cloth, and eventually dipped in Topsin–M solution (0.1%). The fruit are dried naturally in the open air for 4 hours before individual wrapping in paper tissue and packing in either wooden cases or carton boxes (15 kg each) with the conical top of the orange facing downwards. While waiting for shipment the packed oranges are kept in cool storage at 5–7°C and 85–90% r.h., the same conditions under which they are subsequently transported by sea to export markets.

Lychees

The most popular lychee (*Litchi chinensis*) variety in Vietnam is 'Thiou', which is also the most commonly-grown one. It is available only in northern Vietnam.

The fruit is harvested at full maturity when its skin has turned pink or red. The fruit count is about 60–65 lychees/kg with the fruit stem being not over 5 mm long. After being selected and graded, the fruit are dipped in Benlate solution (at 1 g/L and at temperature of 50–52°C for 2 minutes) then placed on a table to be dried and cooled by fan. The treated fruit are tightly sealed in P.E. bags, because the fruit skin will change colour if it comes into contact with air. Each bag contains about 1 kg of fruit . The bags are packed into cartons of 10 kg each. Bags are separated from their neighbours by cardboard walls inserted into the box. The cartons are transported and stored at 10–13°C and 85–90% r.h.

Pineapple

The major pineapple (*Ananas comosus*) variety in Vietnam belongs to the Queen species. Pineapple is harvested when the fruit starts ripening: the fruit flesh is light yellow but the fruit skin has not yet turned yellow. After fruit of acceptable standard are selected, they are graded and the cut end of the fruit stem/crown is dipped in Topsin–M solution (1–2%). Each fruit is later wrapped in paper tissue and packed in a carton, separated from its neighbour by a carton wall. Each box is of 10–15 kg. Pineapple is stored and transported at 10–13°C and 85–90% r.h.

Vegetables

The main vegetables exported by Vietnam are potato, ball onion, carrot, cabbage, and kohlrabi. Postharvest treatment for exported vegetables is still very simple: the commodities will be selected, graded, and held in either bamboo baskets or wooden cases, then stored and transported in cool temperature conditions.

Radiation Treatment

Studies on the use of radiation for preservation of fresh fruit and vegetables have begun in Vietnam. The facility of the Center of Radiation, Hanoi, which is supported by the International Atomic Energy Agency (IAEA), has an initial activity of 2000 Curies. It has operated since 1991. A number of studies have been conducted on the use of radiation in fruit and vegetable treatment, as follows:

- Use of gamma rays for control of the maturity of exported bananas. Findings were:
  – Gamma radiation has effect in slowing down banana maturation process.
  – The optimal dose of radiation for Cavendish bananas is 0.3 kGy which is effective in postponing banana maturity for 10–14 days in comparison with non-treated fruits.
- Use of radiation in storage of champignon de Paris (*Agaricus bisporus*), with the following conclusions:

– The optimal dose of radiation is 1.0–1.5 kGy.

– Radiation inhibits development of champignon de Paris and prolongs shelf life at 5°C by 15 days.

- The use of radiation in onion storage:

  – The optimal dose for preventing onion germination was found to be 56 Gy. The best time for radiation treatment is 3–4 weeks after harvest.

  – Radiated onions can be stored at room temperature for 4–5 months.

Preliminary studies have also been conducted on the use of radiation for fresh lychee storage and for chilli powder treatment.

Postharvest Disease and Pest Control in Tropical Fruit

G.I. Johnson* and N.W. Heather†

Abstract

Postharvest diseases and pest infestations of fresh fruit and vegetables cause serious losses and trade disruptions. Losses can be major when inadequate attention has been given to preharvest control of the problems, or when weather conditions have favoured disease or pest build-up during fruit development, or when the fruit have been exposed to long or unfavourable storage and transportation. Trade disruptions can affect a supplier's reputation as well as long-term market access.

While export opportunities for fruit within the region have increased rapidly, markets have become increasingly concerned about fruit quality, pest and disease occurrence, and chemical residues.

Quarantine restrictions may limit market access. The presence of a particular pest (or less frequently, a pathogen), in a country can, in the absence of an effective eradication treatment, totally exclude access of product to countries free of that organism: e.g. several countries that are free of fireblight caused by *Erwinia amylovora* prohibit the import of apples and pears from countries in which the disease is recorded.

Surveys of the produce available for export will reveal the pests and diseases already present. The information needs to be accurate, and available to researchers and regulators involved in production and marketing of the produce.

Disinfestation protocols will include field and postharvest recommendations, and post-treatment inspection to verify the absence or mortality of all life-stages of the target pest. Postharvest disinfestation protocols need to be negotiated with export market authorities, and may specify fumigation, insecticide, hot air, vapour heat or hot-water dip treatments, cold storage, fruit brushing, visual inspection, and packaging in insect-secure containers. Alternative procedures such as irradiation and microwave treatment also can disinfest fruit. The former has been tested extensively, but is not yet adopted by all markets, while the latter remains experimental.

Chemical-use, either current or previous, can also affect market access. Export markets may have maximum residue limits (MRLs) or nil tolerances for particular pesticides. Previous land-use can impinge upon the export potential of fruit if, for example, high residual levels of DDT or 2,4,5,T are present in the soil and detectable in the produce from cultivated crops or orchards. Market regulations must be determined, and products tested regularly to monitor compliance with pesticide-residue restrictions.

The key to securing and maintaining market access for export fruit, and to greater domestic consumption, is the development of management protocols which will ensure the reliable supply of pest and disease-free produce of consistent quality.

The steps to achieve this are as follows.

(a) Determine the market requirements and restrictions in terms of: (i) seasonal demand; (ii) preferred fruit size, maturity, variety, and price; (iii) disease, pest and chemical residue limitations, prohibitions, or quarantine requirements; and (iv) phytosanitory documentation and trade approval requirements of local and export-destination authorities. Reliable export market agents must also be sought.

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(b) Assess the quality attributes, seasonal availability, pest and disease problems of the produce, the infrastructure and transportation that is available, and the financial returns that could be anticipated.
(c) Define the procedures that must be undertaken by producers, handlers, exporters, and government authorities so that produce can be produced and supplied at a quality standard that will (i) meet export and regulatory requirements and (ii) be recognised by the export markets as worthy of additional, future purchases.
(d) Develop the necessary treatment, handling, storage, transportation, and regulatory clearance systems for prompt, effective, and efficient processing, packaging and distribution of produce.
(e) Train and encourage the workers and managers involved in the production, marketing, and regulatory clearance of produce, so that all of the recommended and mandatory procedures are implemented, any new problems are identified, and solutions sought.

SATISFACTORY disease and pest control is achieved by first accurately identifying the causes of any losses or infestations. With appropriate training, local scientists, adequately supplied with laboratory equipment, taxonomic literature, and reference specimens, can identify the pests or pathogens causing many primary problems. First records should be confirmed by an expert consultant, or by one of the international authorities (such as the Commonwealth Agricultural Bureaux and the British Museum) which curate reference collections of insects or microorganisms.

Accurate diagnosis of the cause allows access to published information on how to reduce, minimise, or eradicate a pest or pathogen. It also enables assessment of whether market access will be restricted or prevented by the occurrence of the problem. The applicability of published protocols and control procedures for any pest or disease should be verified locally before they are recommended. Control measures should be demonstrated to those concerned with applying the technology, and appropriate instruction manuals and operator safety guides produced in the local language or dialect. New problems will require new solutions, developed by staff who have been trained to plan, resource, and undertake any research or other appropriate activities to develop recommendations for controlling the problem.

Diseases

Diseases often develop after fruit has been harvested, cleaned, treated, and packed. Diseases can develop from infections by fungi (or less frequently, bacteria) that occur before or after harvest. Diseases affect the quantity and quality of saleable product, as well as the time period during which it will remain saleable. Control measures will include cultural procedures and fungicide applications in the field, as well as postharvest treatments with heated water (or air), disinfectants or fungicides, and the provision of particular drying, handling, packaging, and storage regimes to slow fruit ripening and limit fruit damage and disease development. Fruit washing may impose additional disease threats, both to the commodity, and to the consumer, and must be undertaken with caution. Alternative measures that are being developed as replacements for fungicides for disease control include biological control using microorganisms, and the use of natural, non-toxic treatments or fruit coatings.

On export markets, disease losses need to be minimised, but absolute control (e.g. as may be required for fruit flies) is usually not necessary. While this latitude may seem advantageous to the producer, from the marketing perspective it is not. The risk of product-loss to disease can be substantial and difficult to predict, particularly in the case of tropical fruit. High-risk fruit, or producers with a record of supplying product with poor outturn, will not be in-demand with importers or supermarket owners. When negotiating 'whole-crop' contract-purchases, and 'special-price' sales promotions, their choice of products to sell, and producers to contact, will be based on past knowledge of product and supplier reliability for quality outturn and punctual delivery. Matching these requirements requires effective orchard and postharvest disease control practices.

Pathogens

Pathogens can be broadly divided into those that contact fruit in the orchard, and those that contact fruit during or after harvest. The pathogens that contact fruit in the field may occur as microscopic surface contaminants on the fruit skin, or in soil and debris on the skin and stem tissue, or they may be present as symptomless infections within the skin or stem end of the fruit (Fig. 1).

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

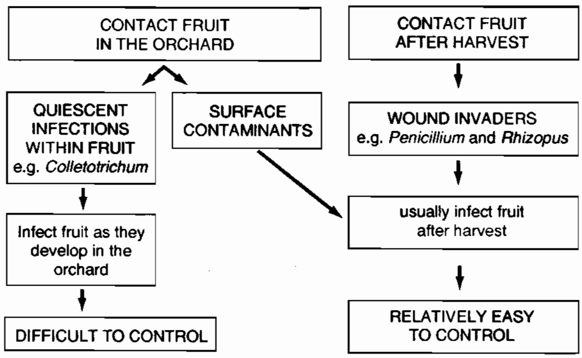

Figure 1. Types of pathogens attacking fruit and their relative ease of control.

caused by *Phytophthora palmivora* (Butler) Butler are respectively 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 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 adapted to develop disease control strategies for less well researched fruit.

Control Measures for Fruit Diseases

Disease control can be achieved by either preventing infection, eradicating infection, or delaying symptom development so that the produce can be eaten or processed before significant losses occur. Effective targeting of control strategies requires basic studies on pathogen biology to identify forms of inoculum, modes of transmission, and time and type of infections that lead to disease losses (Johnson et al. 1991, 1992a) (Table 4).

Preventing infection by pathogens

Infection can be prevented by (a) growing resistant varieties, (b) cultivating crops in conditions where lack of rainfall or unfavourable temperatures interfere with inoculum dispersal and propagule germination and growth, and (c) applying prophylactic treatments. Protective fungicides applied to achieve full coverage, or enclosure of fruit in paper bags interferes with inoculum deposition and infection.

Fungicides

Fungicides are an effective means of preventing postharvest disease development (Table 5). Fungicides can be applied in the field during flowering, fruit set, and growth flushing to reduce infection and inoculum production. Government regulations usually specify the types of fungicides that may be used, the crops on which they may be applied, target pests, dose, time of application, withholding period, maximum residue levels, and measures for disposal of spray residues and used storage containers. Good coverage and timely application are critical (Thompson 1994). In the absence of regulations within a country, international guidelines are available in the Codex Alimentarius (FAO/WHO 1993).

Fungicide resistance

In several cases target pathogens have quickly developed resistance to systemic fungicides applied in the field. Where the risk of resistance development is high, field or orchard applications of the fungicide either should not be permitted or should be restricted to strategic applications: e.g. during flowering, in wet weather, or, immediately before harvest. Benomyl is one fungicide to which pathogens quickly develop 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 many of the modern systemic fungicides threatens the long-term viability of these fungicides for postharvest use. Preharvest application of effective postharvest fungicides should be discouraged.

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

Table 1. A host list of pathogens of tropical and subtropical fruit (after Johnson and Sangchote 1994).

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, Caricaceae, Cucurbitaceae, Guttiferae, Lauraceae, Moraceae, Musaceae, Myrtaceae, Oxalidaceae, Rosaceae, Rutaceae, Sapindaceae, Sapotaceae
• *Ceratocystis**/*Thielaviopsis*** W	• Bromeliaceae, Cucurbitaceae, Musaceae, Myrtaceae
• *Diaporthe** /*Phomopsis***Q	• Anacardiaceae, 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	• Anacardiaceae, 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

Table 1. (cont'd) A host list of pathogens of tropical and subtropical fruit (after Johnson and Sangchote 1994).

Pathogen genus (*Teleomorph/**anamorph)	Host family
• *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
• *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)

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 cultivars Kensington and Keitt 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.

Biological control

Jeffries and Koomen (1992), Korsten et al. (1994), and Wilson and Wisniewski (1994) have reviewed the application of microorganisms or microbial products for the control of fruit pathogens. Several bacteria and yeasts have shown promise as biological control agents for a range of fruit pathogens. Mode of action of the candidate agents may be critical in determining whether a promising agent can be registered. Modes of action which expose consumers to risks as great as those associated with the use of synthetic fungicides should not be contemplated. Other key issues associated with the introduction of biological control agents will be formulation, application and survival of the agent in the orchard and during storage, and international acceptance of the treatments for postharvest use.

Cultural practices

Husbandry practices such as removal of dead branches and leaves in the canopy reduce inoculum available to initiate diseases. Avoidance of foliage wetting during watering reduces free water available for infection. Strategic pruning to open up the canopy to improve light penetration, promote growth flushing and allow air circulation can also reduce postharvest disease levels. Inadequate nutrition, e.g. calcium, and excess nutrients e.g. nitrogen or phosphorus, can also encourage disease via effects on cell structure and nutrient availability. G. Johnson, J. Armour et al. (unpublished) found that susceptibility of harvested potatoes to bacterial soft rot increased with increasing field application rates of phosphorus above that necessary for maximum yield.

Table 2. Tropical and subtropical fruits: recent reviews or assessments of disease losses (after Johnson and Sangchote 1994).

Host (*Genus*) (minimum storage temperature for unripe fruit: °C and time)	Host family	References
Avocado *(Persea)* (5–12°C for 2–4 weeks)	Lauraceae	Cappellini & Ceponis 1988; Snowdon 1990; Persley 1993; Ploetz et al. 1993
Banana (*Musa*) (15°C for 2–4 weeks)	Musaceae	Wardlaw 1972; Slabaugh & Grove 1982; Snowdon 1990; Persley 1993
Breadfruit (*Artocarpus*) (13°C for 1–3 weeks)	Moraceae	Thompson et al. 1974; Snowdon 1990
Carambola *(Averrhoa)* (10°C for 3–5 weeks)	Oxalidaceae	Johnson et al. 1992b; Persley 1993
Cherimoya *(Annona)* (20°C for 2–3 weeks)	Annonaceae	Purss 1953; Persley 1993
Citrus *(Citrus)* (varies from 4–14°C for 2–12 weeks depending on species (Kader & Arpaia 1992)	Rutaceae	Cook 1975; Ceponis et al. 1986a; Whiteside et al. 1988; Persley 1993
Coconut, date *(Cocos, Phoenix)* (25°C for 1 weeks; 0 for 1–2 months)	Arecaceae	Cook 1975; Snowdon 1990
Durian *(Durio)* (15°C for 2 weeks)	Bombacaceae	Lim 1990
Guava *(Psidium)* (7–10°C for 2 weeks)	Myrtaceae	Lim & Khoo 1990; Snowdon 1990
Jackfruit (*Artocarpus*) (15°C for 2 weeks)	Moraceae	Butani 1978
Longan *(Euphoria)* (10°C for 2 weeks)	Sapindaceae	Sarsud et al. 1994
Lychee (*Litchi)* (5°C for 2 weeks)	Sapindaceae	Lonsdale 1988; Johnson 1989; Snowdon 1990
Mango *(Mangifera)* (13°C for 2 weeks)	Anacardiaceae	Lim & Khoo 1985; Prakash & Srivastava 1987; Cappellini & Ceponis 1988; Johnson 1989; Johnson 1992; Ploetz et al. 1993
Mangosteen *(Garcinia)* (13°C for 4 weeks)	Guttiferae	Snowdon 1990
Melon *(Cucumis & Citrullus)* (5°C for 3 weeks; 10–15°C for 2–3 weeks)	Cucurbitaceae	Ceponis et al. 1986b; Snowden 1990, 1992; Persley 1993
Papaya (*Carica)* (7–10°C for 2–3 weeks)	Caricaceae	Alvarez, & Nishijima 1987; Cappellini et al. 1988; Snowdon 1990; Persley 1993
Passionfruit (*Passiflora)* (6–10°C for 3–5 weeks)	Passifloraceae	Inch 1978; Snowdon 1990; Persley 1993
Pineapple *(Ananas)* (15°C for 2–4 weeks)	Bromeliaceae	Cappellini & Ceponis 1988; Snowdon 1990; Persley 1993
Pomegranate (*Punica*) (5°C for 3 months)	Punicaceae	Snowdon 1990
Rambutan *(Nephelium)* (10°C for 2 weeks)	Sapindaceae	Visarathanonth & Ilag 1987; Persley 1993
Roseapple, Lillipilli (*Eugenia, Syzgium*)	Myrtaceae	No references found
Sapodilla (*Manilkara*)	Sapotaceae	Cook 1975; Snowdon 1990

Sampling and selective harvesting

Product outturn on export markets can be improved by using preharvest sampling procedures to select those regions, orchards, individual trees, or parts of trees with lower infection levels. 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

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 (after Johnson and Sangchote 1994).

Genera of fungi (*Teleomorph/ **anamorph)	Minimum temperature (°C) required for disease development[a]	References[b]
*Alternaria***	– 3	Simmons 1967; Ellis 1971
Aspergillus	+ 16	Raper & Fennell 1965; Domsch et al. 1980; Pitt & Hocking 1985
*Botryosphaeria**		Pennycook & Samuels 1985; Hartill 1992
/*Lasiodiplodia***	+ 8	Sutton 1980
/*Dothiorella***	+ 2	Maas & Uecker 1984
/*Fusicoccum***	+ 2	Pennycook &Samuels 1985; Hartill 1992
*Botryotinia**		
/*Botrytis***	– 2	Jarvis 1977; Coley-Smith et al. 1980
*Ceratocystis**		
/*Thielaviopsis***	+ 5	Hunt 1956; Hoog & Scheffer 1984
*Diaporthe**		
/*Phomopsis***	– 2	Sutton 1980; Uecker 1988
*Geotrichum***	+ 2	Carmichael 1957; Butler & 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 to 4	Domsch et al. 1980; Schipper 1984

[a] Sommer 1985; Sommer et al. 1992. [b] Rossman et al. 1987; Snowdon 1990

fruit infection levels has been used to determine the need for postharvest treatments to control alternaria rot of mango caused by *Alternaria alternata* (Prusky et al. 1983). 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, increasing or decreasing the need for pre- and postharvest control measures.

Harvest, Grading, Packing, and Transport Practices

Heat, sunburn, and sapburn

Fruit that are heated (a) in the orchard by high field temperatures at harvest, (b) during excessive delays between harvest and packing, or (c) by postharvest exposure to direct sun may undergo accelerated ripening or develop tissue damage which will encourage disease development. Development of lesions caused by *Aspergillus* spp. are encouraged by high temperatures, and can invade skin damaged by sapburn in mangoes. Invasion of fruit by *Lasiodiplodia theobromae* and *Phytophthora* spp. may also be greater at higher temperatures. Johnson and Sangchote (1994) pointed out that changes in temperature can change the spectrum of fungi involved, as well as the temporal incidence and severity of symptoms.

Mechanical and insect damage

Damage, or injuries which break the skin surface provide points of entry for wound pathogens. Fruit wound healing responses seal damaged tissue within a few hours, but the time delay is often sufficient for pathogens to invade. Adverse environmental conditions (such as higher temperatures) can interfere with wound healing, and lower fruit resistance to invasion. Vibration and impact damage resulting from dropping, throwing, or shaking also affect fruit at the cellular level. Cell wall damage and leakage of cell contents weaken host resistance and stimulate pathogen invasion.

Water and wetting

Free water favours propagule dispersal, germination, and infection. Wetting the fruit surface to clean dirt and sooty mould from the skin can thus increase disease losses, particularly if the skin and cuticle are also abraded by brushes. Water can carry propagules directly into the fruit through wounds or insect punctures. Non-recirculated chlorinated water (at domestic reticulated water rates of available Cl) should be used for fruit washing. Unchlorinated water may contain fruit pathogens which can build-up further in recirculating dip tanks. The pH of the chlorinated water should be adjusted to 6.0 for maximum effectiveness. Bromination of water has been considered as an alternative to chlorination since maintenance of dose is easier. However, concerns about the carcinogenicity of bromine compounds, and possible retention of bromine residues on fruit, discourages their use. Chlorination of water at rates ranging from 50 to 1000 ppm reduces pathogen load, but can accelerate

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. 1992a, 1993) (after Johnson and Sangchote 1994).

Pathogen (*Teleomorph/**anamorph)	Form of inoculum	Mode of transmission	Mode of infection
Alternaria	conidia	airborne	direct
Aspergillus	conidia hyphae	airborne, 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	contact
**Diaporthe*	ascospores	As for *Botryosphaeria*	As for *Botryosphaeria*
*/**Phomopsis*	conidia, hyphae		
Geotrichum	conidia	water-borne, soil-borne, fruit to fruit	wound, water or soil/debris infiltration, contact
**Glomerella*	ascospores	air-borne	direct
*/**Colletotrichum*	conidia	water-borne	direct
*/**Lasiodiplodia*	conidia, hyphae	arthropod-borne	colonisation of floral parts
		seed-borne hyphae	internal colonisation of stems
		air-borne, water-borne, soil-borne, (endophytic?)	wound, colonisation of cut pedicel or floral remnants
Penicillium	conidia, hyphae	air-borne, water-borne, soil-borne, fruit to fruit	wound, water or soil/debris infiltration, contact
Phytophthora	zoospores	water-borne	direct, wound
	hyphae	soil-borne, fruit to fruit	contact
Rhizopus	sporangiospores, hyphae	air-borne, water-borne, soil-borne, fruit to fruit, mycelium to fruit	wound, water or soil/debris infiltration, contact

Table 5. Some fungicides applied in the field to prevent and/or eradicate infection by fungal or bacterial pathogens.

Fungicide[a]	Pathogens controlled
Mancozeb	*Alternaria, Colletotrichum, Elsinoe, Guignardia,*
Copper hydroxide or oxychloride	As for mancozeb plus *Pseudomonas, Xanthomonas*
Chlorothalonil	As for mancozeb
Prochloraz	As for mancozeb
Pyrazophos, fenarimol, tridimefon	Powdery mildews

[a] Regulations need to be established which define permitted uses (crops and target pathogens), application timing, dose, method of application, maximum residue level, applicator precautions, and waste disposal method.

the degradation of organophosphate insecticides. Higher rates can also damage fruit and should be assessed on a case-by-case basis. If insecticides are used for disinfestation, they must be applied separately and last.

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 sulfonate (a by-product of paper manufacture) used to improve flotation of pears in postharvest treatment lines inhibited spore germination by spores of *Botrytis 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 two 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).

Sorting, grading, culling

Sorting and grading provide an opportunity to remove fruit that show signs of disease. Slightly damaged fruit may be downgraded and sold at a lower price, or used for processing. Illustrated charts which show the types of defects, and indicate some maximum tolerance for surface coverage (often 2–5 %) will help packing shed staff to decide what to remove. The charts may also inform them about the types of blemish that increase in severity during storage or which would spread to other fruit by contact, or water- or airborne spores, and suggest procedures to follow when such material is encountered (e.g. discard to bin, put aside for processing).

