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Transport of Vegetables in Papua New Guinea

Editors: **K.J. Scott and G. Atkinson**

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Contents

Foreword

ACIAR supported a project concerned with the postharvest transport of fresh fruit and vegetables in Papua New Guinea that has demonstrated how fresh produce can be moved from the Highlands to the main markets of Papua New Guinea, and (contrary to previously held local belief) arrive in good condition.

The results are currently being put into practice with the establishment of a regular containerised transport system, and its successful functioning would make a significant difference to the economy of the PNG Highlands, and to the country as a whole. Studies are also under way to extend these principles to the transport of produce within and between other Pacific Islands.

The project has involved cooperation and financial support from ACIAR, the PNG Department of Agriculture and Livestock, the Australian International Development Assistance Bureau, the New Zealand Ministry of Foreign Affairs, the CSIRO Division of Food Research, and the New Zealand Department of Scientific and Industrial Research. We thank all these organisations for their cooperation and assistance during the course of the project.

This report contains a description of the project by Garth Atkinson and Kevin Scott, an economic analysis of the different systems for vegetable transportation in Papua New Guinea by Ken Menz, and some of the results of experimental work concerned with the conditions for storage and transport of vegetables, conducted by S.C. Morris, M. Forbes-Smith, and Kevin Scott in Australia and in Papua New Guinea. Other technical information will be published in the scientific literature at a later date.

We trust the information provided here will be of interest to those concerned with agricultural development in Papua New Guinea, and elsewhere, where there is a problem of moving fresh produce to distant markets.

Gabrielle Persley
Research Program Coordinator
ACIAR

Overview of the Project

K.J. Scott* and G. Atkinson†

THE climatic range in Papua New Guinea is considerable, varying from wet tropical on the coast, to temperate in the highlands. The capital, Port Moresby, was originally chosen for its extensive safe harbour. However, the surrounding area is in the dry tropics and the wet season is short — often only six weeks. The capital is isolated from much of the mainland because of the rugged mountains. There are few major roads, but the country enjoys an extensive air service for both passengers and freight. Since the coming of aircraft to Papua New Guinea in the 1930s, light aircraft have served remote parts, many of which remain inaccessible by road.

The major staple foods are sweet potato, taro, sago, bananas, yams, and a number of leafy vegetables. Pigs are the main source of animal protein. As Port Moresby grew in size, there were food shortages due to the dry climate and lack of movement of produce from other areas. The Australian administration introduced rice as a durable food and this, together with canned fish that provides needed protein, has become the preferred diet of many people, including villagers in remote areas. There have also been substantial quantities of temperate vegetables imported into Port Moresby and Kieta (a mining town in the northern Solomons province).

The national government is concerned at the cost of food imports and has considered reducing (or even banning) rice imports. It has imposed quotas on vegetable imports, through a system requiring importers of certain vegetables to purchase locally grown vegetables according to a quota set by the government. Despite this advantage, locally grown produce marketed in Port Moresby is of poor quality and highly priced. It has been suggested that Port Moresby could produce its own food if extensive farming and irrigation were used. However, attempts to produce food on an intensive scale in this area have been unsuccessful. It has also been suggested that the fresh vegetable needs of the capital might be met by the Highland people growing a surplus for transport to Port Moresby and centres such as Kieta where imported food is consumed.

The substitution of imported vegetables with Highland-grown produce also conforms with the government's desire for Highland villagers to remain as subsistence farmers, rather than moving to the coastal towns where there are few employment opportunities and little chance of the newcomers being able to grow their own food.

Cash crops have become important to subsistence farmers since cash is needed for education and medical expenses as well as the purchase of rice, canned fish, and items such as clothing and radios. Traditionally, women grow the family's food supply and obtain cash by selling the surplus in the local market, the social centre of the town. The produce is carried on the woman's back in a string bag or 'billum'. The journey to market may involve a walk of several kilometres over rough terrain, or a motor vehicle may be used for part of the journey. The produce may be badly damaged by the time it reaches the market place. Moderate damage is not a serious problem for local consumers as the produce is eaten soon after it is purchased. A problem arises when an attempt is made to send damaged produce to a distant market, a course which will involve many handlings and the provision of little protection against mechanical damage or the elements.

Assessment of the Problem

At ACIAR's request, we examined the problems associated with the transport of vegetables from the Highlands to major centres such as Port

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Moresby and Kieta. We found that although advisory staff believed that Highlanders were keen to produce vegetables for sale, they had been unable to recommend any substantial increase in production because of the lack of markets.