Brushing and waxing

Brushing fruit with rotating brushes installed on a packing line can improve fruit appearance by removing the superficial growth of sooty mould, as well as deposits of fungicides applied in the field or the packing shed. Brushing also removes organic debris such as leaf and floral material that sometimes adheres to the developing fruit. Brushing, however, also removes some of the fruit cuticle, and can create small wounds through which pathogens can invade. Waxing after brushing helps seal the wounds. Fungicides and insecticides can be incorporated into the wax. Check market acceptance of the practice first. Not all fruit tolerate currently available waxes. Ripening can be adversely affected by their use.

Drying

Drying procedures to remove surface water from the fruit skin decrease opportunities for spores to germinate and infect, and help seal wounds. Drying of freshly harvested onions removes excess water from the tops, reducing losses from aspergillus rot. Heat-curing procedures have also shown promise in citrus, reducing disease by a combination of effects on wound healing, propagule desiccation, and stimulation of fruit resistance (Barkai-Golan and Phillips 1991).

Eradicant Treatments for Pathogens

Heat treatments

Heat treatments are a 'clean' means of eradicating infections of postharvest pathogens. Some regimes are listed in Table 6. Many tropical and subtropical fruit have a moderate tolerance of heat that allows fruit heating in regimes that do not damage fruit, but destroy infections in the skin and stem end (Barkai-Golan and Phillips 1991; Coates and Johnson 1993). Generally, sub-cuticular infections in the skin are more easily eradicated by heat treatments than more deep-seated infections that have penetrated epidermal cells or pedicel tissues. This is because the fungal structures are closer to the surface and more quickly heated to a lethal dose. Hot water can be used in combination with a fungicide to increase efficacy and reduce the temperature needed. There is often a narrow margin between pathogen destruction and fruit damage (Coates and Johnson 1993; Jacobi et al. 1994). 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. On mango, the use of heat in combination with fungicides other than 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 and other pests have received considerable attention (Paull 1990; Armstrong 1992; Heather 1994b) and their use influences disease control strategies. Coates and Johnson (1993) and Jacobi et al. (1994) 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. (1994) reviewed 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 sulfur dioxide and acid treatment of lychee.

Fumigation to control pathogens

Tongdee (1994) reviewed the use of sulfur dioxide (SO_2) to control 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 (1994) also stressed the needs for careful and precise application of SO_2 to ensure that residue levels were not exceeded and for incorporation of a scrubbing system into the treatment facility to prevent atmospheric pollution. Sulfur 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 sulfur dioxide by the use of sodium metabisulfite 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 1994). 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 over a long storage period. Once the package is opened, any residue dissipates readily.

Systemic fungicides

Despite the implementation of comprehensive protective control measures, some infections establish on fruit, particularly when rain falls before harvest. 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 use of the product is permitted in the target market for the commodity.

Some fungicides enter host tissue after application so that their effects may extend beyond the tissue covered during application. Distribution, and the extent of systemic effects, vary with fungicide, and mode and time of application.

Table 6. Commercial and experimental postharvest disease control treatments involving heat, either hot water (HW) or hot air (HA).

Fruit	Pathogen	Heating method	Temperature (°C)	Time	Fungicides	References
Apple	*Penicillium expansum*	HW	54.5	45s	benomyl or thiabendazole	Spalding et al. 1969
	Gloeosporium sp.	HW	45	6–11 min	–	Burchill 1964
Grapefruit	*Penicillium digitatum*	HW	50	5 min	–	Spalding and Reeder 1985
Lemon	*Phytophthora* sp.	HW	46–49	4 min	–	Klotz and De Wolfe 1961
	Penicillium digitatum	HW	52	5–10 min	–	Houck 1967
Lychee	Various fungi	HW	52	2 min	benomyl	Scott et al. 1982
	Various fungi	HW	48–50	2 min	benomyl	Wong et al. 1991
Mango	*Colletotrichum gloeosporioides*	HW	51	15 min	–	Pennock and Maldonaldo 1962
	C. gloeosporioides	HW	55	5 min	–	Smoot and Segall 1963
	C. gloeosporioides	HW	54.5	5 min	benomyl-thiabendazole	Spalding and Reeder 1972
	C. gloeosporioides	HW	51.5	5 min	benomyl	Muirhead 1976
	Dothiorella dominicana	HW	52	5 min	benomyl	Johnson et al. 1990c
	Lasiodiplodia theobromae (Syn. *Diplodia natalensis*)	HW	52	5 min	benomyl	Johnson et al. 1990c
	C. gloeosporioides	HW	53	3 min	imazalil	Spalding and Reeder 1986
	Diplodia natalensis	HW	53	3 min	imazalil	Spalding and Reeder 1986
	Phomopsis citri	HW	53	3 min	imazalil	Spalding and Reeder 1986
Melon	Various fungi	HW	52	2 min	–	Teitel et al. 1989
	Fusarium spp.	HW	57	30 s	–	Wells and Stewart 1968
	Various fungi	HW	55	1 min	benomyl and guazatine	McRae and Muirhead 1983
Nectarine	*Monilinia fructicola*	HA	52	15 min	–	Anthony et al. 1989
Orange	*Phomopsis citri*	HW	53	5 min	–	Smoot and Melvin 1963
	Penicillium digitatum	HW	53	5 min	–	Smoot and Melvin 1963
	Diplodia natalensis	HW	53	5 min	–	Smoot and Melvin 1963
Papaw (papaya)	Various fungi	HW	43–49	20 min	–	Akamine and Arisumi 1953
	Various fungi	HW (spray)	54	3 min	–	Couvey and Alvarez 1984
Peach	*Monilinia fructicola*	HW	54.5	3 min	–	Wells 1972
	Rhizopus stolonifer	HW	54.5	3 min	–	Wells 1972
	M. fructicola	HW (dip or spray)	52	10–30 s	DCNA or benomyl in wax	
Pear	*Alternaria tenuius*	HW	47	7 min	–	Ben-Arie and Guelfat-Reich 1969
Prune	*Monilinia fructicola*	HW	52	3 min	DCNA and benomyl	Jones and Burton 1973
Raspberry	*Rhizopus* sp.	HW	52	1–2 min	–	Worthington and Smith 1965
	Botrytis sp.	HA	43	30–60 min	–	
Strawberry	*Botrytis cinerea*	HA	44	40–60 min	–	Couey and Follstad 1966
	Rhizopus stolonifer	HA	44	40–60 min	–	Couey and Follstad 1966

Systemic fungicides can have a 'kick-back' effect, eradicating infections that were initiated one or more days before treatment. Their ability to eradicate infections will depend upon the time between infection and application of the fungicide, the location of quiescent infection structures, fruit maturity stage, 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. Cuticle removal can, however, increase water loss and susceptibility to brushing damage. Information on the kick-back effect of a particular fungicide is sometimes available from the manufacturer and may be printed on the product label.

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. 1990c; 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 are uncertain.

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 for a complete ban on the postharvest treatment of fruit and vegetables with pesticides within the European Community (E.C.). The ban will only come into effect once 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 United States of America, Du Pont Pty Ltd withdrew all postharvest registrations for benomyl (Vaux, in litt. 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, but 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.

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,b). 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 researchers have reported a synergism of 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. (1990b) found that irradiation of strawberries at doses from 600 to 2000 Gy reduced the incidence of grey mould caused by *Botrytis cinerea* during storage at 0–2°C for 4 weeks, but that during subsequent storage for 24 hours at 18°C, a high incidence of alternaria rot caused by *Alternaria 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.

Packaging

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 sulfur-dioxide fumigated lychees. Packaging materials can provide a physical barrier which excludes inoculum or limits spread within a consignment. Waxes can also function in this way.

Delaying Symptom Appearance

For the postharvest pathogens, which 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 cessation of quiescence for particular postharvest pathogens can result from a decline in the concentration of antifungal compounds (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 before disease appears, with full-ripe fruit considered inferior. Expansion of export markets and demands by the expatriate community and western tourists for ripe fruit requires a greater degree of disease control than is necessary when fruit are consumed mature-green.

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 two 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 (1994) and Ben-Yehoshua et al. (1994) have reviewed the use of modified and controlled atmospheres and surface coatings for extension of storage life. Extension of the critical quiescent period for postharvest pathogens can be concomitant with storage atmosphere effects that delay ripening.

Stimulation of host defences

El Ghaouth et al. (1992) found that chitosan, an ingredient of some fruit waxes, reduced the growth of *R. stolonifer, C. gloeosporioides, Botrytis cinerea* and *Alternaria alternata,* in vitro, and suggested that it had potential for postharvest disease control. Chitosan has elicited phytoalexin production in some hosts (Kendra and Hadwiger 1984; Kendra et al. 1989; Wilson et al. 1994). Wilson et al. (1994) have reviewed another approach to elicitation of host defences, the exposure of fruit to near-UV irradiation. Elicitation of host defences using postharvest carbon dioxide flushing, or pre- or postharvest challenges with non-pathogenic microorganisms also may have commercial applications (Prusky et al. 1993, 1994; Freeman and Rodriguez 1993).

Minimal processing

Siriphanich (1994) has reviewed 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.

Insects and Mites

Most tropical fruits are hosts of fruit flies or other insect pests which are the subject of specific prohibitions by quarantine authorities of importing countries. Mites may also occur in export produce but they are not usually subject to quarantine prohibitions, and some tolerance is usual. Packaging materials and transportation containers can also become infested with insects, molluscs such as the Giant African Snail, or vertebrate pests, and lead to the imposition of mandatory fumigation or other quarantine treatments at the port of entry. Control of insects and other pests begins in the orchard. Vijaysegaran (1994) has reviewed options for the field control of fruit flies; the same primary approaches apply to the field control of other pests. In addition to orchard measures which aim to prevent fruit infestation, postharvest measures are often required to satisfy the requirements of an export market for absolute freedom from a pest.

Disinfestation

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 which 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). Other countries, including Japan and New Zealand, have followed, catalysing initiatives to develop non-chemical alternatives to it and other treatments which leave chemical residues. The use of methyl bromide is currently being challenged because of its effects on the atmosphere (Anderson, U.S. EPA, pers. comm.).

Alternatives to chemical treatments are available. They include physical treatments with heat, cold, or irradiation, and operational measures in 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 and the additional operational costs involved.

The steps involved in obtaining approval for a disinfestation protocol before exporting fruit to Japan are outlined in Figure 2. Note the significant role played by the Japanese authorities in the acceptance and ongoing implementation of the protocol.

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, especially, is constantly under review with a revision of the group of major quarantine importance in Southeast Asia, the *Bactrocera dorsalis* complex, recently completed (Drew and Hancock 1994). The taxonomic identity of the pest against which treatments are being 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 very 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 which infest the fruit are highly relevant. For fruit flies it is the eggs and larvae which are the target 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 the treatment while the age within each stage can influence the result of a treatment markedly (Corcoran 1993; Heather et al. 1991; Balock et al. 1963).

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. 1970a; Von Windeguth et al. 1976; Armstrong and Vargas 1982; Armstrong et al. 1983; Spitler et al. 1984). These studies show that there can be cultivars of a commodity which 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 the 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 where the likelihood of infestation cannot be estimated. These treatments can be required 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 100000 insects of the most tolerant stage occurring in or on commercial fruit, without survivors. 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

QUARANTINE PROTOCOL
MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, JAPAN

The steps necessary for obtaining approval for entry of a fruit are as follows:

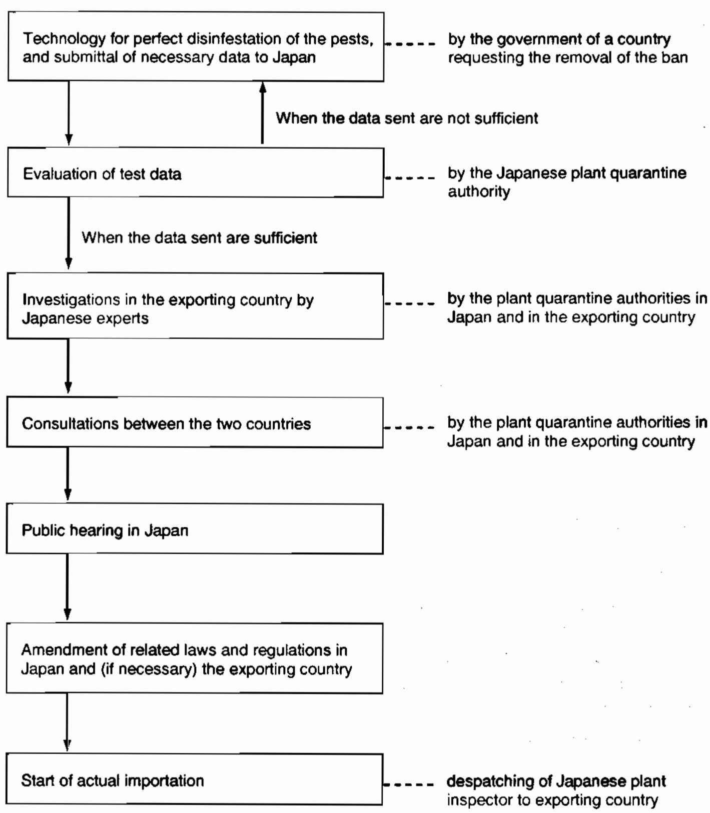

Figure 2. The steps involved in obtaining approval of a disinfestation protocol before exporting fruit to Japan.

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 which are lethal to fruit flies or other pests but do not cause unacceptable damage to fruit (Table 7). 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. 1970b; Hayes et al. 1984), but research on their application is continuing (Sharp 1994).

Heating with air

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, 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' which 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 which carried less risk of fruit damage. Secondly, temperature control equipment before microprocessors became available was bulky and comparatively unreliable. The deregistration of EDB in 1984 by U.S. 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, the 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 vapor heat process' and targeted *B. dorsalis* and *B. cucurbitae* in green peppers, egg plant and cucurbits according to host status (Sugimoto et al. 1983; Furusawa et al. 1984; Sunagawa et al. 1987, 1988, 1989). Treatments are mostly defined in terms of time after reaching a target temperature. However, the run-up time and temperature contribute to fruit fly mortality so fruits which heat quickly, e.g. capsicums (peppers) tend to require longer times at the target temperature. Work in the USA involved forced circulation of hot air at differing 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 *Ceratis capitata*, *Bactrocera* 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. The steps involved in a typical heat disinfestation schedule are shown in Figure 3.

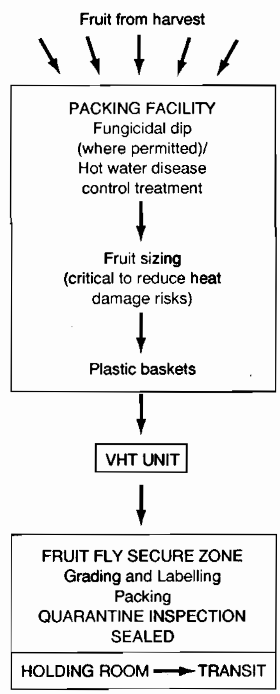

Figure 3. The steps involved in a typical heat disinfestation schedule.

Substantial trade in mangoes has developed from the Philippines to Japan based on a vapour heat schedule against *B. philippinensis* Drew and Hancock, a Philippines geographic race of *B. dorsalis* (Merino et al. 1985). The treatment 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 Philippines papaya, using the same facilities as are used for mango (E. Tuazon, Bureau of Plant Industries, Manila, pers. comm.).

In Thailand, a similar treatment developed against *B. dorsalis* in several cultivars of mango (Unahawutti et al. 1986) identified 46.5°C as a disinfestation temperature which 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 (r.h.) of the treatment air using air of 50% r.h. during a preheating period and 95% r.h. air 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, *B. 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 stage most tolerant 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; Coates and Johnson 1993) 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 *B. dorsalis, B. 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, 1989a,b,c) developed hot water dips as quarantine disinfestation treatments against *Anastrepha* spp. and in one instance, *C. capitata*. The mango varieties involved were 'Tommy Atkins', 'Keitt', 'Oro', 'Kent', 'Francis', 'Haden', and 'Ataulfo'. These authors reported that fruit were undamaged by water 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 disinfestation of mangoes of the variety Kensington in Australia, damage occurred (Jacobi and Wong 1992). This damage involved starch deposits, occurring as granules or lumps in the flesh, and was very similar to that recorded by Esquerra and Lizada (1990) in Philippine mangoes variety Carabao, damaged by vapour heat treatment. As a quarantine treatment, E.S.C. Smith and D. Chin, Berrimah N.T. Australia (pers. comm.) showed that a hot water dip at 47°C for 70 minutes conferred adequate security against *B. aquilonis* (May), a species very closely related to *B. tryoni*. They found that damage was avoided by holding fruit at ambient temperature for 24 hours after harvest before dipping. Considerable additional research is required to establish margins of safety for hot water disinfestation of Kensington mangoes.

Disinfestation schedules involving heated water or hot air are summarised in Table 7.

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, and over-treatment may be occurring. 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°C and it is probable that there is not any true difference in response between the species at any cold disinfestation temperature. Some cold disinfestation schedules are summarised in Table 8.

Benschoter (1984) developed a treatment schedule against *A. suspensa* (Loew) in grapefruit involving 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. Approximately 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 *B. dorsalis*. For *B. tryoni*, Sproul (1976) and Hill et al. (1988) reported that 16 days at 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 can be expected to 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. Spanish exports are one for which it is believed that this is currently being done but it is not possible to cite a reference. 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 has been done in the latter half (Heather 1993). The availability of gamma radiation sources, particularly Cobalt 60, gave 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 10 000 Gy as safe for use on any food. Subsequently, the U.S. Food and Drug Administration (FDA 1986) approved doses of up to 1000 Gy for disinfestation of fresh fruit and vegetables. Many other countries followed suit and it is estimated that the process is now approved in a majority 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 (sterile) 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 over-estimated for fruit flies. The level of infestation present in export quality commercial fruit needs 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 which 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.)

Table 7. Quarantine disinfestation schedules with heat against eggs or larvae of fruit flies in various fruits (after Heather 1994b).

Pest Species	Fruit	Method	Temperature	Time	Reference
Anastrepha distincta (Greene)	Mango	Hot water	46°C	1.5 hours	Sharp and Pincho-Martinez 1990
A. fraterculus (Wiedemann)	Mango	Hot water	46°C	1.5 hours	Sharp and Pincho-Martinez 1990
A. ludens (Loew) (Mexican fruit fly)	Mango	Hot water	46°C	1.5 hours	Sharp et al. 1989b
A. obliqua (Macquart) (West Indian fruit fly)	Mango	Hot air	48°C	1.5–3.5 hours	Mangan & Ingle 1992
A. obliqua (Macquart) (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. 1989a
A. suspensa (Loew) (Caribbean fruit fly)	Carambola	Vapour heat	43.5–46.5°C	1–2 hours	Hallman 1990
A. suspensa (Loew) (Caribbean fruit fly)	Mango	Hot water	46–47°C	1.5 hours	Sharp et al. 1989b
Ceratitis capitata (Wiedemann) (Mediterranean fruit fly)	Mango	Vapour heat	43.5°C	14 hours	Balock & Starr 1945
	Papaya	Hot air	46–47°C	5 hours	Armstrong et al. 1989
	Papaya	Hot air	42 & 49°C	30 minutes + 20 minutes	Couey & Hayes 1986
	Mango	Hot air	46°C	1.5 hours	Sharp et al. 1989a
Bactrocera cucurbitae (Coquillett) (Melon fly)	Papaya	Hot air	45–46°C	5 hours	Armstrong et al. 1989
	Papaya	Hot water	42 & 49°C	30 minutes + 20 minutes	Couey & Hayes 1986
	Momordica	Vapour heat	45°C	30 minutes	Sunagawa et al. 1988
	Papaya	Vapour heat	45.5°C	30 minutes	Sunagawa et al. 1989
	Egg plant	Vapour heat	43°C	2 hours	Furusawa et al. 1984
	Mango	Vapour heat	43.5°C	3 hours	Sunagawa et al. 1987
Bactrocera dorsalis (Hendel) *sens lat* (Oriental fruit fly)	Papaya	Vapour heat	44.5°C	20 hours	Seo et al. 1974
	Papaya	Hot air	45–46°C	5 hours	Armstrong et al.(1989
	Mango	Vapour heat	46°C	2 hours + 10 minutes	Merino et al. 1985
	Mango	Vapour heat	46.5°C	2 hours + 10 minutes	Unahawutti et al. 1986
	Mango	Hot air	46.5°C	2 hours + 10 minutes	Unahawutti et al. 1992
	Papaya	Hot water	42 & 49°C	30 minutes + 20 minutes	Couey & Hayes 1986
	Capsicum	Vapour heat	43°C	3 hours	Sugimoto et al. 1983
Bactrocera tryoni (Froggatt) (Queensland fruit fly)	Mango	Vapour heat	46.5°C	2 hours + 10 minutes	N. Heather, unpublished data
B. cucumis French (Cucumber fly)	Zucchini	Vapour heat	45°C	2 hours + 30 minutes	Corcoran et al. 1993

Table 8. Some cold disinfestation schedules.

Pest	Temperature	Time	Fruits
Anastrepha spp.	scaled 0.5–1.5°C	scaled 18–22 days	citrus pome fruit
Ceratitis capitata	scaled 0–2°C	scaled 10–16 days	citrus grape pome fruit
Bactrocera spp.	scaled 0–2°C	scaled 13–22 days	citrus pome fruit grape

Other nonchemical 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 the USA. This approach has general applicability to pests, 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. Mango seed weevil (*Sternochaetus mangiferae*) is another pest which could be handled in this way. I. Cunningham (pers. comm.) has developed a sampling system which identifies mango orchards free of detectable seed weevil populations, and enables exports to markets which have restrictions against it.

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 a pest becomes available, a review mechanism is needed to ensure that treatments required are neither unnecessarily harsh, nor cause substantial reductions in the shelf life of the fruit.

Chemical treatments

Although there is a trend by consumers away from postharvest chemical treatments they are still acceptable where maximum residue limits (MRLs) can be met, thus avoiding any public health risk. In Australia, fruit fly disinfestation for fruit fly host commodities transported to fruit fly free regions relies heavily on dips or sprays with the insecticides dimethoate and fenthion (Heather 1994a). Depending on the fruit, high levels of efficacy can be achieved, e.g. tomatoes > 99.99% with less risk of phytotoxic effects or damage than for physical treatments. The low cost and low level of technology required makes these treatments suitable for developing countries where it is necessary to demonstrate a commitment to internal quarantine. Methyl bromide, and even EDB, are still accepted by some markets provided that MRLs are not exceeded.

Future Directions

Consumer preference for nonchemical disease control and disinfestation measures can be expected to provide continued incentive for development of physical and biological 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. Attention to accurate targeting of treatments may also improve treatment efficacy for disease control and reduce the risk of fruit damage. If 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. Development of novel disease control strategies will also require more research on the biology of the pathogens involved. For insects, combination treatments are considered to have good potential for future development.

Pest and disease control should be considered as components of a total management system which aims to (i) deliver product to customer specifications, and (ii) monitor performance of both the product and the system against that of the previous season and their competitors—so as to correct deficiencies, address new problems, and maintain the competitive edge.

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References

Aharoni, Y., Copel, A. and Fallik, E. 1993. Hinokitiol (ß-thujaplicin), for postharvest decay control on 'Galia' melons. New Zealand Journal of Crop and Horticultural Science, 21, 165–169.

Akamine, E.K. and Arisumi, T. 1953. Control of postharvest storage decay of fruits of papaya (*Carica papaya* L.) with special reference to the effect of hot water. Proceedings of the American Society of Horticultural Science, 61, 270–274.

Alvarez, A.M. and Nishijima, W.T. 1987. Postharvest diseases of papaya. Plant Disease, 71, 682–686.

Anon. 1984. Ethylene dibromide: amendment of notice to cancel registration of pesticide products containing ethylene dibromide. Washington, D.C., U.S. Government Printing Office, Federal Register, 49, 14182–14185.

— 1985. USDA PPQ Treatment manual, Section VI T106. Vapor heat. Washington, D.C., United States Department of Agriculture.

— 1991. E.C. bans postharvest pesticide treatment. Postharvest News and Information, 22, 3.

Anthony, B.R., Phillips, P.J., Badr, S. and Aharoni, Y. 1989. Decay control and quality maintenance after moist air heat treatment of individually plastic-wrapped nectarines. Journal of the American Society for Horticultural Science, 114, 946–949.

Armstrong, J.W. 1992. Fruit fly disinfestation strategies beyond methyl bromide. New Zealand Journal of Crop Horticulture and Science, 20, 181–193.

Armstrong, J.W. and Couey, H.M. 1989. Fumigation, heat and cold. In: Robinson, A.S. and Hooper, G., ed., Fruit flies, their biology natural enemies and control, Vol. 3B. Amsterdam, Elsevier, 411–424.

Armstrong, J.W., Hansen, J.D., Hu, B.K.S. and Brown, S.A. 1989. High-temperature forced air quarantine treatment for papayas infested with tephritid fruit flies (Diptera: Tephritidae). Journal of Economic Entomology, 82, 1667–1674.

Armstrong, J.W., Mitchell, W.C., and Farias, G.J. 1983. Resistance of 'Sharwil' avocadoes at harvest maturity to infestation by three fruit fly species in Hawaii. Journal of Economic Entomology, 76, 119–121.

Armstrong, J.W. and Vargas, R.I. 1982. Resistance of pineapple variety '59-65' to field populations of oriental fruit flies and melon flies. Journal of Economic Entomology, 75, 781–782.

Avissar, I. and Pesis, E. 1991. The control of postharvest decay in table grapes using acetaldehyde vapours. Annals of Applied Biology, 118, 229–237.

Baker, A.C. 1939. The basis for treatment of products where fruit flies are involved as a condition for entry into the United States. Washington, D.C., U.S. Department of Agriculture, Circular no. 551, 7 p.

Baker, A.C., Stone, W.E., Plummer, C.C. and McPhail, M. 1944. A review of studies on the Mexican fruit fly and related Mexican species. U.S. Department of Agriculture Miscellaneous Publications (from citation by Balock and Starr 1945).

Baker, R.T., Cowley, J.M., Harte, D.S. and Frampton, E.R. 1990. Development of a maximum pest limit for fruit flies (Diptera: Tephritidae) in produce imported into New Zealand. Journal of Economic Entomology, 83, 13–17.

Balock, J.W., Burditt Jr, A.K. and Christenson, L.D. 1963. Effects of gamma radiation on various stages of three fruit fly species. Journal of Economic Entomology, 56, 42–46.

Balock, J.W. and Starr, D.F. 1945. Mortality of the Mexican fruit fly in mangoes treated by vapor-heat process. Journal of Economic Entomology, 38, 646–651.

Barkai-Golan, R. and Phillips, D.J. 1991. Postharvest heat treatment of fresh fruits and vegetables for decay control. Plant Disease, 75, 1085–1089.

Baudoin, A.B.A.M. and Eckert, J.W. 1982. Factors influencing the susceptibility of lemons to infection by *Geotrichum candidum*. Phytopathology, 72, 1592–1597.

Ben-Arie, R. and Guelfat-Reich, S. 1969. Postharvest heat treatment to control storage rots of Spandona pears. Plant Disease Reporter, 53, 363–367.

Ben-Yehoshua, S., Fishman, S., Deqiu Fang and Rodov, V. 1994. Packaging and surface coatings. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings, No.50, 250–260.

Benschoter, C.A. 1984. Low temperature storage as a quarantine treatment for the Caribbean fruit fly (Diptera: Tephritidae) in Florida citrus. Journal of Economic Entomology, 77, 1233–1235.

— 1987. Effects of modified atmospheres and refrigeration temperatures on survival of eggs and larvae of the Caribbean fruit fly (Diptera: Tephritidae) in laboratory diet. Journal of Economic Entomology, 80, 1223–1225.

Bills, G.F., Giacobbe, R.A., Lee, S.H., Pelaez, F. and Tkacz, J.S. 1992. Tremorgenic mycotoxins, paspalitrem A and C, from a tropical *Phomopsis*. Mycological Research, 96, 977–983.

Brown, G.E. and Wilson, W.C. 1968. Mode of entry of *Diplodia natalensis* and *Phomopsis citri* into Florida oranges. Phytopathology, 58, 736–739.

Burchill, R.T. 1964. Hot water as a possible post-harvest control of gloeosporium rots of stored apples. Plant Pathology, 13, 106–107.

Burditt, A.K. Jr 1992. Effectiveness of irradiation as a quarantine treatment against various fruit fly species. In: Use of irradiation as a quarantine treatment of food and agricultural commodities. Vienna, International Atomic Energy Agency.

Burditt, A.K. Jr and Balock, J.W. 1985. Refrigeration as a quarantine treatment for fruits and vegetables infested with eggs and larvae of *Dacus dorsalis* and *Dacus cucurbitae* (Diptera: Tephritidae). Journal of Economic Entomology, 78, 885–887.

Burikam, I., Sarnthoy, O., Charernsom, K., Kanno, T. and Homma, H. 1992. Cold temperature treatment for mangosteen infested with Oriental fruit fly (Diptera : Tephritidae). Journal of Economic Entomology, 85, 2298–2301.

Butani, D.K. 1978. Pests and diseases of jackfruit in India and their control. Fruits, 33, 351–357.

Butler, E.E. and Petersen, L.J. 1972. *Endomyces geotrichum* a perfect state of *Geotrichum candidum*. Mycologia, 64, 365–374.

Cappellini, R.A. and Ceponis, M.J. 1988. Disorders in avocado, mango and pineapple shipments to the New York market 1972–1985. Plant Disease, 72, 270–273.

Cappellini, R.A., Ceponis, M.J. and Lightner, G.W. 1986. Disorders in table grape shipments to the New York market, 1972–1984. Plant Disease, 70, 1075–1079.

— 1988. Disorders in apricot and papaya shipments to the New York market, 1972–1985. Plant Disease, 72, 366–368.

Carmichael, J.W. 1957. *Geotrichum candidum*. Mycologia, 49, 820–830.

Ceponis, M.J., Cappellini, R.A. and Lightner, G.W. 1986a. Disorders in citrus shipments to the New York market 1972–1984. Plant Disease, 70, 605–607.

— 1986b. Disorders in muskmelon shipments to the New York market 1972–1984. Plant Disease, 70, 1162–1165.

Coates, L.M. and Johnson, G.I. 1993. Effective disease control in heat-disinfested fruit. Postharvest News and Information, 4, 35N–40N.

Codex Alimentarius Commission 1984. Codex general standard for irradiated foods and recommended international code of practice for the operation of radiation facilities used for treatment of foods. Codex Vol XV 1984.

Coley-Smith, J.R., Verhoeff, K. and Jarvis, W.R. 1980. The biology of *Botrytis*. New York, Academic Press.

Cook, A.A. 1975. Diseases of tropical and subtropical fruits and nuts. New York, Hafner Press.

Corcoran, R.J. 1993. Heat mortality relationships for eggs of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) at varying ages. Journal of the Australian Entomological Society, 32, 307–310.

Corcoran, R.J., Heather, N.W. and Heard, T.A. 1993. Vapor heat treatment for zucchini infested with *Bactrocera cucumis* (Diptera: Tephritidae). Journal of Economic Entomology, 86, 66–69.

Couey, H.M. and Alvarez, A.M. 1984. Comparison of hot-water spray and immersion treatments for control of postharvest decay of papaya. Plant Disease, 68, 436–437.

Couey, H.M. and Chew, V. 1986. Confidence limits and sample size in quarantine research. Journal of Economic Entomology, 79, 887–890.

Couey, H.M. and Follstad, M.N. 1966. Heat pasteurization for control of postharvest decay in fresh strawberries. Phytopathology, 56, 1345–1347.

Couey, H.M. and Hayes, C.F. 1986. Quarantine procedure for Hawaiian papaya using fruit selection and a two stage hot-water immersion. Journal of Economic Entomology, 79, 1307–1314.

Couey, H.M., Linse, E.S. and Nakamura, A.N. 1984. Quarantine procedure for Hawaii papaya using heat and cold treatments. Journal of Economic Entomology, 77, 984–988.

Cowley, J.M., Baker, R.T. and Harte, D.S. 1992. Definition and determination of host status for fruit fly (Diptera: Tephritidae) species. Journal of Economic Entomology, 85, 312–317.

Davis, L.L. and Baudoin, A.B.A.M. 1986. Effect of osmotic potential on *Geotrichom candidum:* growth, polygalacturonase production and polygalacturonase action. Physiological and Molecular Plant Pathology, 28, 53–60.

Dodd, J.C. and Jefferies, P. 1989. Management strategies to control latent infection in tropical fruit. Aspects of Applied Biology, 20, 49–56.

Domsch, K.H., Gams, W. and Anderson, T-H. 1980. Compendium of soil fungi, Vols 1 and 2. New York, Academic Press.

Drew, R.A.I. and Hancock, D.L. 1994. The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bulletin of Entomological Research (Supplement Series), Supplement No. 2, 68 p.

Droby, S., Prusky, D., Jacoby, B. and Goldman, A. 1987. Induction of anti-fungal resorcinols in flesh of unripe mango fruits and its relation to latent infection by *Alternaria alternata*. Physiological and Molecular Plant Pathology, 30, 285–292.

Eckert, J.W. 1990. Recent developments in the chemical control of postharvest diseases. Acta Horticulturae, 269, 477–494.

Eckert, J.W. and Ogawa, J.M. 1985. The chemical control of postharvest diseases: sub tropical and tropical fruits. Annual Review of Phytopathology, 23, 421–454.

El Ghaouth, A., Arul, J., Asselin, A. and Benhamou, N. 1992. Antifungal activity of chitosan on postharvest pathogens: induction of morphological and cytological alterations in *Rhizopus stolonifer.* Mycological Research, 96, 769–779.

Ellis, M.B. 1971. Dematious hyphomycetes. Kew, U.K., Commonwealth Mycological Institute.

Esquerra, E.B. and Lizada, M.C.C. 1990. The postharvest behaviour and quality of 'Carabao' mangoes subjected to vapour heat treatment. ASEAN Food Journal, 5, 6–12.

Fallik, E. and Grinberg, S. 1992. Hinokitiol: a natural substance that controls postharvest diseases in eggplant and pepper fruits. Postharvest Biology and Technology, 2, 137–144.

FAO/WHO 1993. Report of the fourth session of the Codex Commitee on tropical fresh fruits and vegetables. Mexico City, 1–5 February 1993 as presented to the Joint FAO/WHO Food Standards Programme. Codex Alimentarius Commission twentieth Session, Geneva 28 June–7 July 1993. ALINORM 93/35 A, 64 p.

Farungsang, U. and Farungsang, N. 1992. Resistance to benomyl of *Colletotrichum* spp. causing anthracnose of rambutan and mango in Thailand. Acta Horticulturae, 321, 891–897.

FDA (Food and Drug Administration) 1986. Irradiation in the production, processing and handling of food; final rule. U.S. Federal Register, 51, 1986 13376–13399.

Finney, D.J. 1971. Probit analysis, 3rd ed. London, Cambridge University Press, 333 p.

Freeman, S. and Rodriguez, R.J. 1993. Genetic conversion of a fungal plant pathogen to a nonpathogenic, endophytic mutualist. Science, 260, 75–78.

Furusawa, K., Sugimoto, T. and Gaja, T. 1984. The effectiveness of vapor heat treatment against the melon fly, *Dacus cucurbitae* (Coquillett) in egg plant and fruit tolerance to the treatment. Research Bulletin of the Plant Protection Service Japan, 20, 17–24.

Gerretson-Cornell, L. 1985. A working key to the species of *Phytophthora* de Bary. Acta Botanica Hungarica, 31, 89–97.

Gueho, E., Tredick, J. and Phaff, H.J. 1985. DNA relatedness among species of *Geotrichum* and *Dipodascus*. Canadian Journal of Botany, 63, 961–964.

Hallman, G.J. 1990. Vapor-heat treatment of carambolas infested with Caribbean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 83, 2340–2342.

Hallman, G.J. and Sharp, J.L. 1990. Hot water immersion quarantine treatments for carambolas infested with Caribbean fruit fly (Diptera : Tephritidae). Journal of Economic Entomology, 83, 1471–1474.

Hartill, W.F.T. 1992. Post-harvest rots of avocados in New Zealand and their control. Brighton Crop Protection Conference — Pests and Diseases, 1157–1162.

Hayes, C.F., Chignon, H.T.G., Nitta, F.A. and Wang, W.J. 1984. Temperature control as an alternative to ethylene dibromide fumigation for the control of fruit flies (Diptera : Tephritidae) in papaya. Journal of Economic Entomology, 77, 683–686.

Heard, T.A., Heather, N.W. and Corcoran, R.J. 1991. Dose-mortality relationships for eggs and larvae of *Bactrocera tryoni* (Diptera: Tephritidae) immersed in hot water. Journal of Economic Entomology, 84, 1968–1770.

Heard, T.A., Heather, N.W. and Peterson, P.M. 1992. Relative tolerance to vapor heat treatment of eggs and larvae of *Bactrocera tryoni* (Diptera: Tephritidae) in mangoes. Journal of Economic Entomology, 85, 461–463.

Heather, N.W. 1993. Irradiation as a quarantine treatment of agricultural commodities against arthropod pests. Proceedings of symposium on management of insect pests: nuclear and related molecular and genetic techniques. Vienna, International Atomic Energy Agency Vienna, in press.

— 1994a. Pesticide quarantine treatments. In: Sharp, J.L. and Hallman, B.J., ed., Quarantine treatments for pests of food plants. USA, Westview Press, 89–100.

— 1994b. Disinfestation: non-chemical options. In Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 272–279.

Heather, N.W., Corcoran, R.J. and Banos, C. 1991. Disinfestation of mangoes with gamma irradiation against two Australian fruit flies (Diptera: Tephritidae). Journal of Economic Entomology, 84, 1304–1307.

Hershenhorn, J., Behr, L., Barash, I. and Arzee, T. 1989. Mode of sour rot formation as inferred from comparative studies with virulent and avirulent strains of *Geotrichum candidum*. Journal of Phytopathology, 126, 257–271.

Hill, A.R., Rigney, C.J. and Sproul, A.N. 1988. Cold storage of oranges as a disinfestation treatment against the fruit flies, *Dacus tryoni* (Froggatt), and *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). Journal of Economic Entomology, 81, 257–260.

Ho, H.H. 1981. Synoptic key to the species of *Phytophthora*. Mycologia, 73, 705–714.

Holliday, P. 1980. Fungus diseases of tropical crops. Cambridge, Cambridge University Press.

Hoog, G.S. de. and Scheffer, R.J. 1984. *Ceratocystis* versus *Ophiostoma*. A reappraisal. Mycologia, 76, 292–299.

Horne, W.T. and Palmer, D.F. 1935. The control of *Dothiorella* rot on avocado fruits. Berkeley, University of California, College of Agriculture, Agricultural Experiment Station, Bulletin 594.

Houck, L.G. (1967). Hot water treatments for control of *Penicillium digitatum* green mold of Eureka lemons. Phytopathology, 57, 99.

Hunt, J. 1956. The taxonomy of the genus *Ceratocystis*. Lloydia, 19, 1–58.

Inch, A.J. 1978. Passionfruit diseases. Queensland Agricultural Journal, 101, 479–484.

International Consultative Group on Food Irradiation 1986. Task Force meeting on irradiation as a quarantine treatment. A report of the Task Force convened by the International Consultative Group on Food Irradiation, Chiang Mai, Thailand. Vienna, International Atomic Energy Agency, 24 p.

— 1991. Irradiation as a quarantine treatment. A report of the Task Force convened by the International Consultative Group on Food Irradiation, Bethesda, Maryland, USA, 1991. International Atomic Energy Agency, Vienna 35 p.

Jacobi, K., Coates, L. and Wong, L. 1994. Heat disinfestation of mangoes: effect on fruit quality and disease control. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 280–287.

Jacobi, K.K. and Wong, L.S. 1992. Quality of 'Kensington' mango (*Mangifera indico* Linn.) following hot water and vapour heat treatments. Postharvest Biology and Technology, 1, 349–359.

Jarvis, W.R. 1977. *Botryotinia* and *Botrytis* species: taxonomy, physiology and pathogenicity. A guide to the literature. Canadian Department of Agriculture Monograph 15.

Jeffries, P. and Koomen, I., 1992. Strategies and prospects for biological control of diseases caused by *Colletotrichum*. In: Bailey, J.A. and Jeger, M.J., ed., *Colletotrichum:* biology, pathology and control. Wallingford, U.K., CAB International, 337–357.

Jessup, A.J. 1992. Low temperature storage as a quarantine treatment for table grapes infested with Queensland fruit fly (*Bactrocera tryoni* (Froggatt)). New Zealand Journal of Crop and Horticultural Science, 20, 235–239.

Jessup, A.J. and Baheer, A. 1990. Low temperature storage as a quarantine treatment for kiwi fruit infested with *Dacus tryoni* (Diptera: Tephritidae). Journal of Economic Entomology, 83, 2317–2319.

Johnson, G.I. 1989. Lychee disease control. Proceedings Second National Lychee Seminar, Cairns, Australia, 90–93.

— 1992. Biology and control of the stem end rot pathogens of mango. Ph.D. Thesis, Botany Department, The University of Queensland, St Lucia, Queensland, Australia.

Johnson, G.I., Boag, T.S., Cooke, A.W., Izard, M., Panitz, M. and Sangchote, S. 1990a. Interaction of postharvest disease control treatments and gamma irradiation on mangoes. Annals of Applied Biology, 116, 245–257.

Johnson, G.I. and Coates, L.M. 1993. Postharvest diseases of mango. Postharvest News and Information, 4, 27N–34N.

Johnson, G.I. and Cooke, L.M. 1989. Stop the rot: disease control after harvest. Queensland Agricultural Journal, 115, 17–18.

Johnson, G.I., Cooke, A.W., Hutton, D.G. and Muirhead, I.F. 1992b. Diseases of carambola (*Averrhoa carambola*L.) in Queensland. Maroochy Horticultural Research

Station Report No 6, Research Establishments Publication QR9 1001, Department of Primary Industries, Queensland, 106.

Johnson, G.I., McLauchlan, R.L., Gillen, A.A. and Banos, C. 1990b. Irradiation of fresh horticultural produce: disease control. In: Beattie, B.B., ed., Managing postharvest horticulture in Australasia. Proceedings Australasian Postharvest Conference 1989. AIAS Occasional Publication No. 46, 199–206.

Johnson, G.I., Mayne, D.W. and Cooke, A.W. 1993. Seed transmission of mango fruit pathogens. Australiasian Plant Pathology Society Conference, 1993, Abstracts.

Johnson, G.I., Mead, A.J., Cooke, A.W. and Dean, J.R. 1991. Mango stem end rot pathogens — infection levels between flowering and harvest. Annals of Applied Biology, 119, 465–473.

— 1992a. Mango stem end rot pathogens — fruit infection by endophytic colonisation of the inflorescence and pedicel. Annals of Applied Biology, 120, 225–234.

Johnson, G.I. and Sangchote, S. 1994. Control of postharvest diseases of tropical fruits: challenges for the 21st century. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993, ACIAR Proceedings No. 50, 140–161.

Johnson, G.I., Sangchote, S. and Cooke, A.W. 1990c. Control of stem end rot (*Dothiorella dominicana*) and other postharvest diseases of mangoes (cv. Kensington Pride) during short- and long-term storage. Tropical Agriculture (Trinidad), 67, 183–187.

Jones, A.L. and Burton, C. 1973. Heat and fungicide treatments to control postharvest brown rot of stone fruits. Plant Disease Reporter, 57, 62–66.

Jones, D.R. 1991. Chemical control of crown rot in Queensland bananas. Australian Journal of Experimental Agriculture, 31, 693–698.

Kader, A.A. 1994. Modified and controlled atmosphere storage of tropical fruits. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 239–249.

Kader, A.A. and Arpaia, M.L. 1992. Postharvest handling systems: subtropical fruits. In: Kader, A.A., ed., Postharvest technology of horticultural crops, 2nd ed. Oakland, California, University of California, Division of Natural Resources, Publication 3311, 233–240.

Kaneshiro, K.Y., Ohta, A.T., Kurihara, J.S., Kanegawa, K.M. and Nagomine, L.R. 1983. Gamma radiation treatment for disinfestation of the Mediterranean fruit fly in California grown fruit, I. Stone fruits. Proceedings of the Hawaiian Entomology Society, 24, 245–259.

Keetsa, S. and Leelawatana, K. 1992. Effect of pre and poststorage dipping on browning of lychee fruits. Acta Horticulturae, 321, 726–731.

Kendra, D.F., Christian, D. and Hadwiger, L.A. 1989. Chitosan oligomers from *Fusarium solani* /pea interactions, chitinase/ß-glucanase digestion of sporlings and from fungal wall chitin actively inhibit fungal growth and enhance disease resistance. Physiological and Molecular Plant Pathology, 35, 215–230.

Kendra, F.D. and Hadwiger, L.A. 1984. Characterisation of the smallest chitosan oligomer that is mainly antifungal to *Fusarium solani* and elicits pisatin formation in *Pisium sativum*. Experimental Mycology, 8, 276–281.

Kitagawa, H., Manabe, K. and Esguerra, E.B. 1992. Bagging of fruit on the tree to control disease. Acta Horticulturae, 321, 871–875.

Klotz, L.J. and De Wolfe, T.A. 1961. Limitations of the hot water immersion treatment for the control of Phytophthora brown rot of lemons. Plant Disease Reporter, 45, 264–267.

Korsten, L.,Villiers, E. de and Kotze, J. 1994. Biological control of postharvest diseases of tropical fruit. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 172–185.

Kremer-Kohne, S. 1993. SO_2 residues in litchi after postharvest SO_2 treatments (1990). South African Litchi Growers' Association Yearbook, 5, 15–16.

Landolt, P.J., Chambers, D.L. and Chew, V. 1984. Alternative to the use of probit 9 as a criterion for quarantine treatments of fruit fly (Diptera: Tephritidae)-infested fruit. Journal of Economic Entomology, 77, 285–287.

Lim, T.K. 1990. Durian diseases and disorders. Kuala Lumpur, Malaysia, Tropical Press.

Lim, T.K. and Khoo, K.C. 1985. Diseases and disorders of mango in Malaysia. Kuala Lumpur, Malaysia, Tropical Press.

— 1990. Guava in Malaysia, production, pests and diseases. Kuala Lumpur, Malaysia, Tropical Press.

Lim, T.K. and Razak, A.R. 1986. Studies on a *Phomopsis* rot of bagged guava *(Psidium guajava)* fruits in Malaysia. Fitopatologia Brasileira, 11, 227–236.

Lonsdale, J.H. 1988. Postharvest diseases of litchis (*Litchi chinensis*) and their control. South African Litchi Growers' Association Yearbook, 1, 16–18.

Lonsdale, J. H., Lonsdale, J.M., Greef, H. and Brooks, W. 1991. The efficacy of prochloraz, chloramizol-sulphate and quazatine on postharvest diseases of mango. South African Mango Growers' Annual Report, 11, 35–38.

McLauchlan, R.L., Mitchell, G.E., Johnson, G.I., Nottingham, S.M., Smillie, R.M. and Wills, P.A. 1990. Ionising energy treatment for fresh horticultural produce. Lychee and mango Trial III Jan–Feb 1988, Queensland Department of Primary Industries Project Report, 45 p.

McRae, K.B. and Muirhead, I.F. 1983. Rockmelons — postharvest treatment. Queensland Department of Primary Industries Farmnote, 264/630.