In the late 1970s a marketing organisation — the Food Marketing Corporation (FMC) — was set up within a national government department to buy vegetables in the Highlands and air freight them to Port Moresby. The project had many problems: among other things, the method of transport was inadequate and low quality produce was offered for sale at high prices. The project failed. Three provincial governments carried on the project with subsidies for a time. Only one, the Monobe province, has persevered with the system but with substantial operating losses.

In 1983, when postharvest problems were first examined by the ACIAR team, fruit and vegetable buying in the Highlands was in the hands of small, privately owned companies or cooperatives operating out of centres such as Goroka. Also, three provincial government companies were trading in vegetables and competing with the private companies. All the groups involved had high overheads and used air freight and air charter to transport the produce. All were competing against each other in supplying the few major wholesalers in Port Moresby. Kieta was too distant to supply by air. At the time of our visit, all groups were facing financial problems due to high costs and low-quality produce and were struggling to survive. Two provincial government trading companies ceased trading shortly after the visit.

Poor Handling Practices

The attitude of local agriculturalists and business people was that there was something inherently wrong with the produce. Perhaps it was the way it was grown, or the use of wrong cultivars that was causing the high wastage and low quality. The ACIAR team, however, was quickly convinced that the problem was basically a handling one. Poor handling often began in the field where the produce was harvested and excessive quantities of leafy vegetables were packed into poorly designed boxes and bags. The traditional billum used by women to transport produce to market was found to cause serious injury to soft produce, which was yet further damaged at each stage of the handling process, including loading and unloading of the aircraft. Since the produce was already severely damaged at the time of loading, the speed of air transport counted for nothing.

Potatoes were seen by many as a valuable crop for altitudes too high for coffee production, but lack of markets was preventing expansion of the crop. There was also a serious transport problem. On the one hand, air freight was too expensive for potatoes, while on the other they suffered severe damage, particularly from bacterial soft rot, when transported by road and sea as ordinary cargo to Port Moresby.

Clearly, a cheaper and more reliable system was required if Highland vegetables were to be successfully marketed in Port Moresby.

Potential of Cooling and Containerisation

Surface transport involves carriage by road from the Highland towns to Lae and by sea from Lae to Port Moresby. It was considered that wastage would be reduced considerably if the produce were cooled and containerised at the point of production.

The normal methods for doing this are:

1. Set up precooling plants in the production area; transport produce by refrigerated or insulated truck to the port; transfer to a refrigerated container at the port and load onto a suitable ship.
2. Set up precooling plants in the production area; take refrigerated container to production area and load the precooled produce; transport the container to the port and load onto a suitable ship.

We considered that the costs of setting up expatriate-run precooling plants in several centres would be very high and that there would be major difficulties in obtaining land on which to build stores. There would also be a long wait to obtain finance. Following the demise of the Food Marketing Corporation, there was considerable local scepticism about the suitability of PNG vegetables for long-distance transport.

Portable Cooling Plant Needed

Clearly, if ACIAR were to assist in the short term, considerable innovation would be required. A portable cooling plant seemed essential to overcome the problem of obtaining land, and could also be easily relocated if local producers changed their minds about wanting to produce vegetables for distant markets. In the more remote areas, tribal conflicts might erupt and prevent the harvesting and sale of produce. (This did, in fact, happen during the project.) It was considered that a refrigerated container might be used to precool and transport the produce. Refrigerated containers are designed to receive precooled produce and to maintain its temperature within acceptable limits when moving through extremes of climate.

At the time of the initial investigation, expatriate-led operations obtained produce on the day of departure of the aircraft. They could pack their own produce or buy from other producers only on the days freight space was likely to be available, or when a charter flight was due. As the passenger service has priority, freight space could be limited when there was adverse weather and the chartered aircraft was rescheduled to passenger services. A delay of a day in obtaining freight space for the vegetables would often result in further heavy losses due to wastage. Total loss sometimes occurred and buyers in Port Moresby often had to meet this cost.

It was considered that if the ACIAR project worked within existing production and distribution limitations, only 1–2 tonnes of produce would need to be cooled per day and at this rate of loading of the container, precooling could probably be done using either the same container as would be used for transport of the produce, or others placed in suitable parts of the production area. Initially, it would be difficult to get a full load of produce requiring refrigeration. Accordingly, it was proposed to include produce such as potatoes which were too costly to transport by air but which were subject to heavy losses when forwarded by a combination of road and sea.