Maas, J.L. and Uecker, F.A. 1984. *Botryosphaeria dothidea* cane canker of thornless blackberry. Plant Disease, 68, 726–726.

Mangan, R.L. and Ingle, S.J. 1992. Forced hot-air quarantine treatment for mangoes infested with West Indian fruit fly (Diptera : Tephritidae). Journal of Economic Entomology, 85, 1859–1864.

Mayers, P.E. and Owen Turner, J. 1989. Export citrus: black spot control essential. Queensland Agricultural Journal, 115, 41–42.

Merino, S.R., Eugenio, M.M., Ramos, A.U. and Hernandez, S.T. 1985. Fruit fly disinfestation of mangoes by vapor heat treatment. Bureau of Plant Industry. Manila, Philippines, Ministry of Agriculture and Food, 76 p.

Moffitt, H.R. 1990. A systems approach to meeting import quarantine requirements for insect pests of deciduous fruits. Proceedings of the Washington State Horticulture Association, 85, 223–225.

Moy, J.H. 1983. Radurization and radicidation: fruit and vegetables. In: Preservation of food by ionising radiation, vol. III. Boca Raton, Florida, CRC Press, 83–108.

Muirhead, I.F. 1976. Post-harvest control of mango anthracnose with benomyl and hot water. Australian Journal of Experimental Agriculture and Animal Husbandry, 16, 600–603.

Muirhead, I.F. and Grattidge, R. 1986. Postharvest diseases of mango — the Queensland experience. Melbourne, CSIRO, First Australian Mango Research Workshop Proceedings, 248–252.

Newhook, F.J., Waterhouse, G.M. and Stamps, D.J. 1978. Tabular key to the species of *Phytophthora* De Bary. Mycological Research Papers, 143, 1–20.

Ouye, M.T. and Gilmore, J.E. 1985. The philosophy of quarantine treatment as related to low-dose radiation. In: Moy, J.H., ed., Radiation disinfestation of Food and Agricultural Products. Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, Hawaii USA, 67–69.

Paull, R.E. 1990. Postharvest heat treatments and fruit ripening. Postharvest News and Information, 1, 355–363.

Pelser, P. du T. and Lesar, K. 1990. Post-harvest decay control in mangoes with combinations of prochlaraz, imazalil, benomyl or TBZ. South African Mango Growers' Association Yearbook, 11, 9–10.

— 1991. Post-harvest decay control in mangoes under South African conditions. South African Mango Growers' Association Yearbook, 10, 11–17.

Pena, J.B. and Duncan, R. 1989. Role of arthropods in the transmission of postbloom fruit drop. Proceedings of the Florida State Horticultural Society, 102, 249–251.

Pennock, W. and Maldonaldo, G. 1962. Hot-water treatment of mango fruits to reduce anthracnose decay. Journal of Agriculture, University of Peurto Rico, 46, 272–283.

Pennycook, S.R. and Samuels, G.J. 1985. *Botryosphaeria* and *Fusicoccum* species associated with ripe fruit rot of *Actidinia deliciosa* (kiwifruit) in New Zealand. Mycotaxon, 24, 445–458.

Persley, D., ed. 1993. Diseases of fruit crops. Brisbane, Queensland, Department of Primary Industries.

Peterson, R.A. 1978. Susceptibility of Fuerte avocado fruit at various stages of growth to infection by anthracnose and stem end rot fungi. Australian Journal of Experimental Agriculture and Animal Husbandry, 18, 158–160.

Phillips, D.J. 1984. Mycotoxins as a postharvest problem. In: Moline, H.E., ed., Postharvest pathology of fruits and vegetables: postharvest losses in perishible crops. Berkeley, California, Publication NE-87 (UC Bulletin 1914), University of California, Agricultural Experiment Station, 50–54.

Pitt, J.I. 1979. The genus *Penicillium* and its teleomorphic states *Eupenicillium* and *Talaromyces*. New York, Academic Press.

— 1985. A laboratory guide to the common *Penicillium* species. North Ryde, NSW, Australia, Commonwealth Scientific and Industrial Research Organisation.

Pitt, J.I. and Hocking, A.D. 1985. Interfaces among genera related to *Aspergillus* and *Penicillium*. Mycologia, 77, 810–824.

Ploetz, R.C., Zentmyer, G.A., Nishijima, W.T. and Rohrbach, K.G., ed. 1993. Compendium of tropical fruit diseases. St Paul, MN, APS Press.

Prakash, O. and Srivastava, K.C. 1987. Mango diseases and their management. A world review. New Delhi, Today and Tomorrow's Printers and Publishers.

Prusky, D., Freeman, S., Rodriguez, R.J. and Keen, N.T. 1994. A nonpathogenic mutant strain of *Colletotrichum magna* induces resistance to *C. gloeosporioides* in avocado fruits. Molecular Plant-Microbe Interactions, 7, 326–333.

Prusky, D., Fuchs, Y. and Yanko, U. 1983. Assessment of latent infections as a basis for control of postharvest diseases of mango. Plant Disease, 67, 816–818.

Prusky, D., Gat, Z. and Burd, P. 1993. Effect of relative humidity during growth on the incidence of quiescent infections of *Alternaria alternata*. Plant Disease, 77, 249–252.

Prusky, D. and Keen, N.T. 1993. Involvement of preformed antifungal compounds in the resistance of subtropical fruits to fungal decay. Plant Disease, 77, 114–119.

Prusky, D., Kobiler, I. and Jacoby, B. 1988. Involvement of epicatechin in cultivar susceptibility of avocado fruits to *Colletotrichum gloeosporioides* after harvest. Journal of Phytopathology, 123, 140–146.

Purss, G.S. 1953. The fruit rots of the custard apple. Queensland Journal of Agricultural Science, 10, 247–265.

Rahman, R., Rigney, C. and Busch–Petersen, E. 1990. Irradiation as a quarantine treatment against *Ceratitis capitata* (Diptera: Tephritidae): Anatomical and cytogenetic changes in mature larvae after gamma irradiation. Journal of Economic Entomology, 83, 1449–1454.

Raper, K.B. and Fennell, D.I. 1965. The genus *Aspergillus*. Baltimore, MD, The Williams & Wilkins Co.

Rigney, C.J. and Wills, P.A. 1985. Efficacy of gamma irradiation as a quarantine treatment against Queensland fruit fly. In: Moy, J.H., ed., Radiation disinfestation of food and agricultural products. Honolulu, HI, University of Hawaii at Manoa, Hawaii Institute of Tropical Agriculture and Human Resources, 116–120.

Rohwer, G.C. and Williamson, D.L. 1983. Pest risk evaluation in regulatory entomology. Bulletin of the Entomological Society of America, Winter 1983, 41–46.

Rossman, A.Y., Palm, M.E. and Spillman, L.J. 1987. A literature guide for the identification of plant pathogenic fungi. St Paul, MN, APS Press.

Sarsud, V., Sarsud, U., Sittigul, C. and Chaiwangsri, T. 1994. Effects of postfumigation washing treatments and storage temperature on disease development in fresh longan. In: Johnson, G.I. and Highley, E., ed., Development of postharvest handling technology for tropical tree fruits. A workshop held in Bangkok, Thailand, 16–18 July 1992. ACIAR Proceedings No. 58, 77–79.

Schiffmann-Nadel, M., Michaely, H., Zauberman, G. and Chet, I. 1985. Physiological changes occurring in picked climacteric fruit infected with different pathogenic fungi. Phytopathology Zeitschrift, 113, 277–284.

Schipper, M.A.A. 1984. A revision of the genus *Rhizopus* I. The *Rhizopus stolonifer* group and *Rhizopus oryzae*. Studies in Mycology, 25, 1–19.

Scott, K.J., Brown, B.I., Chaplin, G.R., Wilcox, M.E. and Bain, J.M. 1982. The control of rotting and browning of litchi fruit by hot benomyl and plastic film. Scientia Horticulturae, 16, 253–262.

Seo, S.T., Chambers, D.L., Kobayashi, Lee, C.Y.L. and Komura, M. 1970a. Infestations of Oriental fruit flies in 53-116 and smooth cayenne varieties grown near supporting guava or other host fruits. Journal of Economic Entomology, 63, 1830–1831.

Seo, S.T., Chambers, D.L., Komura, M. and Lee, C.Y.L. 1970b. Mortality of mango weevils in mangoes heated by dielectric heating. Journal of Economic Entomology, 63, 1977–1978.

Seo, S.T., Hu, B.K.S., Komura, M., Lee, C.Y.L. and Harris, E.J. 1974. *Dacus dorsalis*: Vapor heat treatment in papayas. Journal of Economic Entomology, 67, 240–242.

Sharp, J.L. 1985. Submersion of Florida grapefruit in heated water to kill stages of Caribbean fruit fly, *Anastrepha suspensa*. Proceedings Florida State Horticulture Society, 98, 78–80.

— 1986. Hot water treatment for control of *Anastrepha suspensa* (Diptera: Tephritidae) in mangoes. Journal of Economic Entomology, 79, 706–708.

— 1992. Hot-air quarantine treatment for mango infested with Caribbean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 85, 2302–2304.

— 1994. Microwaves as a quarantine treatment to disinfest commodities of pests. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., 1994. Postharvest handling of tropical fruits. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 362–364.

Sharp, J.L., Ouye, M.T., Hart, W., Ingle, S., Hallman, G., Gould, W. and Chew, V. 1989c. Immersion of Florida mangoes in hot water as a quarantine treatment for Caribbean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 82, 186–188.

Sharp, J.L., Ouye, M.T., Ingle, S.J., Hart, W.G., Enkerlin, H., Celedonio, H., Toledo, H.J., Stevens, A.L., Quintero, E., Reyes, J. and Schwarz, A. 1989a. Hot water treatment for mangoes from the State of Chiapas, Mexico, infested with Mediterranean fruit fly and *Anastrepha serpentina* (Wiedemann) (Diptera: Tephritidae). Journal of Economic Entomology, 82, 1663–1666.

— 1989b. Hot water treatment for mangoes from Mexico infested with Mexican fruit fly and West Indian fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 82, 1657–1662.

Sharp, J.L., Ouye, M.T., Thalman, R., Hart, W., Ingle, S. and Chew, V. 1988. Submersion of Francis mango in hot water as a quarantine treatment for the West Indian fruit fly and the Caribbean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 81, 1431–1436.

Sharp, J.L. and Picho-Martinez, H. 1990. Hot water quarantine treatment to control fruit flies in mangoes imported into the United States from Peru. Journal of Economic Entomology, 83, 1940–1943.

Simmons, E.G. 1967. Typification of *Alternaria, Stemphylium* and *Ulocladium*. Mycologia, 59, 67–92.

Simmonds, J.H. 1941. Latent infection in tropical fruit discussed in relation to the part played by species of *Gloeosporium* and *Colletotrichum*. Proceedings of the Royal Society of Queensland, 52, 92–100.

— 1966. Host index of plant diseases in Queensland. Brisbane, Queensland Department of Primary Industries.

Siriphanich, J. 1994. Minimal processing of tropical fruit. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 127–137.

Slabaugh, W.R. and Grove, M.D. 1982. Postharvest diseases of bananas and their control. Plant Disease, 66, 746–750.

Smoot, J.J. and Melvin, C.F. 1963. Hot water as a control for decay of oranges. Proceedings of the Florida State Horticultural Society, 76, 322–327.

Smoot, J.J. and Segall, R.H. 1963. Hot water as a postharvest control of mango anthracnose. Plant Disease Reporter, 47, 739–742.

Snowdon, A. 1990. A colour atlas of post-harvest diseases and disorders of fruits and vegetables, volume 1. Fruits and general introduction. Wolf Scientific.

— 1992. A colour atlas of post-harvest diseases and disorders of fruits and vegetables, volume 2. Vegetables. Wolf Scientific.

Sommer, N.F. 1985. Strategies for control of postharvest diseases of selected commodities. In Kader, A.A., et al., ed., Postharvest technology of horticultural crops. Cooperative Extension, University of California, Division of Agriculture and Natural Resources, 75–82.

Sommer, N.F., Fortlage, R.J. and Edwards, D.C. 1992. Postharvest diseases of selected commodoties. In: Kader, A.A., ed., Postharvest technology of horticultural crops, 2nd ed. University of California, Division of Agriculture and Natural Resources, Publication 3311,117–160.

Spalding, D.H. 1982. Resistance of mango pathogens to fungicides used to control postharvest diseases. Plant Disease, 66, 1185–1186.

Spalding, D.H. and Reeder, W.F. 1972. Postharvest disorders of mangoes as affected by fungicides and heat treatments. Plant Disease Reporter, 56, 751–573.

— 1985. Effect of hot water and gamma radiation on postharvest decay of grapefruit. Proceedings of the Florida State Horticultural Society, 98, 207–208.

— 1986. Decay and acceptability of mangoes treated with combinations of hot water, imazalil, and γ-radiation. Plant Disease, 70, 1149–1151.

Spalding, D.H., Vaught, H.C., Day, R.H. and Brown, G.A. 1969. Control of blue mold rot development in apples treated with heated and unheated fungicides. Plant Disease Reporter, 53, 738–742.

Spitler, G.H., Armstrong, J.W. and Couey, H.M. 1984. Host status of commercial lemon. Journal of Economic Entomology, 77, 1441–1444.

Sproul, A.N. 1976. Disinfestation of Western Australian Granny Smith apples by cold treatment against the egg and larval stages of the Mediterranean fruit fly *Ceratitis capitata*. Australian Journal of Experimental Agriculture and Animal Husbandry, 16, 280–285.

Sugar, D. and Spotts, R.A. 1986. Effects of flotation salt solutions on spore germination of four decay fungi and on side rot of pear. Plant Disease, 70, 1110–1112.

Sugimoto, T., Furusawa, K. and Mizobuchi, M. 1983. The effectiveness of vapor heat treatment against the oriental fruit fly *Dacus dorsalis* Hendel, in green peppers and fruit tolerance to treatment. Research Bulletin of the Plant Protection Service of Japan, 19, 81–88.

Sunagawa, K., Kume, K., Ishikawa, A., Iwaizumi, R., Sugimoto, T. and Tanabe, K. 1989. Papaya (*Carica papaya*) vapor heat treatment—lethal effect on *Dacus cucurbitae* and thermal injury to fruits. Research Bulletin of the Plant Protection Service of Japan, 25, 23–30.

Sunagawa, K., Kume, K., Ishikawa, A., Sugimoto, T. and Tanabe, K. 1988. Efficacy of vapor heat treatment for bitter momordica fruit infested with melon fly, *Dacus cucurbitae* (Coquillett). Research Bulletin of the Plant Protection Service of Japan, 24, 1–5.

Sunagawa, K., Kume, K. and Iwaizumi, R. 1987. The effectiveness of vapor heat treatment against the melon fly, *Dacus cucurbitae* Coquillett, in mango and fruit tolerance to the treatment. Research Bulletin of the Plant Protection Service of Japan, 23, 13–20.

Sutton, B.C. 1980. The Coelomycetes. Kew, U.K., CAB International.

— 1992. The genus *Glomerella* and its anamorph *Colletotrichum*. In Bailey, J.A. and Jeger, M.J., ed., *Colletotrichum:* biology, pathology and control. Wallingford, U.K., CAB International, 1–26.

Teitel, D.C., Aharoni, Y. and Barkai-Golan, R. 1989. The use of heat treatments to extend the shelf life of 'Galia' melons. Journal of Horticultural Science, 64, 367–372.

Thomas, P. 1985. Radiation preservation of foods of plant origin. III. Tropical fruits: bananas, mangoes and papayas. CRC Critical Reviews in Food Science and Nutrition, 23, 147–205.

Thompson, A.K. 1994. Preharvest fungicidal sprays for postharvest disease control. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 169–171.

Thompson, A.K., Been, B.O. and Perkins, C. 1974. Storage of fresh breadfruit. Tropical Agriculture, 51, 407–415.

Tongdee, S.C. 1994. Sulphur dioxide fumigation in postharvest handling of fresh longan and lychee for export. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruit. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 186–195.

Uecker, F.A. 1988. A world list of *Phomopsis* names with notes on nomenclature, morphology and biology. Berlin, J. Cramer, Mycological Memoirs No 13.

Unahawutti, U., Chettanachitara, C. Poomthong, M., Komson, P., Smitasiri, E., Lapasathukool, C., Worawisitthumrong, W., and Intarakumheng, R. 1986. Evaluation of vapor heat treatment for control of the oriental fruit fly and the melon fly in 'Nang Klarngwun' mango. Bangkok, Thailand, Department of Agriculture, Technical Report, 106 p.

Unahawutti, U., Poomthong, M., Intarakumheng, R., Worawisitthumrong, W., Lapasathukool, C., Smitasiri, E., Srisook, P. and Ratanawaraha, C. 1992. Vapor heat as plant quarantine treatment of 'Nsg. Klarngwan', 'Nam Dorkmai', 'Rad' and 'Pimsen Daeng' mangoes infested with fruit flies (Diptera: Tephritidae). Chatuchak, Bangkok, Thailand, Department of Agriculture, Technical Report, 64 p.

Underhill, S.J.R., Bagshaw, J., Prasad, A., Zauberman, G., Ronen, R. and Fuchs, Y. 1992. The control of lychee (*Litchi chinensis* Sonn.) postharvest skin browning using sulphur dioxide and low pH. Acta Horticulturae, 321, 721–741.

USDA (United States Department of Agriculture) 1989. Use of irradiation as a quarantine treatment for fresh fruit of papaya from Hawaii. U.S. Federal Register, 54, 387–393.

Vijaysegaran, S. 1994. Preharvest fruit fly control: strategies for the tropics. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., 1994. Postharvest handling of tropical fruits. Proceedings of an international conference held at Chiang Mai, Thailand, 19–23 July 1993. ACIAR Proceedings No. 50, 288–303.

Visarathanonth, N. and Ilag, L.L. 1987. Postharvest disorders of rambutan. In Lam, P.F. and Kosiyachinda, S., ed., Rambutan, fruit development, postharvest physiology and marketing in ASEAN. Kuala Lumpur, Malaysia, ASEAN Food Handling Bureau, 51–57.

Von Windeguth, D.L., Arner, A., Owens, J.B. and Burditt, A.K. 1976. Comparison of natural field infestation versus laboratory infestability of 'Marsh' white grapefruit by Caribbean fruit fly *Anastrepha suspensa* (Loew). Proceedings of the Florida State Horticulture Society, 89, 248–249.

Von Windeguth, D.L. and Gould, W.P. 1990. Gamma irradiation followed by cold storage as a quarantine treatment for Florida grapefruit infested with Caribbean fruit fly. Florida Entomologist, 74, 242–247.

Wadley, F.M. 1949. Dosage–mortality correlation with number treated estimated from a parallel sample. Annals of Applied Biology, 36, 196–202.

Wardlaw, C.W. 1972. Banana diseases including plantain and abaca. London, Longmans.

Waterhouse, G.M. 1963. Key to the species of *Phytophthora* De Bary. Mycological Papers, 92, 1–22.

Wells, J.M. 1972. Heated wax-emulsions with benomyl or 2, 6-dichloro-4-nitroaniline for control of postharvest decay of peaches and nectarines. Phytopathology, 62, 129–133.

Wells, J.M. and Stewart, J.K. 1968. Heat pasteurization and chemical fungicides for control of fusarium rot of California cantaloups. Plant Disease Reporter, 52, 262–264.

Whiteside, J.O., Garnsey, S.M. and Timmer, L.W. 1988. Compendium of citrus diseases. St Paul, MN, APS Press.

Wilson, C.L., El Ghaouth, A., Chalutz, E., Droby, S., Stevens, C., Lu, J.Y., Khan, V. and Arul, J. 1994. Potential of induced resistance to control postharvest diseases of fruits and vegetables. Plant Disease, 78, 837–844.

Wilson, C.L. and Wisniewski, M.E., ed. 1994. Biological control of postharvest diseases: theory and practice. Boca Raton, Florida, CRC Press.

Wong, L.S.W., Jacobi, K.K. and Giles, J.E. 1991. The influence of hot benomyl dips on the appearance of cool stored lychee (*Litchi chinensis* Sonn.) Scientia Horticulturae, 46, 245–251.

Worthington, J.T. and Smith, W.L. 1965. Postharvest decay control of red raspberries. Plant Disease Reporter, 49, 783–786.

Zauberman, G., Ronen, R., Akerman, M. and Fuchs, Y. 1990. Low pH treatment protects litchi fruit color. Acta Horticulturae, 269, 309–314.

Seafood Products

Postharvest Technology of Seafood Products

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Abstract

Postharvest fishery losses can play a significant role in determining the availability of fresh and processed seafood products, especially for lower income groups in tropical countries. Within the past 25 years fishery production has increased substantially throughout the world, and is now 100 Mt/year. However, population increases and the inability to control seafood postharvest losses that probably average over 30% mean that fishery landings from marine and freshwater areas, including aquaculture, will need to be increased, or losses reduced and utilisation improved, if current per capita consumption is to be maintained.

This paper summarises developments in postharvest technology of seafood relevant to developing countries with a tropical climate. Improvements in handling and processing techniques, quality considerations, waste utilisation, and training needs are highlighted. Fresh, cured, frozen, canned, and fermented fish products are discussed, with particular reference to strategies that may reduce postharvest losses and thus better utilise resources. Developments in postharvest technology of seafoods that have been examined since the International Workshop on Fishery Losses held in the USA in 1987 are reviewed.

THE total world catch of fish and marine invertebrates (molluscs, crustaceans etc.) is about 100 Mt, of which only about 20% is processed for food use. Of the latter about 30% is consumed while the remainder is discarded as waste from which some by-products are recovered (Shahidi and Botta 1994). Many small, ugly, or odd-shaped species are underutilised, as are others because of deficiencies in colour, flavour, or texture. These are often converted into fish oils and fish meal, or silage, concentrates, hydrolysates, and fermented foods such as sauce or paste. Some underutilised species in recent years have been converted into surimi-like products in which bland, colourless protein products are coloured and flavoured to suit specialised markets.

Seafoods are generally highly nutritious, with significant protein contents (12–26%) and levels of polyunsaturated fatty acids which contribute to health benefits for human nutrition. However, these attributes also contribute to significant spoilage and quality changes during postharvest handling, processing, and storage. Some seafoods are also susceptible to significant microbiological contamination from bacterial, viral or algal sources, and the public health safety of products such as molluscan shellfish is under increasing pressure due to anthropogenic pollution or environmental changes that lead to algal blooms.

Aquaculture of fish, shrimp, and other seafood products has increased dramatically in the past 10 years, coinciding in some cases with depletion of natural stocks of marine species. If per capita consumption of seafoods is to increase, or even be maintained at current levels, considerable attention will have to be placed on the reduction of losses during the postharvest chain by application of appropriate technologies, and on the better utilisation of existing resources by the innovative development of new products for increasingly sophisticated markets.

In the lesser developed countries, the principal emphasis will be on the development of some simple technologies, as well as the application of existing knowledge and technologies, and their implementation at a level which is culturally and sociologically acceptable and manageable. The high ambient temperatures and humidities, lack of infrastructure and equipment (such as refrigerated transport and storage facilities), and in many cases product handling and processing by untrained or inadequately trained per-

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sonnel represent major stumbling blocks to the maintenance of high quality of seafoods. This invariably results in the processing of poor quality raw materials into a range of more shelf-stable products by drying, curing, or fermenting, while higher quality raw materials are used for canning and freezing into products destined for export and invariably beyond the purchasing capacity of the lower income groups in the population.

Postharvest losses in traditionally processed fishery products are substantial yet often poorly documented (Poulter et al. 1988). In products such as cured or salted and dried fish, losses are due to decreased nutrient availability, as a result of oxidation and browning reactions, physical and sensory losses due to insect attack, and economic losses due to product fragmentation, quality downgrading, and spoilage by a variety of mechanisms. From our studies on the dried fish industry in Indonesia over the past 10 years it is abundantly clear that much fish used for salting and drying is initially only of low to medium quality by comparison with quality standards for fresh fish, but this appears to be acceptable to the market since about 60% of the consumers either cannot afford higher quality and hence higher price products, or they are used to and expect dried products of a quality less than what we would regard as optimum. Under these conditions, significant changes to postharvest handling practices may not only be resisted but also discouraged since the existing handling and processing practices are regarded as acceptable to significant markets. The increasing urbanisation of the population, and the availability of higher incomes as development expands, may lead to substitution of traditionally processed products by fresh seafoods or other animal protein foods (e.g. beef, pork, poultry), rather than by higher quality dried salted fish.

Irrespective of the type of seafood, current losses are high and unacceptable, and any applications of postharvest technologies to reduce such losses will become increasingly important.

Quality of Postharvest Seafoods

The overall quality of seafood products involves both sensory properties and those which are related to wholesomeness. Wholesomeness is affected by the chemical composition of the product (e.g. protein, lipid) and its changes during storage, by the presence of physiologically objectionable compounds of endogenous or environmental origin (e.g. toxins, pollutants), and by bacterial, viral, and parasitic contamination (Sikorski and Sun Pan 1994).

The initial sensory quality of seafoods is related to species, growing area conditions, fishing/harvest techniques, and seasonal biological changes in muscles and other organs, and is then influenced by postharvest storage and processing conditions, principally temperature and time. Sensory quality covers taste, texture, odour, and colour, and each is important for particular products. Maintenance of quality requires a full appreciation of all factors affecting it, and the means to achieve required controls.

Principal Chemical and Biochemical Mechanisms of Seafood Deterioration

The maintenance of quality of seafoods and seafood products is inextricably linked to biochemical and chemical changes in the major constituents (proteins, lipids), and in the microbiological quality of the raw materials or of the waters from which they are harvested. I will briefly examine desirable and undesirable changes in proteins and lipids in seafoods, since control of these is critical if quality is to be maintained. The principal sources of microbiological contamination also will be examined, and means of control outlined.

Biochemical changes in proteins

Proteins in seafood products are subject to significant changes during postharvest storage, processing, and spoilage, and the proteinases responsible for such changes have also been extensively studied (Haard 1994). Hydrolysis of proteins is responsible for both beneficial and detrimental changes to the quality of seafoods.

Quality improvement

Protein hydrolysis by tissue or endogenous enzymes can result in desirable changes to the aroma, texture, taste, and colour of seafoods in traditional fermented foods such as sauces and pastes, and in mildly salted fish. Digestive proteolytic enzymes are increasingly used as processing aids for both seafood and non-seafood products (Haard 1992). Work in our laboratory is examining the utilisation of tropical fish viscera by conversion into protein hydrolysates and silage. The properties of proteases from tropical fish are currently of some interest, as most of the previous work has been conducted on enzymes from fish of temperate waters, and the differences may be of commercial relevance.

Quality deterioration

During postharvest storage of fish, crustaceans, and shellfish, endogenous proteinases and other enzymes cause significant losses of quality during both iced and un-iced storage, not only in flavour and odour but also in texture. Proteinases from the spoilage microflora also contribute to significant changes, especially during the later stages of spoilage. Rapid reduction in temperature by refrigeration or icing generally is critical in reducing the activity of tissue enzymes and of the spoilage flora. Other factors of importance are the hygiene and sanitation of fishing vessels and processing plants.

Seafood lipids and lipid oxidation

Seafood lipids have both positive and negative attributes regarding nutrition and quality (Ackman 1994). Fish vary in lipid content from less than 1% to over 20%, and the lipids are characterised by a high content of C20 (eicosapentaenoic, 20:5, n-3) and C22 (docosahexaenoic, 22:6, n-3) omega-3 fatty acids. Tropical fish tend to be quite lean, while those from colder waters often contain more fat, although tropical sardines (e.g. *Sardinella longiceps*, Indian oil sardine) can contain fat contents greater than 25% at certain times of the year or phase of the life cycle. These fatty acids appear to benefit the human vascular system and modify the adhesive properties of blood platelets.

Seafoods contain high lipid levels in certain organs (e.g. in the liver of cod, and under the skin of mackerel) while the lean muscle generally contains less than 1% fat. For fish that contain light and dark muscles, fat contents vary seasonally and are higher in the dark muscle, and this can affect storage stability of processed seafoods.

Lipid oxidation is a major cause of quality deterioration in seafood, because of the lipid content *per se* and the extent of polyunsaturation (Hultin 1994). Catalysts for lipid oxidation are molecular and singlet *oxygen*, *metals* such as iron and copper, and *enzymes* such as lipoxygenase. In biological systems, molecular oxygen is relatively unreactive until transformed into superoxide, hydrogen peroxide, or hydroxyl free radicals, which can and do interact with unsaturated fatty acids to initiate lipid oxidation. Iron is present in tissues, especially dark muscle, in haem proteins (myoglobin and hemoglobin), in soluble proteins such as ferritin which store iron for later use, and as ferrous iron complexed to a variety of low molecular weight compounds.

While these pro-oxidant systems are present in fish tissues, inhibitors of lipid oxidation are also present, e.g. enzymes — superoxide dismutase, catalase and peroxidases, iron chelators, ascorbate and other free radical scavengers, and lipid-soluble tocopherols and carotenoids.

Lipid oxidation post-mortem

Post-mortem changes in fish muscle related to lipid oxidation are significant, as shown in Table 1 (Hultin 1994). The changes listed make the tissue more susceptible to oxidation, especially through changes in membranes.

Processing changes

In addition, processing of seafood products into fillets, minces, and extracts can increase lipid oxidation by exposing more lipid to oxygen, and by the heat destruction of antioxidants such as tocopherols. However, enzymes also play a significant role in lipid oxidation and their destruction is helpful. Salt is generally known to accelerate lipid oxidation, hence lightly salted seafood products oxidise faster than unsalted products.

Inhibiting lipid oxidation

Considering all of the changes that can occur in seafood lipids during postharvest handling and storage, the principal strategies required to reduce lipid oxidation to a minimum include reducing oxygen access (e.g. vacuum packaging or glazing), maintaining natural antioxidants or by adding antioxidants during processing, minimising increases in pro-oxidants (e.g. iron), maintaining low temperature, minimising the use of salt consistent with taste and stability, and removing unstable lipids (e.g. subcutaneous fat) and dark muscle. More knowledge of the mechanisms of control of lipid oxidation in intact tissues (i.e. fresh seafoods) will assist in developing practical procedures for the control of this problem in processed and stored products (Hultin 1994).

Microbiological Quality of Postharvest Seafoods

Considerable information is available on the microbiological quality of a variety of seafoods at the point of harvest and during distribution and sale (Ward and

Table 1. Changes in post-mortem fish muscle related to lipid oxidation.

Decrease in ATP
Increase in ATP breakdown products, e.g. hypoxanthine
Change in xanthine dehydrogenase to xanthine oxidase
Loss of reducing compounds, e.g. ascorbate, glutathione
Increase in content of low molecular weight transition metals
Conversion of haem (Fe II) pigments to oxidised form (Fe III)
Loss of structural integrity of membranes
Loss of antioxidants in membranes, e.g. tocopherols
Inability of muscle cell to maintain calcium gradients

Source: Hultin (1994).

Hackney 1991). The microbial flora at harvest is determined by the nature of the seafood and the quality of the water, with some differences observed between tropical and temperate species, while the temperature of storage is the predominant determinant of shelf life.

Hazard analysis critical control point concepts in seafood processing

There is now considerable impetus for the introduction of hazard analysis critical control point (HACCP)-based procedures for monitoring the microbiological quality and hence public health safety of seafood products (Huss 1992). Microbiological quality is not only associated with other aspects of quality and shelf life, but microbiological criteria are an important component of many current import and export standards that are difficult to implement and increasingly failing to reduce public health problems.

Huss (1992) has summarised the hazard analysis of fresh and frozen fish and crustaceans (Table 2).

Critical control points (CCPs) can be established for most of the hazards, of which some can be controlled and others minimised. Large scale pollution (faecal) or the presence of biotoxins requires regional or national monitoring by governments and assessments by specialised laboratories.

Adherence to good manufacturing practices (GMP) by proper sanitation and hygiene in factories will minimise bacterial contamination, and temperature control will limit growth. Sensory assessments before processing can ensure spoiled product is excluded.

HACCP systems can be applied both to large-scale modern seafood processing plants and to more traditional processes in which there are public health risks. However, its application requires knowledge of the principles by both industry personnel and regulatory agencies, and also methods for its assessment and implementation. However, at the traditional as well as the sophisticated ends of the spectrum, it is clear that a thermometer, a watch, and common sense can have a far greater impact than detailed laboratory examinations for a range of microbiological contaminants. This again highlights the critical role of trained technologists in assuring adequate shelf life and safety of seafoods (Huss 1989).

Microbial hazards

Microbial hazards of seafood consumption are primarily associated with uncooked shellfish and certain tropical reef fish that become contaminated with toxins derived from dinoflagellates. The principal agents of seafood-borne disease are shown in Figures 1–4, and include seafood toxins, bacteria (e.g. *Vibrio cholerae, V. parahaemolyticus, V. vulnificus, Listeria monocytogenes*) and viruses (e.g. Norwalk) (Wekell et al. 1994). Seafood toxins are derived from toxic phytoplankton and possibly toxin-producing bacteria which have become increasingly of concern to public health agencies throughout the world (Liston 1990; Wekell and Hungerford 1994).

Table 2. Hazard analysis of fresh and frozen fish and crustaceans.

Organism/component of concern	Hazard		Severity	Risk
	Contamination	Growth		
Pathogenic bacteria:				
Aquatic environment		+	high/low	low/NR[a]
From humans/animals	(+)	+	high	low
Biogenic amine producers		+	low	high
Spoilage bacteria	+	+	low	high
Parasites	+		low	low/NR
Biotoxins	+		high	high/NR[b]
Viruses	+		high	low/NR[b]

NR no risk
[a] Providing fish is cooked before consumption
[b] Depending on fishing area, local condition and season
Source: Huss (1992).

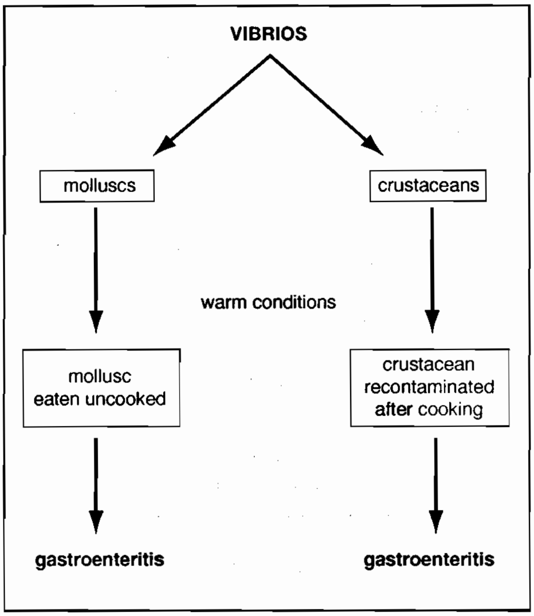

Figure 1. Microbial hazards from vibrios.

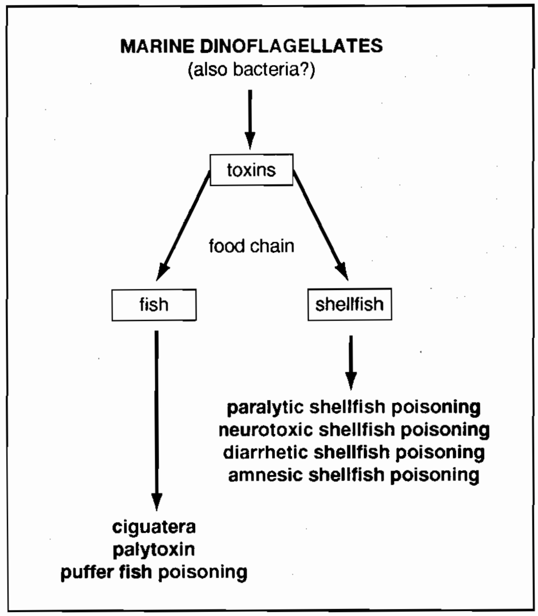

Figure 3. Microbial hazards from toxic dinoflagellates.

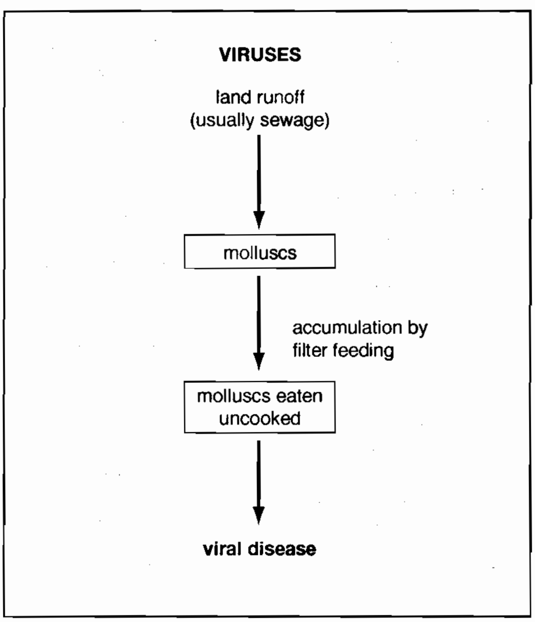

Figure 2. Microbial hazards from viruses.

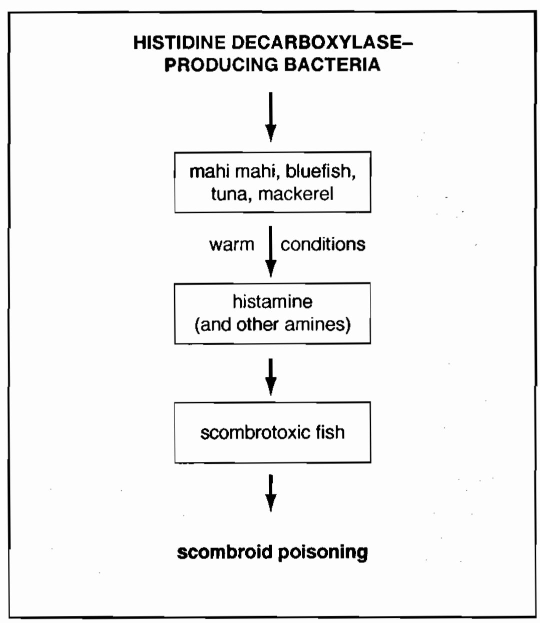

Figure 4. Microbial hazards from biogenic amines.

Vibrios are marine organisms naturally associated with marine and estuarine waters and hence with fish and especially shellfish. *V. cholerae* is spread by both contaminated food and water and is a serious cause of illness. *V. vulnificus* has more recently been associated with morbidity and mortality from shellfish, especially raw oysters, and considerable research is in progress regarding its accumulation and release during processes such as oyster depuration. It can cause both enteritis and severe wound infections. *V. parahaemolyticus* is more commonly associated with outbreaks of food-borne disease derived from contaminated cooked seafoods.

Viral agents probably account for most of the unknown causes of seafood illness not related to toxic algal blooms, and are still of considerable concern. Modern methods including PCR and other specific probes can detect specific viruses in hours and will assist in tracing causes of seafood-borne illness.

There are several *toxin-related seafood problems* (Hall 1991). *Ciguatera* poisoning is derived from the consumption of certain tropical reef fish which take up ciguatoxin produced by the dinoflagellate *Gambierdiscus toxicus* that often grows near tropical seaweeds. *Paralytic shellfish poisoning* (PSP) is a potentially lethal syndrome caused by up to 17 saxitoxins produced by the dinoflagellates *Alexandrium catenella, Pyrodinium bahamense, Gymnodinium catenatum,* and *Gonyaulax polyedra,* and possibly by bacteria such as *Moraxella* and *Bacillus. Amnesic shellfish poisoning* (ASP) is caused by a neurotoxic amino acid, domoic acid, produced by the diatom *Nitschia pungens* f. *multiseries* and retained by shellfish such as mussels. *Diarrhetic shellfish poisoning* (DSP) is caused by consumption of lipophilic compounds including okadaic acid accumulated by shellfish contaminated by the dinoflagellates *Dinophysis* and *Prorocentrum. Neurotoxic shellfish poisoning* (NSP) results from red tide blooms of the dinoflagellate *Ptychodiscus* (or previously *Gymnodinium) brevis* that produce a range of brevetoxins. *Scombroid* poisoning results from the consumption of certain species of fish containing high levels of free histamine or other biogenic amines that are produced microbiologically by decarboxylation of histidine and other amino acids as a result of severe time–temperature abuse. *Pufferfish* poisoning is caused by tetrodotoxins and related compounds produced by symbiont bacteria associated with pufferfish or fugu.

At the 1st International Conference on Molluscan Shellfish Safety which I hosted at The University of New South Wales, Sydney, Australia on 13–17 November 1994, the public health importance of toxic algae, viruses, and *V. vulnificus* was again reinforced. Significant efforts will need to be directed to these problems in the future if shellfish, in particular, are to continue to be an important seafood item. Increasing water pollution caused by industrialisation and coastal development will put increasing pressure on harvest areas in many countries, including Vietnam.

Postharvest Preservation Technology of Seafoods

Chilling

Chilling to 0°C in ice or refrigerated areas is an essential requirement for quality retention for most seafoods. Unsatisfactory catching conditions and handling practices can severely decrease shelf life, and a range of requirements has been formulated by FAO and other bodies to achieve this end. Reduced temperatures decrease microbial growth as well as the rate of endogenous enzymes, and storage at –2° to –4°C is better than at 0°C or 2–5°C from a microbial point of view, but not necessarily from a quality point of view due to toughening and autolytic changes such as lipid hydrolysis.

Shelf life may be extended further by the use of sorbate (e.g. shucked scallops) or sulfite (e.g. shrimp, for black spot inhibition) dips, or by the use of modified atmospheres using enriched CO_2 levels, providing the temperature does not exceed 3°C to ensure inhibition of *Clostridium botulinum* type E. Irradiation at levels of 1–3 kGy can extend significantly the shelf life of fish and other seafoods stored at up to 3°C. Possible sensory deterioration and changes in the microbial spoilage flora are impediments to its wider use, as are regulatory controls on irradiation in many countries.

Suitable packaging at both the wholesale and retail levels is obviously important.

Freezing and frozen storage

Storage temperatures of frozen seafood should be lower than –12°C, and ideally –18° to –30°C. Quality of frozen seafoods depends on initial quality, rate of freezing, temperature and time of storage, and protection against desiccation and oxidation. Very slow freezing generally produces textural changes leading to increased drip, toughness, and colour changes, and thus freezing should be as rapid as practicable. Protection against subsequent drying out by packaging or glazing will retain sensory quality. Factors affecting freezing damage include moisture and hence fat contents, and lipid oxidation-related reactions involving both lipids and proteins. Cryoprotectants can inhibit some freezing damage in formulated surimi products and some minces.

Salting and drying

A reduction in the water activity (a_w) of flesh tissues by salting and/or drying decreases or prevents microbial growth and preserves seafoods for varying periods. Many seafoods are dried to some extent and the practice is still widespread throughout the world. Drying is probably the first preservation technique applied to fishery products, yet significant losses still occur in salted and dried fish, with estimates of 30% still reported. Principal causes are insects (blowflies, beetles), lipid oxidation, discoloration, and tissue fragmentation. Mould growth occurs but is not a major problem since toxigenic moulds grow only on higher moisture products in the absence of significant levels of salt.

A substantial ACIAR-funded project on fish drying in Indonesia developed a rice husk-fired furnace and drying chamber that, with modification, may find use in the drying of fish or other products when weather conditions are unsuitable for sun drying. The furnace shows promise as a source of significant heat for cooking or processing (Wibowo et al. 1993).

We have found dried fish quality in the markets of Indonesia to be very complex. Much of the product in the market place is of poor quality and is produced deliberately to satisfy market requirements. The technology and stability of many dried and cured fish products has been extensively reviewed by several authors, including James (1983) and Reilly and Barile (1986).

Smoking

Smoking has been used extensively in the past for the preservation of a range of seafood products, and their long shelf life is due to the low a_w, presence of salt, and the preservative action of smoke constituents. If the degree of smoking is reduced and hence the moisture content is increased, alternative preservation strategies or hurdles are required, including refrigeration, vacuum packaging, and nitrite.

Increased toxicological concern over smoked products has been due to the recognition that these foods may contain polycyclic aromatic hydrocarbons (PAH), some of which are known to be carcinogenic. Although foods other than smoked fish contain PAHs, there is interest in and a need to develop alternative smoking strategies to improve public health safety while maintaining sensory attributes.

The trend to light smoking conditions and the need for other preservation hurdles to maintain stability has been highlighted by recent outbreaks of listeriosis in New Zealand caused by the consumption of smoked mussels contaminated with the bacterium *Listeria monocytogenes*. Deaths of aborted foetuses occurred in pregnant women, and company personnel were charged.

Fermenting

Many traditional fermented fishery products are consumed in Asian countries, including fish sauces and pastes in Thailand, Vietnam, and Indonesia (Steinkraus 1983; Saisithi 1987). Their technology and detailed microbiology and biochemistry are not well known and understood in many cases, yet these products are of great importance to the gastronomic and cultural life of large populations in this region.

Canning

The heat processing of low-acid foods, including seafoods, in hermetically sealed containers is a well-understood and safe means of preserving a variety of seafoods, including fish, molluscs, and crustaceans. However, the technology is expensive and requires access to steel-based or other containers capable of being heat processed to temperatures above 110°C. The principal risks are from underprocessing that can lead to spoilage or intoxication by fatal toxins formed by *Clostridium botulinum* type E, or from post-processing contamination through leaky seams. Observations I made in Vietnam during the week before this workshop indicate that considerable training is required of some personnel working in some canneries if spoilage and public health dangers are to be reduced or avoided.

Seafood Wastes

Significant quantities of seafoods are spoiled, wasted, or badly utilised, and much still can be done to make current catches go further (Morrissey 1988). Shahidi (1994) has estimated that seafood processing discards account for about 75% of the total catch of seafoods caught for human consumption.

Shrimp by-catch is an important example of this and if by-catch cannot be handled more efficiently or converted on board into utilisable material, then catching methods may have to be amended to reduce unintentional catches.

Fish silage and hydrolysates are possible means of conversion of by-products into feeds for aquaculture or land animals. Principal by-products include offal, heads, frames, residual flesh, discards, shells, and spoiled or culled materials. Possible recovered materials include specific enzymes, antifreeze proteins, and omega-3 fatty acids, as well as established materials such as chitin and chitosan and carotenoid pigments. Recovery is more difficult when the greatest proportion of the catch is landed by small boats with inadequate facilities.

Fish wastes from canneries and other large processing plants may lend themselves to fermentation into traditional products such as pastes and sauces.

Training Needs

Any strategy implemented to reduce postharvest fishery losses must involve the training of appropriate personnel and the application of existing knowledge to reduce wastage. In developing countries, training programs must begin at the beach or the pond and involve all steps in the processing and marketing chains. Training programs should be both in-country and involve overseas visits so that methodologies and current practices can be examined and then implemented at the level desired.

Strategies to Reduce Seafood Losses and Improve Postharvest Technology Practises

At the International Workshop on Postharvest Fishery Losses held at the University of Rhode Island in 1987 (Morrissey 1988) a number of strategies were examined to guide researchers and policy personnel in reducing losses and improving postharvest technologies for seafoods. The major recommendations included the following. In many cases they are still valid, especially for developing countries, and hence are relevant to consider in the Vietnamese context.

Policy implementation

- Integrate development programs
- Back research activities, develop networks
- Train trainers and technologists
- Exchange information (workshops, seminars)
- Transfer technologies using appropriate agencies with experience in socioeconomic assessment

Fish handling

- Optimise handling for small fish in bulk
- Design boats, gear for this catch
- More studies on chilled sea water (CSW) to preserve catch
- Devise sorting systems for on-board storage, processing

Preservation

- More studies on composition
- Examine microflora and biochemistry of tropical fish
- Preserve small pelagics on board
- Examine rancidity in high fat species
- Optimise ice use on boat and land

Quality control, inspection

- Standardise sensory evaluation methodologies
- Develop instrumental quality assurance (QA) procedures
- Uniform international criteria
- Develop codes of GMP for tropical products
- Re-evaluate health risk standards for seafoods
- Develop standardised procedures for preparing export seafoods

Processing

Cured and Dried Products

- Define principles involved in each process
- Define product characteristics for consumer acceptance
- Assess materials for bulk packaging to exclude moisture and insects
- Review hygiene and sanitation practices for all processes

Canned Products

- Develop plastic containers and pouches as alternatives to metal cans

Frozen Products

- Examine freezing as alternative to canning
- Research stability of high fat products

New Products for Nutrition Enhancement and Resource Utilisation

- Enrich traditional products
- Undertake social marketing before product development
- Develop methodologies for measuring consumer acceptance
- Develop 'classless' products appealing to a range of socioeconomic levels

Training

- Address specific problems on a regional basis
- Train the trainers
- Develop training programs for national seafood inspection
- Expand extension services to identify problems
- Specialised courses in traditional fish processing, handling, sanitation and hygiene, and QA needed for developing countries.

Acknowledgment

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References

Ackman, R.G. 1994. Seafood lipids. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 34–48.

Haard, N.F. 1992. Enzymes from marine organisms as food processing aids. Journal of Aquatic Food Production Technology, 1(1), 17–35.

— 1994. Protein hydrolysis in seafoods. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 10–33.
Hall, S. 1991. Natural toxins. In: Ward, D.R. and Hackney, C.R., ed., Microbiology of marine food products. New York, Van Nostrand Reinhold, 301–330.
Hultin, H.O. 1994. Oxidation of lipids in seafoods. In: Shahidi, F. and Botta, J.R.. ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 49–74.
Huss, H.H. 1989. Microbiological quality assurance in the fish industry. INFOFISH International, 5, 36–37.
— 1992. Development and use of the HACCP concept in fish processing. International Journal of Food Microbiology, 15, 33–44.
James, D.G. 1983. Production and storage of dried fish. Proceedings of the Workshop, Universiti Pertanian Malaysia, Serdang, Malaysia, 2–5 November 1982. FAO Fisheries Report No. 279 Supplement.
Liston, J. 1990. Microbial hazards in seafood consumption. Food Technology, 44(12), 56–62.
Morrissey, M.T., ed. 1988. Postharvest fishery losses. Proceedings of an International Workshop, University of Rhode Island, Kingston, RI, 12–16 April 1987. Kingston, Rhode Island, International Center for Marine Resource Development.
Poulter, R.G., Ames, G.R. and Evans, N.J. 1988. Postharvest losses in traditionally processed fish products in less developed countries. In: Morrissey, M.T., ed., Postharvest fishery losses. Proceedings of an International Workshop, University of Rhode Island, Kingston, R.I., 12–16 April 1987. Kingston, Rhode Island, International Center for Marine Resource Development.
Reilly, A. and Barile, L.E., ed. 1986. Cured fish production in the tropics. Proceedings of a workshop, College of Fisheries, UP Visayas, Diliman, GTZ.
Saisithi, P. 1987. Traditional fermented fish products with special references to Thai products. ASEAN Food Journal, 3(1), 3–10.
Shahidi, F. 1994. Seafood processing by-products. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 320–334.
Shahidi, F. and Botta, J.R., ed. 1994. Seafoods: chemistry, processing technology and quality. London, Blackie Academic.
Sikorski, Z.E. and Sun Pan, B. 1994. Preservation of seafood quality. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 168–195.
Steinkraus, K.H., ed. 1983. Handbook of indigenous fermented foods. New York, Marcel Dekker.
Ward, D.R. and Hackney, C.R., ed. 1991. Microbiology of marine food products. New York, Van Nostrand Reinhold.
Wekell, M.M., Manger, R., Colburn, K., Adams, A. and Hill, W. 1994. Microbiological quality of seafoods: viruses, bacteria and parasites. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 196–219.
Wekell, M.M. and Hungerford, J.M. 1994. Microbiological quality of seafoods: Marine toxins. In: Shahidi, F. and Botta, J.R., ed., Seafoods: chemistry, processing technology and quality. London, Blackie Academic, 220–232.
Wibowo, S., Sari, A., Suherman, M., Poernomo, A. and Souness, R.A. 1993. Development of a fish drier using rice husk as a heat source. Liang, O.B., Buchanan, R.A. and Fardiaz, D., ed., Development of food science and technology in Southeast Asia. Proceedings of the 4th ASEAN Food Conference, Jakarta, Indonesia, 17–21 February 1992. Bogor, Institut Pertanian Press, 184–188.

Postharvest Technology of Seafood Products in Vietnam

Nguyen Van Le*

Abstract

In recent years, postharvest technology of marine products in Vietnam has made considerable advances. The sector has moved from one primarily producing low-quality products for domestic consumption to one geared towards exporting higher quality commodities, and is now making a significant contribution to Vietnam's economy.

MARINE products have been accorded a high priority in Vietnam for reasons of their capacity to earn foreign exchange, create employment, and improve the general nutrition of the population.

Fishing is a traditional occupation in Vietnam, but organised marine fisheries production began only in the 1960s. Much progress has been made in the past 30 years, greatly assisted by the renovation of Vietnam's economy.

After overcoming the most difficult period from 1976-1980, marine fisheries production has gradually increased since 1981. According to the 1994 report of the Ministry of Fisheries, total marine fisheries production reached 1.2 million t. Of this, 107600 t were exported, made up as follows:

- shrimp, 63100 t
- fin fishes, 26400 t
- frozen squid, 7200 t
- dry squid, 3300 t
- other products, 7600 t.

Major products for domestic consumption were fish sauce (150 ML) and fish powder (15000 t).

Total export earnings from marine fisheries products were US$458.2 million, an increase of 24–36% over 1993.

At present there are 164 processing plants for frozen seafood with a total capacity of 780 t of product per day, or 130–140000 t/year. There are 21 IQF in the whole country.

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Seafood processors have made great efforts to improve production facilities, especially in terms of sanitation, product quality and diversification, more efficient use of raw materials, and development of high-value products.

Nevertheless, conditions of storage and transportation of raw materials remain poor, resulting in postharvest losses estimated at 30–35% of the catch.

Procurement Methods

There are currently three main methods of purchase of fish for processing:

- a form of 'tender' at markets and river and beach landing sites;
- a form of contract from catching to processing; and
- according to either formal or informal advance contracts with fishermen.

Small traders can buy from the boats but the price is often determined by larger buyers and traders who offer higher prices to monopolise sources of supply during procurement.

Some companies follow a detailed contract procedure which permits better planning and collaboration between the production and processing sectors.

The normal contract system may seem to be price inefficient but it provides assurance of supply of raw materials for processing.

Storage and Transportation

To limit losses during transportation, including quality deterioration, processing facilities have been established near major fish-landing sites: examples are the

Halong canned fish plant in Haiphong, and frozen fish processing plant No. 34 in Vungtau (Dongnai).

Although Seaprodex plants No. 1 and No. 2 in Ho Chi Minh City are distant from the fish market, they have well-established contracts with fishing ports within a radius of 200 km and a transport network based on their own or sellers' trucks.

Some processing plants located near fish markets use simple forms of transport such as rickshaws and small trucks, may not use ice, and may procure from boats that do not have good storage facilities. In such cases, the quality of products falls markedly.

Processed Products

Export seafood products

Over the past 20 years the importance of marine products exports as earners of foreign exchange for Vietnam has steadily increased, and fisheries now comprise one of the country's leading economic sectors.

Frozen products make up the bulk of exported seafoods: 80% by quantity and 75% by value.

The main export product is shrimp, but there is a range of other commodities including: frozen, dry, and fried squid; frozen cuttlefish; frozen redfish and tuna; frozen fried mackerel, anchovy, and tuna; and frozen crab, tiger shrimp, fish fins, sea horse, etc. There are also many plants producing canned seafood, and products such as surimi and fish powder.

The marine products processing sector is now producing high-value products, appropriately and attractively packaged. Full advantage is being taken of all raw material sources, and postharvest losses have been reduced by exporting processed products.

Products for domestic production

During the past 10 years, the quantity and quality of marine products offered for domestic consumption have improved.

Production of high-value fishes consumed fresh—such as dalag, catfish, butterfish, and mackerel cod—has increased to meet rising demand. Traditional commodities such as shrimp sauce and natural flavoured fish sauce, and newer processed commodities such as instant spiced mixed cuttlefish, spiced mixed dry 'golden line' fish, and instant shrimp cakes, have been put into mass production to meet the growing requirements of consumers. In addition, ready-made fish products such as fried fish cake, fried fish, and surimi products have been attractive to local markets.

Other marine products of importance in the domestic market are agar-agar from seaweeds, and fish oil tablets.

Export Markets

The major markets for Vietnam's marine products are Japan, Singapore, and Hong Kong. Vietnam ranks fifth among countries exporting shrimp to Japan. Most shrimps exported to Japan are frozen and in 2 kg packages. Frozen shrimp and other marine products have been exported also to Australia, Canada, France, and the U.K.

It is estimated that Vietnam will earn about US$760 million from its marine products exports this year, and that returns will reach $US1 billion by the year 2000.

During the past 30 years, the fisheries sector in general, and postharvest technology of marine products in particular, have made steady progress. Because of the need to be self-supporting, processing plants have been active in all areas: procurement of raw materials, greater investment activity, expansion of production, and product diversification and quality improvement. The quality of export products, in particular, has improved markedly.

New markets are being sought in Europe and North America. To tap these, new, high-value products need to be developed, and this will require new and improved processing technologies for marine products.

Livestock and Livestock Products

Postharvest Handling and Storage of Livestock Products in Vietnam

Nguyen Van Hai*

Abstract

This paper gives a brief overview of livestock postharvest handling practices and problems in Vietnam. Research is needed to improve handling practices to reduce losses and improve the quality of product available to domestic consumers. Objectives are listed for a collaborative research project involving international support, to develop appropriate handling and storage practices for livestock and livestock products in Vietnam.

As part of the Government of Vietnam's policy to increase food production, livestock development has been targeted and the livestock herd has been expanding rapidly to meet the needs of domestic consumption and export marketing. Over the period 1990–1993 buffalo and cattle numbers increased by 9 and 95%, buffalo from 2.3 million to 2.6 million head, and cattle from 1.7 to 3.3 million head. The pig population increased by 49%, from 10.0 to 14.8 million head, and the poultry population by 117%, from 61.5 to 133.3 million birds. Numbers of other livestock have also increased.

Vietnamese animal producers and scientists are paying greater attention to the study and rearing of animal breeds that have high productivity and product quality, such as super meat duck, super egg chicken, super lean meat pig, etc. However, postharvest handling and storage technologies for livestock products are not well researched or endowed with appropriate facilities. More resources, financial and human, need to be invested in this area.

A major target should be to reduce losses occurring during transport of animals from farms to abattoirs. These losses are estimated to be 6–8% in pigs (occasionally 10%), 5–7% in chickens, and 8–10% in duck (occasionally 12–18%). The losses in buffalo and cattle are assumed to be higher. These losses reduce processors' incomes, so that they do not like buying animals in rural areas far from their slaughterhouses. This, in turn, limits exploitation of the full potential of production resources in rural areas.

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Handling and Storage Methods

Commercial

Although there are 24 slaughterhouses with total capacity of 64000 t/year, meat processing has not developed to any great degree in Vietnam. The bulk of the product of these units is frozen meat. Only ANIMEX (Haiphong) and VISSAN (Ho Chi Minh City) have processed significant amounts of product for local consumption, but they have commercial problems because consumers in Vietnam are used to buying raw rather than frozen meat.

Traditional

Most of the meat produced in Vietnam is consumed locally. Some 90% is manually processed by methods which differ from place to place.

In the plains, midlands, and coastlands, areas of high population, unprocessed meat and other livestock products are often sold in shops and markets under conditions of high temperature and humidity and lack of proper packaging and storage facilities. Meat rapidly spoils and becomes unfit for human consumption. Customers usually buy no more than two days requirement. In order to reduce quantitative and qualitative losses of meat, more attention should be given to livestock postharvest handling and storage, and to product packaging to meet the needs and financial capacity of consumers.

In sparsely populated and inaccessible mountainous areas, meat is processed for consumption within family or community. Minority groups have developed different methods of meat handling and storage. Cattle and buffalo meat are first dried over a wood fire and then smoked by hanging pieces of meat under the kitchen ceiling. Meat processed by this method can be kept for at least 5–6 months. Ham is preserved by salting and/or use of yeast in meat vats. However, the quality of meat processed by such means, and the losses of nutritional value etc. are unknown and should be investigated.

Different minority groups have their own methods of meat processing and preservation. All of these methods are practiced under ambient conditions and the quantity of meat preserved depends on the level of hygiene.

Current Research

During 1994, the Animal and Poultry Processing Research Centre undertook the following work.

- Investigations on the processing of poultry and smoked duck meat, in terms of food hygiene requirements, reduction of losses, and acceptability of the product to local consumers.
- Processing of by-products from slaughterhouses into animal feeds.
  - production of bone meal by combustion.
  - blood meal
  - animal hair meal and extraction of cysteine (amino acid).
- Environmental hygiene aspects of the waste water from meat processing treatment.

Studies of livestock and livestock products postharvest handling and storage are in their infancy in Vietnam, but improvements in these areas are essential to the government's economic policies.

Project Proposal

If international support were forthcoming, we would envisage implementing, in collaboration with specialists from Australia and elsewhere, a project to develop appropriate handling and storage practices for livestock and livestock products in Vietnam. Project objectives would be to:

- reduce livestock postharvest losses by studying and applying technology successful in other countries in the region and appropriate to circumstances in Vietnam;
- improve traditional methods of livestock handling and storage by minority groups in mountain areas, so as to reduce quality and quantity losses during processing;
- strengthen research capacity in the field of livestock postharvest handling and storage;
- develop a cooperation program on matters related to livestock postproduction activities; and
- organise training courses and seminars for scientists and others involved in this area.

Such a project would yield benefits to local and overseas researchers and to community development in Vietnam.

Recent Developments in ASEAN in Postharvest Handling of Livestock and Meat

G.I. Alexander*

Abstract

In the ASEAN countries, meat export industries have adopted procedures for animal handling and meat processing that conform to world standards. However, there has not been the same level of development on the domestic market. The catalyst for a number of recent advances in postharvest handling of livestock and meat for domestic consumption in ASEAN has been the ASEAN–Australia Postharvest Systems Improvement Project (AAPSIP). Within the ambit of this project, each ASEAN country developed improved methods of postharvest handling to meet their national priorities.

Livestock: Brunei Darussalam, Indonesia, and the Philippines examined sea transport of livestock; Indonesia and the Philippines studied land transport of cattle; the Philippines examined an alternative marketing system for livestock; and Indonesia studied land transport of goats. *Abattoir*: In abattoir handling of meat, Thailand, Brunei Darussalam, and Malaysia emphasised improvement of abattoir hygiene through upgrading facilities and training workshops; and Malaysia used training to introduce a system of total quality management into abattoir operations. *Transport*: Malaysia, Singapore, and Thailand investigated refrigerated meat transport; and Indonesia developed improved methods of meat transport for small provincial towns. *Retail handling*: Thailand introduced improved wet market stalls (pilot study) in a provincial city; Malaysia demonstrated an integrated system of stalls using refrigerated display and storage of meat in a wet market; Singapore placed emphasis on the cold-chain system from the abattoir through to retail; and Indonesia demonstrated an upgraded and more hygienic system of chicken slaughter and sale in wet markets.

THE current methods of postharvest handling of livestock and meat in ASEAN have provided fresh meat to the consumer as quickly as possible after slaughter, to reduce the degree of spoilage. This process has involved the transport of live animals over quite long distances to a slaughterhouse (or place of slaughter) close to the point of consumption. This lengthy transport and marketing chain results in weight loss and the risk of injury. Fortunately, the animals are used to proximity to people and to being handled frequently. Slaughter usually takes place in the early morning with sale at a wet market during the morning or, at the latest, the afternoon of the same day. Meat is seldom held over for sale the next day. After purchase, the consumer usually prepares the meat and commences cooking that morning.

At the traditional wet market, contaminating organisms may build up in numbers quite rapidly and may spoil the meat and become a threat to the health of the consumer. The practice of cooking meat soon after purchase and so destroying contaminants helps minimise problems. However, contamination still occurs and the spoilage organisms multiply rapidly if the meat is held at room temperature for any substantial period. All ASEAN countries recognise that changes have been occurring in the methods of marketing perishable products, with a general movement away from the established wet markets, and towards shopping centres and supermarkets. This movement is most pronounced in cities, where higher disposable household incomes, frequently due to two incomes in the household, result in a desire for greater convenience in meat and other food purchasing and preparation. Increasing availability of refrigerators means that householders are storing perishable purchases and keeping meat for some days before cooking.

With increasing meat consumption, refrigeration, and changes in eating patterns, greater opportunities exist for mishandling of meat, contamination of other foods, and the build-up of serious levels of patho-

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genic bacteria. Consequently, it is desirable to establish good handling practices for meat, because the problem can be greatly reduced by proper hygiene and timely and adequate refrigeration.

While the real extent of public health problems from the consumption of unhygienic meat is not known, there is no doubt that large numbers of consumers are expecting meat to be hygienically prepared so that it can be held under refrigeration. In addition, authorities consider that there is a need for improved presentation of meat to help increase consumption. Government officials responsible for veterinary public health in the various ASEAN countries recognise the problems and are moving to improve slaughtering and meat handling in general. Some of these measures were addressed in the Livestock Project of the ASEAN–Australia Postharvest Systems Improvement Project (AAPSIP), which ran from 1991 to 1994.

AAPSIP Livestock Project

The AAPSIP project was part of Phase II of the ASEAN–Australia Economic Cooperation Program (AAECP). Phase I of AAECP began work on reducing postharvest losses to increase the quality and quantity of food supply. Within the livestock sector, Phase I was concerned with establishing and upgrading facilities and increasing the technical knowledge of personnel in the handling of livestock and milk products. A number of improved abattoirs were established in Indonesia, Malaysia, Philippines, and Thailand. Phase II continued this process with projects aimed at improving livestock transport and handling post-farm, and meat handling to the point of retail sale.

Each ASEAN country designed a project to meet national priorities. However, these projects were also related and present a coherent program of measures to improve the postharvest handling of livestock and meat in ASEAN. In general, the projects were directed at transport and marketing of livestock, marketing of meat by smallholders, and supply of meat for local consumption, rather than for export where internationally accepted processing and meat inspection standards already apply.

There were four major components of the AAPSIP project:

- Improvement of transport and marketing of livestock, encompassing sea and land transport, pre- and post-transport care, selling systems and reporting of market information to farmers.
- Development of improved standards of slaughter and handling of meat, involving abattoir procedures, hygiene, and handling of meat at the abattoir, in store, and during transport.
- Improved facilities and methods for wholesale/retail handling of meat.
- Training of research, extension, and regulatory staff, and industry personnel.

Livestock Transport and Marketing

ASEAN countries that conducted studies under AAPSIP into the improvement of livestock transport and marketing were Indonesia, Brunei Darussalam, and the Philippines. The Philippines and Indonesia, being archipelagoes, were concerned with sea and land transport of livestock, with the Philippines placing additional emphasis on marketing. Brunei Darussalam, as an importer of livestock, was concerned with ensuring that the animals were slaughtered in as good condition as possible.

Sea transport (Indonesia)

Indonesia comprises 27 provinces and 296 districts distributed over 17 000 islands stretching 5100 km from west to east. Livestock are transported by ship and road to slaughtering establishments close to points of consumption in the larger cities and towns. The flow of livestock within Indonesia is from the production areas of Bali, West Nusa Tenggara (NTB), East Nusa Tenggara (NTT), and South Sulawesi, to Jakarta and West Java. Approximately 66% of cattle slaughtered in Jakarta come from East and Central Java and 33% from NTB/NTT, Bali, and the Sulawesi Islands. About 80% of livestock transported by sea is carried on sailing vessels (*perahu layar* or PL), motorised sailing vessels (*perahu layar motor* or PLM), or wooden motor vessels (*kapal motor* or KM). The remaining 20% is carried on steel motor vessels (KM). The PL and the PLM can carry between 50 and 150 head, while the larger KMs can accommodate more than 500 head. However, these vessels are designed for general cargo not for livestock, which is the least preferred cargo.

An earlier study of livestock transport concluded that short journeys of 1–5 days using the PLM seemed satisfactory and economical, but could be improved by making provision for better loading and unloading, ventilation, and types of pens for the stock (Fig. 1). Poor loading and unreliable schedules were also problem areas. Further examination of the situation by the Indonesian authorities led to the decision to concentrate on the PLM because they are smaller, and easier to ventilate and construct pens on for stock. Also, they are more flexible in that they can use smaller and shallower harbours. PLMs can have more frequent sailing schedules so that stock are not held for long periods pending shipment.

Portable panels (Fig. 2) and a reticulated drinking water system (Fig. 3) were tested on a PLM and compared with the usual system of bamboo pens with no

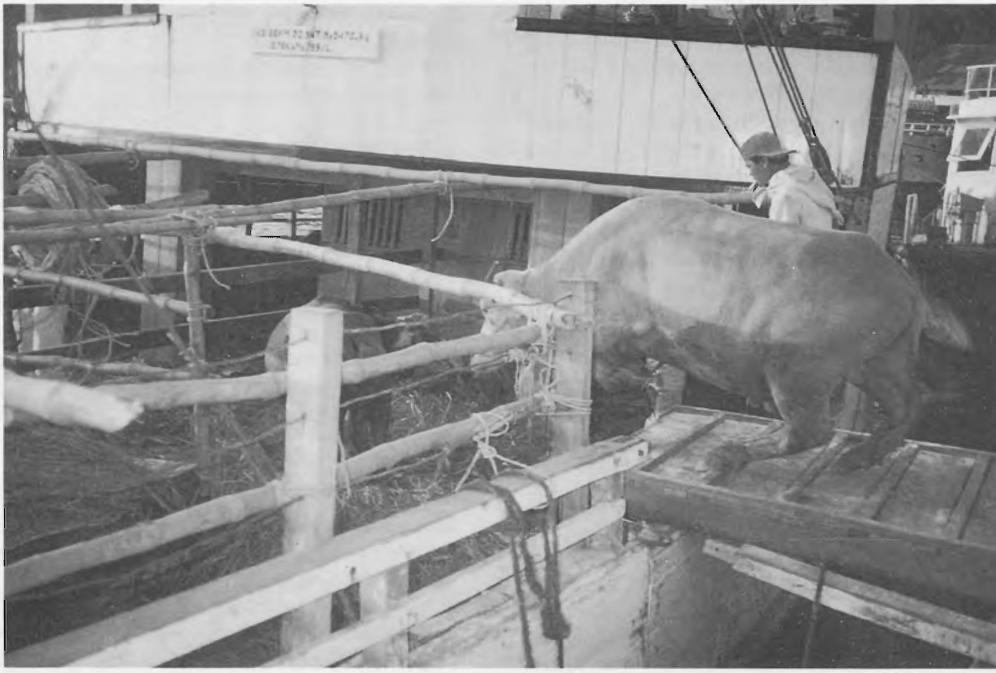

Figure 1. Loading a buffalo on to a conventional Indonesian motorised sailing vessel. Note that the animal was bracing itself to jump down into the hold of the vessel.

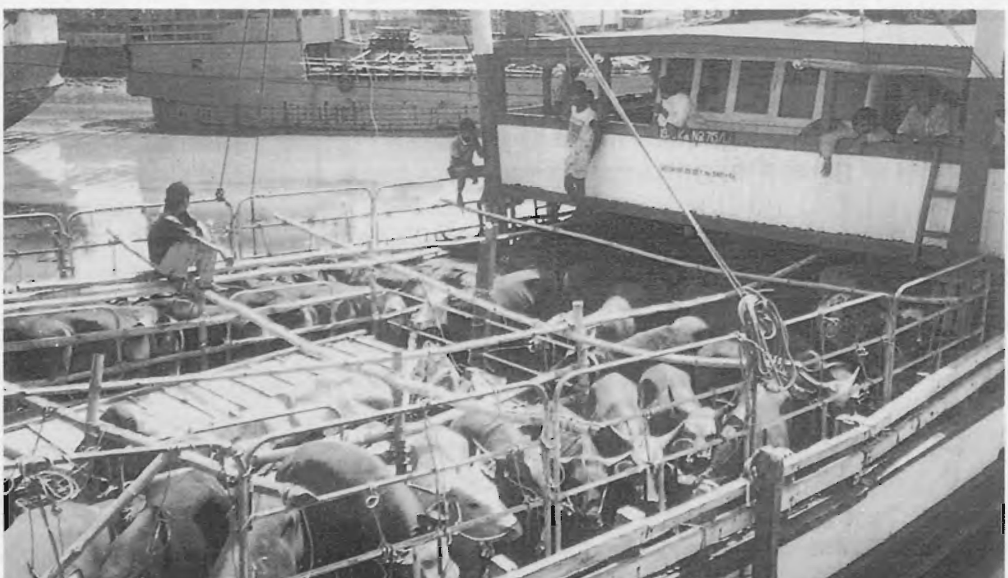

Figure 2. A modified Indonesian motorised sailing vessel on arrival at Surabaya with a load of cattle. The portable panels are used but have been supplemented by some bamboo rails. It is not possible to see the feeding troughs or the water supply.

water reticulation. A number of animals in each shipment were weighed to record weight changes. While the reduced weight loss in the limited number of animals which had reticulated water and which were weighed was not significant, the use of improved facilities resulted in a greater income per shipment than for conventional ships. In addition, the general condition of cattle being unloaded from the modified ship appeared to be better than those on the conventional ship. Modifications were also of benefit in normal cargo handling and many of the portable panels were used for other cargoes, facilitating the conversion of the ship to and from handling cattle and other cargoes.

Sea transport (Brunei Darussalam)

Cattle and buffalo are imported by Brunei Darussalam from northern Australia. The available data indicate that stock generally lose weight while in transit. When animals are injured during the voyage, this occurs mostly during unloading, as a result of the animals slipping and falling over when the unloading ramp is too high (at high-tide) and stress. During a voyage of 9 days, average weight losses of 3.4 kg for cattle and 2.6 kg for buffalo have been recorded. However, there is considerable variation, with weight gains in animals that eat and drink readily, to substantial losses in those animals that do not eat or drink readily. After arrival in Brunei Darussalam, the stock are held in feedlots for periods up to 2 months before slaughter (Fig. 4).

Because of the cost of imported pelleted fodder and the limited supply of locally produced feed, feeding is restricted to a level to minimise weight losses during the holding period before slaughter. Two experiments were conducted to determine the level of feeding which would prevent weight losses. Unfortunately, despite reasonably high feeding levels, many animals continued to lose weight, leading to the conclusion that only those animals that eat readily should be selected for longer term holding as these have the greatest chance of retaining their bodily condition over the holding period.

Road transport (Indonesia)

General purpose trucks are used in Java to transport live animals to abattoirs (Fig. 5). The trucks can carry 8–10 head of cattle and buffalo or, in two decks, 80–100 head of sheep and goats. Usually these trucks have been modified to carry stock, by using bamboo crates. After a study of the livestock road transport system in Java, a multipurpose crate system was designed for use with cattle, small ruminants, chickens, and general cargo (Figs 6 and 7) with the capability of loading through a side-gate or by a fold-down loading ramp built into the rear door, for use when no other loading ramps are available.

Figure 3. A modified Indonesian motorised sailing vessel before being set up for the receipt of cattle. A large water tank is evident in the forward part of the vessel with some portable panels along the sides.

Figure 4. Cattle held in a commercial holding facility before slaughter in Brunei Darussalam.

Figure 5. Buffalo about to be unloaded at the Mulaut Abattoir in Brunei Darussalam.

Figure 6. Goats being loaded on to the lower deck of the multipurpose livestock crate with chickens in bamboo crates on the upper deck. A traditional Indonesian truck was being loaded alongside the modified truck.

Figure 7. The modified livestock crate with the second deck removed for the transport of cattle in Indonesia.

The transport of cattle by road, in trucks of traditional Indonesian design, was compared with trucks of an Australian design over a distance of 780 km. The percentage of weight loss for the traditional truck (5.1%) was higher than the weight loss of cattle on the Australian-designed truck (4.5%). When the Australian-designed truck was compared with a traditional Indonesian truck for carrying goats, the percentage weight loss was higher for the traditional truck (11.1%) than for the Australian-designed truck (9.4%). When financial returns for the two types of vehicle were compared there was a slight advantage for the Australian-designed truck, despite the fact that the traditional truck was loaded considerably beyond the dimensional limits for length and rear overhang. The increased capacity of the traditional truck was gained by tying the rear row of cattle facing rearward with their heads and necks extended over the back of the truck, making them susceptible to injury and stress in transit. The Australian-designed rear-loading truck could be loaded much more efficiently than the traditional truck, which is side-loading, and the cattle rode well in the crate rather than being tied to it, as is the case with the traditional truck.

Sea and road transport (Philippines)

Livestock production in the archipelago of the Philippines is widely dispersed over many islands and is dominated by smallholders. By contrast, the large meat processing establishments are concentrated close to the points of consumption. Metro Manila, as the main consumption area, receives large numbers of stock for slaughter. Cattle are shipped to Manila from as far away as Mindanao. Stock are collected by *assemblers* who purchase or accept animals on consignment from a farmer. They are then transported by road and sea to the nearest trading centre, which is a market for a wide range of commodities, or to a livestock *oksyon* market (LOM) which is used specifically for the sale of animals for fattening, draught, or slaughter. Cattle, in particular, may pass through a series of markets before finally being sold for slaughter. A schematic representation of the livestock marketing system in the Philippines is shown in Figure 8. This is representative of the systems operating in most ASEAN countries.

Weight losses of 0.03% for cattle and 0.02% for buffalo were recorded in livestock transported by road and sea from Mindoro Island to Batangas Port. These losses were attributed to stress at unloading at check points during the road journey and the delays caused by the low priority for livestock vehicles for shipping space. This system used roll-on roll-off vehicular ferries. At other ports, systems similar to those reported for Indonesia are used, with the likelihood of incurring similar weight losses.

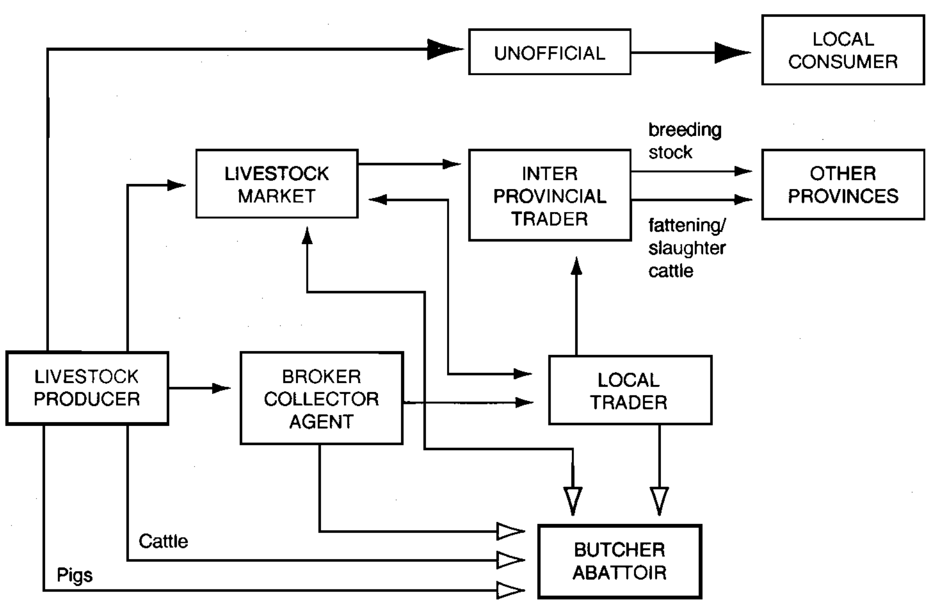

Figure 8. A schematic representation of the structure of the livestock system in the Philippines.

Livestock marketing (Philippines)

The establishment of LOMs in the Philippines commenced in 1973 as a government initiative operated through the Bureau of Animal Industry (BAI). Administration of LOMs, now totalling 147 throughout the country, was recently transferred from the BAI to local government. A variety of operators, including farmers, agents, assemblers, traders, slaughterhouse operators, butchers, and meat dealers are active at the LOMs. Various classes of animal are sold, ranging from pigs, goats, sheep, cattle for fattening and draught, horses for riding or draught, and cattle, carabao, sheep, and goats for slaughter. Multiple transactions may occur: stock may be sold two or three times before finally leaving the LOM, or may not be sold at all. Also, animals may be sold at different LOMs in different provinces and even the same province before final sale for slaughter.

The LOM concept is limited to providing livestock producers and buyers with a venue for the sale of animals. Each LOM is equipped with weighing scales and an office to record transactions (change of ownership). Animals are sold by private treaty between buyer and seller. This results in secrecy and uncertainty as to the actual selling price. The present system involves weighing and grading of animals before sale. Prices for the trading day are collected from a small number of farmers and traders. However, as there is no capacity to check authenticity of price reports, market information arising from the sales is of limited value in returning price signals to farmers and traders.

Batangas Province has the largest concentration of livestock of all the provinces in the country, receiving cattle and other livestock from Mindoro Island and other islands for fattening and slaughter. Batangas (with seven LOMs operating) was therefore a logical centre for testing new systems of selling livestock. A facility was constructed so that an Australian-type auction system in which the selling price was publicly announced, could be implemented. An extension campaign was conducted to educate all parties to the advantages of the system. This process will entail acceptance by traders' agents of the need for change and that such change will not threaten their livelihoods. However, time will be needed for all parties to understand and accept the benefits of the proposed new system.

Comments

Increasing use is being made of sea transport for livestock by ASEAN countries, both for imports and for internal trade. Brunei Darussalam is continuing to import livestock for slaughter to meet the demand for fresh meat by its population. Indonesia is increasing livestock imports as part of its program to expand cattle production, particularly in eastern Indonesia. This will result in increased sea transport of live cattle to the major cities in Java and Kalimantan which are the main markets for meat (Fig. 9). The Philippines is importing cattle to build up its livestock population as a counter to increased imports of beef. As beef breeding is carried out on the southern islands, with smallholder fattening in Luzon, there is a substantial movement of livestock by sea to be fattened closer to the main market of Manila before slaughter.

Road transport of livestock will continue to be a major component of the postharvest system. Because of the attenuated system of livestock movement to the point of final slaughter, there are losses in weight, meat quality, and in the financial return to the farmer. In the longer term, there will be increased use of slaughter facilities near the point of production, with chilled carcases and meat transported to the major markets. However, the tradition of purchasing fresh meat for immediate cooking will sustain the movement of livestock to the main markets for some time to come.

A major need in ASEAN is to provide farmers with adequate market reports to assist them in production and marketing decisions. The Philippines BAI is moving to the use of weight and grade as the basis for providing marketing information. Also, the introduction of a more transparent system of purchase through auctions should assist in keeping farmers informed on price movements.

Livestock Slaughtering and Abattoir Handling Procedures

The meat marketing structure in most ASEAN countries is similar to that of the Philippines (Fig. 10). Malaysia and Thailand carried out projects within AAPSIP to improve the hygiene and standard of slaughtering at abattoirs and to provide refrigerated storage of carcases before transport to the market. In both instances, this involved the modification of an abattoir so that it could serve as a model for other regional abattoirs and for training of regional abattoir managers, inspectors, and operatives in butchering skills and hygienic practices.

Malaysia

Malaysia has implemented, under its two recent National Plans, a program of consolidating and upgrading of regional abattoirs. Most major towns have an abattoir which is run by the town council or municipality. However, most country abattoirs are slaughterhouses with minimum facilities. There are currently about 230 local abattoirs and it was intended to reduce this number to about 60 regional abattoirs. The Malaysian Department of Veterinary Services (DVS) has assumed responsibility for oper-

Figure 9. Cattle being held before slaughter at an abattoir in Jakarta, Indonesia.

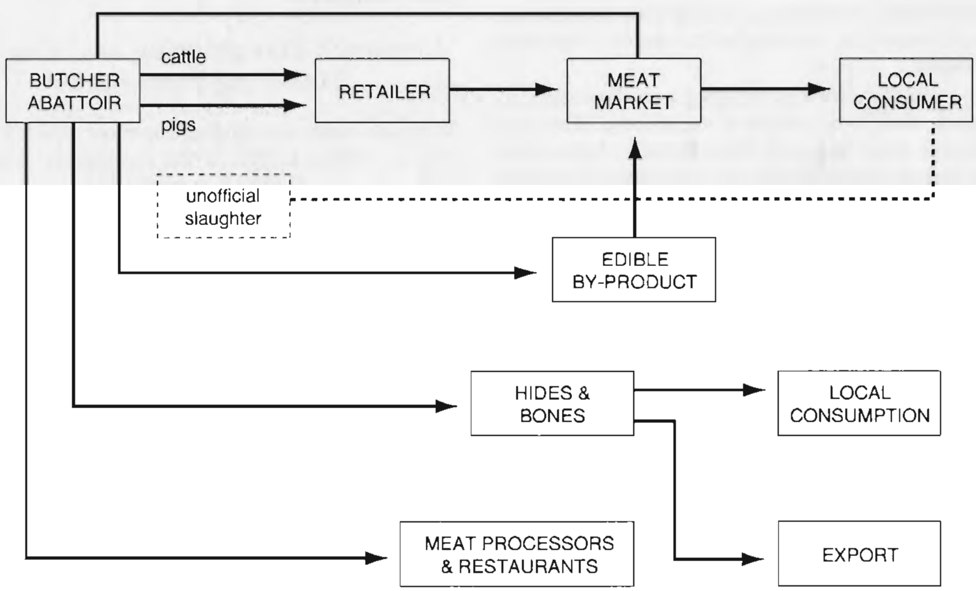

Figure 10. A schematic representation of the meat marketing system in the Philippines, which is representative of ASEAN systems.

ating the regional abattoirs and has constructed 10 new abattoirs at the main towns throughout the country under the Sixth Malaysia Plan (1991–95). However, funds are now being applied to upgrading existing country abattoirs in the remaining states, with emphasis on the improvement in equipment, sanitation, hygiene, and effluent control.

Pig production is being concentrated in special pig farming areas (PFAs), with either specialised abattoirs or transport for live animals to Singapore for slaughter. Currently, three PFAs have been established, one each in Johore, Penang, and Seremban.

The Senawang Abattoir was developed as a training abattoir with improved equipment such as a carcase splitting saw (Fig. 11), brisket opening saw, and saniplas cutting boards, plus a chiller capable of holding 20 carcases awaiting dispatch to retail outlets. A training program for the country's abattoir managers, operators, and inspectors has been developed by DVS, so that overall efficiency and hygiene are improved and maintained. As a result of this training, managers from other abattoirs are expected to develop a quality assurance system based on Hazard Analysis and Critical Control Points, leading ultimately to a program of *total quality management* (TQM) for each abattoir. This TQM program would be subject to periodic audit by DVS to ensure the maintenance of required standards. With TQM in place, it can be expected that the operation of the abattoirs could be privatised, with DVS maintaining an auditing role.

Thailand

The abattoir at Loei in northern Thailand was constructed as part of the earlier Phase I of AAECP under the Abattoir Designs and Design Concepts for ASEAN (1981) and has been used as a model for constructing provincial abattoirs throughout the country.

Under AAPSIP, it was decided to enlarge the Loei abattoir so it could be used as a training facility for provincial abattoir managers and veterinary inspectors. These modifications increased the capacity of the abattoir to 15 pigs/hour, which involved the provision of a larger hot-water system with a more rapid recovery time to provide boiling water as required by the higher slaughter rate. The rail system was also designed to assist in speedier carcase handling. As an interim measure (until funds are available for the construction of a chiller for holding the pig carcases after slaughter and before dispatch to the wet market), a refrigerated insulated container with carcase hanging rails was mounted on the chassis of an existing six-wheel truck owned by the Loei municipality. The refrigerated system was capable of using power from either the mains supply or the vehicle's motor. How-

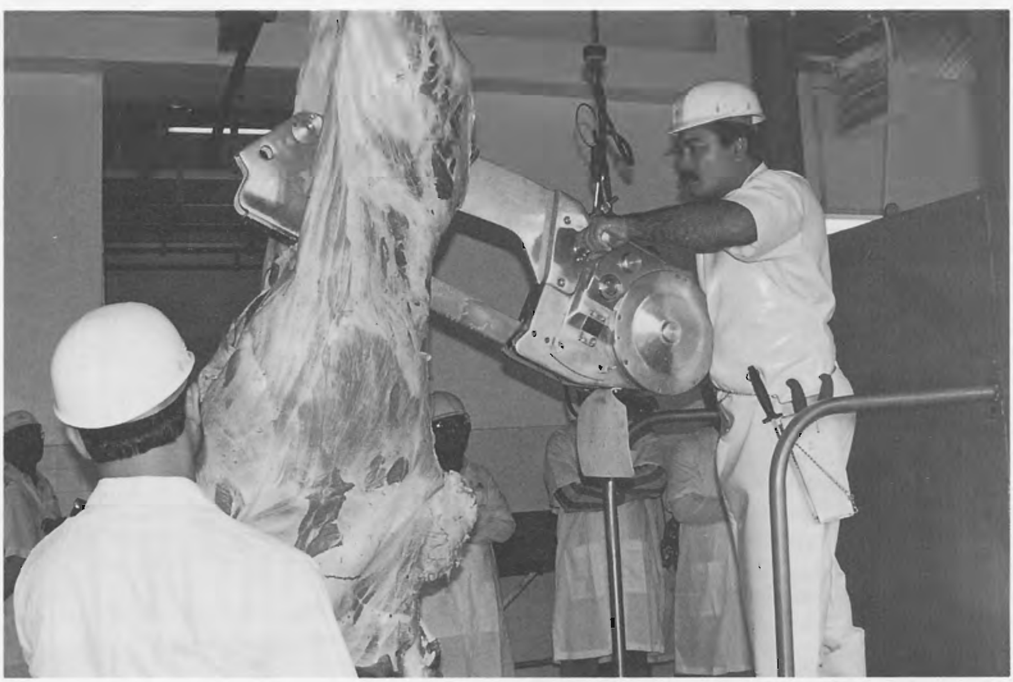

Figure 11. Use of the carcase splitting saw at the Senawang abattoir in Malaysia.

ever, this represents an inadequate compromise as the chilling capacity of the container is not sufficient to lower carcase temperature rapidly enough. Nevertheless, it is better than the existing system where the carcases are held at ambient temperatures and carried in open trucks to the wet market.

A number of training courses were carried out during AAPSIP 1991–94 using the Loei abattoir and the training facilities at the Thai Department of Livestock Development headquarters in Bangkok.

Meat Transport

Indonesia

In smaller cities and provincial towns in Indonesia, meat is transported to the markets in various types of vehicles, including small trucks, livestock trucks, carts, and rickshaws. These vehicles are difficult to clean, and there is very little recognition by butchers, transporters, and retailers of the need for sanitation during slaughter, transport, and retailing at the meat market. In 1993, Indonesian authorities reviewed the options for providing a more hygienic meat transport system in the smaller cities and provincial towns. After much discussion and consideration of available resources, a system of transporting in provincial towns was developed using a motorised tricycle (*becak*) with a meat transport container which can be thoroughly cleaned and sterilised. These prototype vehicles, developed under AAPSIP, will be tested in a number of centres including Semarang, Lampung, and Surabaya.

Malaysia

Under AAPSIP an Australian-designed prototype refrigerated meat transport vehicle was fabricated in Malaysia. It comprised an insulated box mounted on a truck chassis with a refrigeration unit, capable of carrying 6–10 cattle carcases on hanging rails and with stainless steel bins for offal. This vehicle was used to deliver carcases from a coolroom at the Senawang abattoir to retail outlets, or to meat cutting rooms for preparation of primal cuts. It was designed to demonstrate that carcases need to be held under refrigeration and free from contamination during transport. The Malaysian authorities take the view that, unless meat is handled hygienically along the whole handling chain, there is little point in upgrading handling methods at the abattoir.

Malaysia plans an education program to facilitate adoption of refrigerated meat transport from the coolrooms at abattoirs to retail outlets. This program will encompass improved hygienic slaughtering at abattoirs, refrigerated transport and more hygienic methods at retail outlets ↄ that the consumers will have more confidence in the 'keeping quality' of meat which has been chilled. The use of refrigeration will be accepted more rapidly in cities where supermarkets are already making consumers aware of these features.

Singapore

Singapore has emphasised development of a cold-chain system of meat handling from the abattoir to consumer. At present, carcases collected from the Singapore's Jurong Abattoir in the early morning are transported to a meat cutting plant for processing into primal cuts and viscera, and quickly distributed to retail outlets (Fig. 12). The Singapore authorities have been concerned that two systems for handling meat were developing within the country: one for imported chilled meat, and another for hot meat pro-

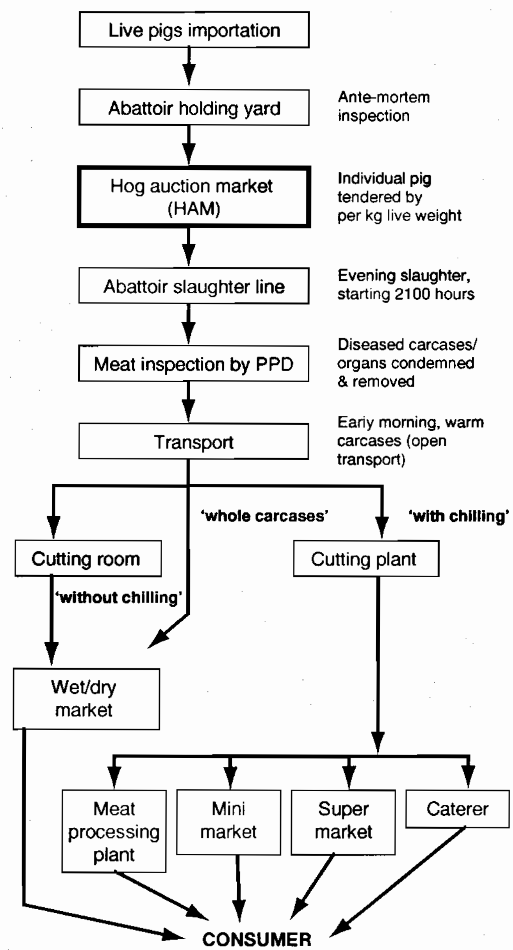

Figure 12. A schematic representation of the current pork distribution system in Singapore.

duced at the abattoirs. With the worldwide trend to phase out hot meat, a decision was taken to demonstrate the benefits of refrigerated transport in reducing contamination and maintaining meat quality.

As a demonstration to the industry, a refrigerated meat transport vehicle was fabricated in Singapore using an Australian design. The prototype unit comprised a truck chassis with a refrigerated insulated 'box' capable of holding 35 pig carcases on four overhead rails or in pallets on the floor of the container. A modified version of this AAPSIP refrigerated truck has now been developed by a transport agent to carry larger numbers of carcases. Recently, four major operators in the industry have set up integrated chilled meat operations involving refrigerated transport vehicles and cutting plants with refrigerated facilities, indicating support for the cold-chain program. It is anticipated that, with this rate of development, the use of refrigerated trucks for meat distribution will be standard in Singapore within the next 2 years.

Meetings have been held with the Singapore Pork Merchants Association to discuss the implementation of a cold-chain system and the ultimate conversion of night slaughter operations to daylight hours. At the Jurong Abattoir, slaughter operations have been advanced by an hour to start at 2000 hours, and operators with chiller facilities for handling carcases are given priority for early slaughter of their animals to allow sufficient time for adequate carcase chilling and deboning before distribution to the outlets. Two new abattoirs are being constructed and they will incorporate blast chiller facilities for carcases. Chiller facilities will also be upgraded at existing abattoirs. It is expected that, in future, all carcases will be chilled down, cut into primals at licensed cutting plants with refrigeration facilities, and then chilled primal cuts transported to retail outlets for storage, display, and sale as chilled meat.

When the cold-chain system is fully established, day slaughter operations can commence as there will no longer be a need to rush carcases slaughtered in the night to the markets for sale before noon to prevent spoilage. The carcases will require adequate time after slaughter for chilling, cut-up, and packing before delivery to the retail outlets throughout the following day (Fig. 13). Consumer education on the benefits of chilled meat will be an essential component to facilitate this social change. Without the security problems associated with night operations, more women are expected to be involved in abattoir meat inspection, carcase collection, and delivery etc. when these are converted to day operations.

Comments

Refrigerated meat transport is effective only when it is combined with forced air coolrooms at abattoirs so that the carcases are chilled rapidly and held at a low temperature before being loaded into the refrigerated transport. It is uneconomic to incorporate forced

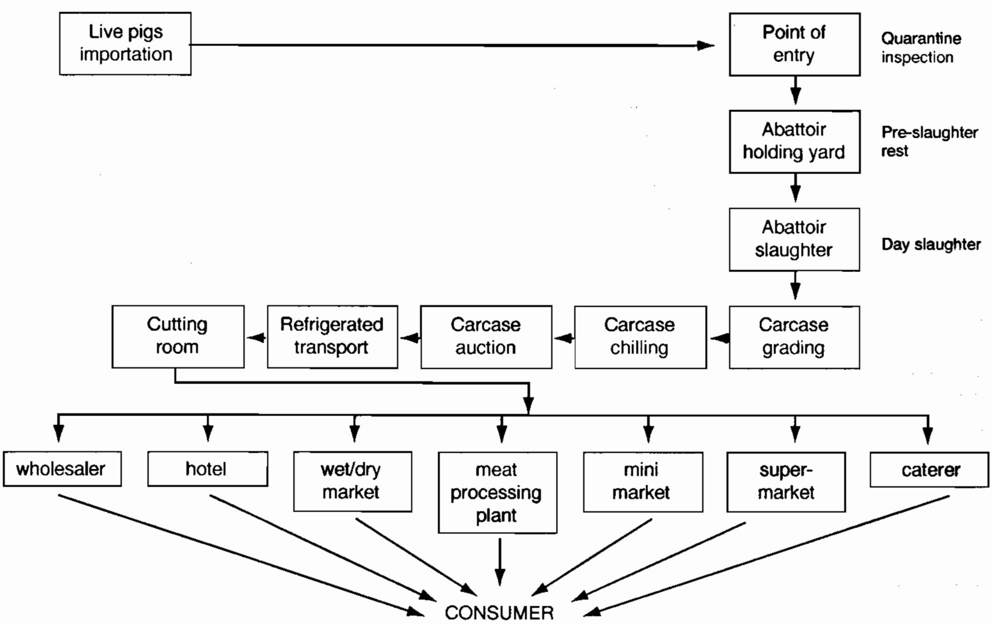

Figure 13. A diagrammatic representation of the proposed pork cold chain system in Singapore.

air cooling into refrigerated vehicles, so that they are usually designed to maintain cool temperatures rather than to reduce temperatures.

The change from traditional methods of slaughter and meat transport to a more hygienic system involving the use of a cold-chain system will probably be a slow process. There is a natural resistance to change, as the current system has served the population reasonably well in the past. In Malaysia, the move by authorities to adopt a quality management system is an important initiative which deserves support as it should promote early adoption of hygienic slaughter and transport. In Singapore the process of change towards a complete cold-chain system illustrates how the change will proceed in concert with a change in lifestyle.

Retail Meat Handling and Marketing

In ASEAN cities, patterns of retail meat handling and marketing are slowly changing, with the trend away from butchers' stalls in farmers' markets and wet markets, towards retailing in meat shops, supermarkets, and minimarkets. Nevertheless, wet markets are still patronised by the majority of consumers, so that there is a need to generally improve the wholesale and retail handling of meat. The authorities in ASEAN are concerned that meat traders and butchers in the wet markets do not understand the importance of hygienic methods and the capabilities and limitations of refrigeration in postharvest handling of meat.

Indonesia – poultry

In Indonesia, broiler retailing has expanded rapidly in the past few years with consumption now up to 300 000 birds per day in Jakarta. However, only 15% of birds consumed are slaughtered at chicken slaughterhouses (CSHs) where the standard of slaughtering is controlled by the veterinary public health authorities. The remaining 85% of birds are from chicken slaughter places (CSPs) which are adjacent to retail premises at the wet market and do not comply with conditions imposed by the veterinary public health authorities on the CSHs. Because conditions of slaughter at the CSPs at wet markets are so poor, most consumers prefer to purchase live broilers from a retailer at the wet market, have the bird slaughtered on the spot and take it home for immediate cooking. Indonesian authorities have been increasingly concerned at the poor quality of broiler meat offered to the consumer, a result of inadequate pre- and post-slaughter handling, and rapid spoilage caused by the effect of poor hygiene and the tropical climate.

Responding to this concern, the veterinary public health authorities and the Jakarta City Council veterinary staff have developed a system of more hygienic slaughter at the wet market, by introducing a defeathering machine and other equipment which can be cleaned and disinfected. This system has been tested in a small number of wet markets with a substantial level of support from consumers. The wet market authorities will be encouraged to upgrade the standard of the broiler retail premises incorporating these features.

Malaysia

The Department of Veterinary Services (DVS) in Malaysia has a program to improve hygienic standards of meat handling at the wet markets. This will complement the DVS program of improved hygiene and refrigeration at abattoirs and transport of meat to wet markets in refrigerated vehicles. As a demonstration under AAPSIP, 10 wet-market stalls were constructed at the Seremban Market (Fig. 14). Each stall was equipped with a chilled display showcase and chiller storage unit, a hand wash basin supplied with hot water, a work table with saniplas cutting boards, and a dry storage cupboard. Initially, the retailers evinced little interest in the new system but a change in their attitude was stimulated by public curiosity. As anticipated by the DVS, the new system of retailing incorporating the use of chilled beef has been accepted after initial reluctance.

Similar improvements are being undertaken at the Pudu Market in Kuala Lumpur using national funds. It is anticipated that other markets will be improved in stages in collaboration with the various local authorities and the Ministry of Health.

Outdoor farmers' markets are a feature in Malaysia. As part of the project, development began of a prototype mobile meat vending stall for use at these markets. The work is continuing with national funding. The prototype consists of a truck equipped with a refrigerated showcase, chest chiller, sink with a water tank and hot water, an electric generator, and a storage box. Modifications will be made to the vehicle on the basis of evaluation at a number of farmers' markets. When a satisfactory unit has been developed, it will be promoted for adoption at these markets.

Singapore

At present, about 90% of pork retailed in Singapore is unrefrigerated. Fresh, unrefrigerated meat is sold to the public at the wet markets in the older housing estates and at dry-meat shops in the new suburban housing estates. There is virtually no chilled meat sold in either the wet or dry markets. At the wet market, the meat stalls are uncovered and are not conducive to hygienic handling of meat. Their operation provides ample opportunities for organisms to contaminate and multiply, posing a health threat to consumers. Meat sold in dry-meat shops presents similar problems, due to limitations of space and layout of the stalls which make the facilities unsuitable for deboning and cutting carcases. Singapore authorities consider there is a need to establish meat deboning and cutting plants to allow butchers and meat vendors in the markets to handle only primal cuts or pre-packed meats. Also, there is a growing practice of extended trading hours in meat stalls where unrefrigerated meat is exposed for sale for up to 8–10 hours, which further increases the likelihood of spoilage and public health hazards. Therefore, the time is ripe for Singapore to develop a cold-chain distribution system, for which momentum is growing. Refrigeration in distribution and at the retail level will maintain the freshness and safety of meat. This will allow the meat to be retailed over extended periods throughout the day and evening for the convenience of the purchasing public.

The Primary Production Department (PPD) is collaborating with the Food Control, Hawkers and Environmental Public Health Departments of the Ministry of the Environment (ENV) in the introduction of a cold-chain system for meat handling, transportation, and retailing. With AAPSIP as a catalyst, this comprehensive program will include upgrading of meat retail stores and meat shops to handle only chilled meat, establishment of meat cutting plants, and licensing requirements for refrigerated meat transport.

Designs of prototype refrigerated meat stalls for use in suburban wet markets and dry markets have been developed by the Singapore authorities. The dry market design allows for four retail stalls within a *shop lot*, while the design for a wet market is based on clusters of meat stalls within an airconditioned environment. These designs and a proposed Code of Practice for construction of wet and dry markets have been made available to the licensing and retail control agencies of the Ministry of the Environment. This documentation should assist in the incorporation of the meat stalls into the new generation wet markets now being developed.

Thailand

Meat sold in wet markets in Thailand is freshly killed. Animals are slaughtered during the night between about 2300 hours and 0300 hours and the meat sold from 0500 hours the following morning until the afternoon. In the wet markets the meats are not refrigerated. Meat cuts are placed on top of tables or hung on rails above the table (Fig. 15).

Included in the Thailand component of AAPSIP was an improved retail facility at the afternoon market at Loei in northern Thailand, to serve as a model for other provinces. Five pork stalls and three beef stalls were constructed, each measuring 2 m × 4 m.

Figure 14. Consumers purchasing meat from a stall using a refrigerated display unit at the Seremban Market, Malaysia.

Each stall was provided with a smooth surface marble table, meat hanging rail, a hand wash basin, electric lights, concrete flooring, and a roof. Each pork stall was also provided with a refrigerated cabinet for the storage and display of selected viscera and other cuts. The complex was designed so that the stalls could be fully enclosed, air conditioned, and equipped with chiller display cabinets. Additional stalls can be incorporated when funds are available.

By the time the stalls were completed, the number of pork sellers wishing to use the afternoon market had increased to 10, so that the beef sellers were unable to take up their allocated stalls. The impasse was solved by the provincial government allocating funds for the construction of five additional stalls to cater for all meat retailers at the market. This development indicated the favourable impact of the more hygienic stalls on the retailers.

Comment

The AAPSIP projects selected by the ASEAN countries illustrate the wide diversity of meat retail operations within ASEAN. Supermarkets and mini-markets in the cities are routinely adopting refrigeration and placing greater emphasis on hygiene in food preparation and display. Wet markets are much slower to adopt these practices. However, changes are being made, with the lead being shown by some of the more progressive authorities. In the country towns where changes in work practices and life-style are less apparent and more gradual, developments will be slower. However, community pressure for improved presentation and extended shelf life of the product will increase over time, and the authorities will respond and make the changes required.

Studies on Meat Contamination

Thailand

Before developing an improved retail facility at the Loei wet market, a study was conducted by the Department of Livestock Development (DLD) to investigate the quality characteristics of meats sold in the wet markets in Thailand. This study also examined meat drip loss and meat microbiology under two types of storage conditions, so that results could be used as basis for improving meat handling and retailing. Samples of pork loins and beef loins were bought in the early morning from wet markets in 17 provinces located in the central part of Thailand (Bangkok, Samutprakan, Nonthanburi, Pathumthani, Nakhonprathom, Samutsakhon), in the northeast (Khonkaen, Kalasin, Skonnakhon, Udonthani, Loei), the north (Nakhonsawan, Sukhothai, Lampang), and the south (Surajthani, Nakhon Srithamaraj, Songkhla).

Figure 15. A traditional meat marketing stall in Loei, Thailand.

The study conducted by DLD showed that freshly killed hot meat traditionally sold in the morning wet markets is inferior in terms of eating quality, has high drip loss, and high bacterial contamination. Refrigerated storage can reduce drip loss and prolong shelf life of meat during retailing. However, this must be accompanied by hygienic practices and proper handling of meat before retailing in order to prevent initial contamination of the meat. Visual colour assessment could be of practical use in predicting meat drip loss, particularly in pork.

Singapore

A comparison was made by the Veterinary Public Health Division of PPD of the level of bacterial contamination at various stages in the handling process for pork carcases from the abattoir to the retail outlet. Under the existing distribution system (open trucks and unchilled meat), transportation over relatively short distances in the cooler hours of the night and early morning did not contribute significantly to increases in microbial load. Temperatures dropped slowly in unrefrigerated carcases. Carcase deep muscle temperatures were at 41–42°C immediately post-slaughter, dropping to a final temperature of 27°C some 8 hours after slaughtering. Temperatures were maintained at this level throughout the retail hours at wet/dry markets which usually stop operations at noon.

Under the above conditions, the most significant factor for rapid exponential growth of bacteria is holding the unrefrigerated meat under ambient conditions at the wet and dry markets. Quality of unrefrigerated meat deteriorates over time under the retail conditions in these environments to reach bacteria counts greater than 10^7/gram. Bacterial counts in meat in wet and dry markets were at least 10 times higher than those in supermarkets and minimarts with refrigerated storage and display. As retail hours progressed from morning to noon at the wet and dry markets, there was a further 5–8-fold increase in counts in unrefrigerated meat. Counts of *Escherichia coli* were also consistently high in wet/dry market retailed meat. Hence, the effects of ambient temperature and increasing bacterial loads restrict the trading hours of the retailer and severely shorten the shelf life of the meat which has to be prepared and consumed on the day of purchase.

Meat retailed in refrigerated conditions generally performed better with counts in the range of 10^5–10^7 organisms/g over extended retail hours.

Under the cold-chain distribution pilot study, carcase temperatures dropped to 7°C after 10 hours chilling. Temperatures can be further reduced, and at a faster rate, with the use of blast chillers. With refrigerated handling, counts of 10^4–10^5 organisms/g were obtained. This level could be further reduced by better observance of hygienic handling and operational hygiene. Chilled storage over an 8-day period showed only 10-fold increase in total counts and a lower increase in psychrotrophic count levels. Meat handled under the cold-chain system was still organoleptically and bacteriologically acceptable for human consumption after 8 days of chilled storage.

Application of AAPSIP Developments to Vietnam

Animal production in Vietnam has undergone a major expansion over the last 5 years. This expansion has been reflected in the increase in numbers of poultry, pigs, and cattle. Growth in the buffalo herd has also been substantial but not as rapid as the increase in cattle numbers. The initial impetus has been for increased numbers, but the emphasis now is changing to higher productivity and quality. This change in emphasis towards higher meat quality follows a pattern which has been occurring in all the ASEAN countries. Vietnam is mirroring these changes. The factors which are catalysing these changes arise from changes in consumption patterns in the country resulting from a higher disposable income for an increasing proportion of the population, increased numbers of expatriate residents associated with foreign investment in the country, and increased tourism.

When Vietnam joins ASEAN there will be increased opportunities for industry and government personnel to study developments in the other ASEAN countries and select those practices which are most appropriate to their circumstances.

Selected Bibliography

Aziz b. Mangkat, Abd. 1994. ASEAN–Australia Postharvest Systems Improvement Project country project report — Malaysia. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Chaisrisongkram, W. 1994. Overview of livestock postharvest activities in Thailand. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Chew Siang Thai 1994. Commercial trials on refrigerated meat distribution/analysis of meat quality and safety — traditional versus the new system in Singapore. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Eldridge, G.A. and Davies, G.T. 1982. The transport of livestock. Proceedings of the Australian Society for Animal Production, 14, 125.

Francisco, Z.F. 1994. Women in postharvest livestock activities in the Philippines. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Lestari, S. 1994. Women in postharvest livestock activities in Indonesia. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Lyons, D.J. and Steven, R. 1985. A study on livestock transportation by sea. Report of Australian National Material Handling Bureau to Director General of Livestock Services, Ministry of Agriculture, Indonesia.

Matayompong, P. 1994. ASEAN–Australia Postharvest Systems Improvement Project country project report — Thailand. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Matayompong, P., Vijitjan, T. and Jindawong, C. 1994. Quality assessment of meat sold in wet markets in Thailand. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Mudigdo, R. 1994. ASEAN–Australia Postharvest Systems Improvement Project country project report — Indonesia. Road transport trials. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Nordin bin Mohamid Nor, Mohd. 1994. Overview of livestock postharvest activities in Malaysia. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Pasaribu, T. 1994. ASEAN–Australia Postharvest Systems Improvement Project country project report — Indonesia. Sea transport trials. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Promentilla, R. 1994. Overview of livestock postharvest activities in the Philippines. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

— 1994. ASEAN–Australia Postharvest Systems Improvement Project country project report — the Philippines. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Wirjosoehanto, S. D. 1994. Overview of livestock postharvest activities in Indonesia. In: Proceedings of an End-of-project Workshop, ASEAN–Australia Postharvest Systems Improvement Project, Seremban, Malaysia. Kuala Lumpur, ASEAN Food Handling Bureau.

Wythes, J.R., Johnston, G.N., Beaman, N. and O'Rourke, P.K. 1985. Pre-slaughter handling of cattle: The availability of water during the lairage period. Australian Veterinary Journal, 62, 163–165.

Wythes, J.R., Smith, P.C., Arthur, R.J. and Round, P.J. 1984. Feeding cattle at abattoirs: the effect on carcass attributes and muscle pH. Proceedings of the Australian Society for Animal Production, 15, 643–6.

Workshop Recommendations

Recommendations

The establishment of a joint project on reducing postharvest losses of foodgrains by strengthening postharvest technologies, including drying and storage, was proposed by Professor Le Doan Dien. It was suggested that such a project could be organised under the auspices of, and with the technical and financial support of, ACIAR, AFHB, and the Asian Development Bank.

Its main objectives would be as follows:

- To reduce postharvest losses of food grains by applying appropriate technologies from the various countries in Asia, while taking advantage of exchanges of knowledge between scientists of Asian countries.
- To train scientific researchers of Asian countries on specific topics in the field of postharvest technologies and agro-industry (for example, prevention of mycotoxins in foodgrains, outdoor storage of foodgrains in plastic enclosures or small-scale mobile silos, with the technical support of ACIAR etc.).
- To increase the research potential of the different institutions involved in postharvest activities and agro-industry from Asian countries.
- To develop a program of short- and long-term research and development cooperation on problems of the postharvest subsector in agriculture and agro-industry among countries of Asia.
- To establish a network of different countries for execution and implementation of specific topics of general interest.

The implementation of a project to develop appropriate handling and storage practices for livestock and livestock products in Vietnam, in collaboration with specialists from Australia and elsewhere, was proposed by Dr Nguyen Van Hai. Project objectives would be to:

- reduce livestock postharvest losses by studying and applying technology successful in other countries in the region and appropriate to circumstances in Vietnam;
- improve traditional methods of livestock handling and storage by minority groups in mountain areas, so as to reduce quality and quantity losses during processing;
- strengthen research capacity in the field of livestock postharvest handling and storage;
- develop a cooperation program on matters related to livestock postproduction activities; and
- organise training courses and seminars for scientists and others involved in this area. Such a project would yield benefits to local and overseas researchers and to community development in Vietnam.

In addition, the following recommendations specific to the main topic areas of the workshop were made.

Grain Drying

Needs identified for the grain industry in Vietnam were as follows:

- Establishment of targets for introduction of drying technologies in terms of crops (quality vs price) and users (scale).
- Development of drying techniques appropriate to users. Use of mathematical models and simulations may help here.
- Economic assessment of the use of dryers.
- Assessment of the commercial and social acceptability of dryers.
- Dissemination of flat-bed drying technology.
- Development of in-store drying to enhance grain quality.

Quality Management in Stored Grain

Actions necessary to maintain a quality management program for the grain industry in Vietnam were as follows:

- Development of a national strategy and action plan to deal with the mycotoxin problem. (The Vietnamese plan should be available for presentation at the meeting of specialists from ASEAN countries in Lumut in July 1995.)
- Undertaking studies in phosphine fumigation technology. (The studies would address the issues of application rates, fumigation times, concentration × time products, and gastightness of fumigation enclosures.)
- Undertaking studies of phosphine resistance. (The surveys would initially use FAO methodology and would produce data comparable with those from other ASEAN countries.)
- Undertaking surveys of pesticide residues in grain. (The survey would target major pesticides used, and ensure compliance with Vietnamese law.)

Comment by Workshop Chairman

We have heard in the report on mycotoxins by Professor Le Van To of the known extent of the problem in Vietnam.

The situation must be one of considerable concern to Vietnam and I assume that the various authorities are eager to address the problem.

I understand that ASEAN authorities have prepared a Strategy and Action Plan for the management of the mycotoxin and spoilage fungi problem in the region.

The *regional* plan is being supplemented by *national* strategy and action plans which will provide the infrastructure needed to address the problem within each of the ASEAN countries.

I also understand that there is a proposal for countries in the region to meet in Malaysia during 1995 in a conference on grain quality that will consider integration and complementarity in national plans to manage mycotoxins.

It would therefore be appropriate, particularly in view of the closer association being developed between Vietnam and the ASEAN countries, for development of a national strategy and action plan for addressing the mycotoxin problem. This plan should be promoted, supported, and actioned by the government, and should provide for Vietnamese involvement in the regional (ASEAN) initiatives currently being developed.

Quality Maintenance of Fruit and Vegetables

The following matters were considered esential to improving quality in the Vietnamese industries:

- Developing a thorough understanding of the postharvest system for fruit and vegetables.
- Documenting the various fruits and vegetables produced in Vietnam with respect to their importance to the national economy in terms of:
  - dietary significance
  - nutritional value
  - ability to earn foreign exchange
  - production value, quantity, variety, etc.
- Collecting detailed information on target markets
  - domestic and international
  - preferences, consumer and market
  - trends
  - supply and demand patterns, etc.

- Identifying major technical and non-technical postharvest constraints affecting the horticultural industry
- Cataloguing and quantifying existing practices and available postharvest equipment, facilities, and technologies
- Establishing realistic, far-reaching, sustainable, and coordinated national and regional priorities and strategies
- Allocating needed physical and political resources to achieve stated objectives
- Monitoring.

'Additional' recommendations

- Set up key centres of postharvest technology at strategic areas to concentrate and coordinate multidisciplinary postharvest research and development activities and foster critical masses
- Facilitate the rapid increase in the number of scientific, technical, and management personnel with broad or specialised postharvest knowledge through short intensive and long-term trainings
- Establish suitable information systems to provide up-to-date information
- Put in place relevant mechanisms and services to disseminate postharvest information and assistance to the industry

Seafood Products

The following areas were identified as needing attention in Vietnam:

- Communications/training
  - Researchers, industry, fish handlers, fishermen
  - HACCP workshops
- Hygiene/sanitation
  - Review current practices
  - Upgrade export practices
- Quality
  - Better ice use/quality
  - Specific technologies for high priced export foods
  - Assess traditional products
- Losses/wastes
  - Explore more ways of waste utilisation
- Improve marketing
- Environment — keep watch on water quality.

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