Although PNG has imported potatoes for many years, there have often been surpluses in the Highlands which could not be transported to where they were needed. There was strong interest in potato production in the Enga province which is generally at too high an altitude for production of coffee, the preferred cash crop in the Highlands. Potato production was seen as an industry which could help to reduce the migration of young men to the capital. The road to Enga province from Mt Hagen was very rough and facilities for handling containers were not available. It was decided to initially base container operations at Goroka, a centre used for air shipments of vegetables to the capital. This town also had facilities for handling dry (non-refrigerated) containers for the rice trade and was linked by a bitumen road with Lae. The shipping companies were asked to collaborate but were unable to assist in providing containers. They were, however, prepared to transport the containers when a suitable ship was available.

Static Trials with Refrigerated Container

A refrigerated container was obtained from the Sydney branch of the cargo handling equipment company CHEP and forwarded to Goroka. This older-type EMAIL container had been divided into two compartments thus allowing the simultaneous carriage of frozen and fresh produce. This met the experimental requirements very well as it allowed the transport in the one container of vegetables that are normally carried at 0°–3°C and others, including some fruit, that require a higher temperature. It could also be used to cure potatoes during transport to market. The conversion had been carried out by installing an insulated partition down the length of the container. The warmer side had its own air circulation system and, when required, a thermostat opened a vent that was connected to the refrigeration system in the 'cold' side. Heating was also provided in the 'warm' side. The two compartments of the container were found to operate at 3° and 20°C or, when required, at 3° and 12°C.

A static trial of the container was carried out at Goroka. Produce was harvested, carefully loaded by the investigators, and held for 10 days at storage temperatures. It was reexamined after a few days at ambient temperature in Goroka. The small quantities of the various temperate vegetables were all in good condition 12 days after harvest. There was no sign of bacterial soft rot in the cabbage and lettuce. Broccoli was also in acceptable condition. This confirmed the earlier opinion that better handling and temperature control would dramatically improve the shelf life of PNG vegetables.

Transport Trials

Four transport trials were carried out by the investigators; two to Kieta and two to Port Moresby. Potatoes from remote Enga were particularly well received. Initially, vegetables were obtained from larger producers. However, they seemed unwilling to improve their handling and packing and were not reliable suppliers. The subsistence farmers became major suppliers. This was achieved by working with local groups who bought from subsistence farmers at the markets or sent a truck into different production areas each day. Many small producers, most of whom are women, seemed prepared to sell all their produce on a particular day to the buying group rather than spend all day at the markets.

The technique of buying from subsistence farmers nearer their gardens reduced mechanical damage, but the continued use of large jute coffee bags and plastic fertiliser bags as containers for the produce is unsatisfactory and better packages need to be found. A strong carton is needed for the more easily damaged produce such as tomatoes and lettuce. Locally made cartons were found to be of poor quality and were expensive. Some form of returnable crate seems desirable but the difficulties in accounting for crates are considerable. Unfortunately, baskets made from local materials are little used in PNG and imported one-piece cartons, which may have a second-hand value, are probably required.

It was found that 1–2 tonnes of produce could be cooled in a day at Goroka using the two-compartment container. Initially, the potatoes were bought locally or forwarded by truck from Enga and were loaded into the warm side of the container to allow curing for a few days. Later, they were sometimes loaded into the cool side as well. It took almost four days to load the container. After a further day, the temperature of most produce was close to that required for carrying. A generator to provide power for the refrigeration plant was not used during road transport. Although air temperature inside the container rose during the six-hour travelling period to the port, the temperature of the produce rose only a few degrees. When power was reconnected at the port, the desired carriage temperatures were again obtained during the next 24 hours or so.

The shipments showed that Highland produce could be forwarded to Kieta and Port Moresby by surface transport and generally could be expected to arrive in an acceptable condition. Shrivelling was a problem with some produce such as carrots. This was largely overcome by packing the vegetables in perforated plastic bags. The humidity was also raised by returning defrost water to the floor of the container. In addition, use of a humidity controller to provide constant high humidity in the container was investigated.

Rotting was a problem in tomatoes. It could probably be largely overcome by the use of cultivars with a tough skin, such as Flora-Dade, but fungicidal treatment may be needed. Quality could be further improved by growing better cultivars, setting up simple packing houses, and using better packaging.

So far, studies have involved the larger ships and ports. However, there are smaller ports served by smaller ships which cannot handle 20-foot containers. Smaller containers can be made by cutting 8 feet from the standard container. These can be managed by small ships and are in use for frozen meat and dairy produce in PNG. It is likely that this arrangement could be used for the transport of fresh vegetables. By placing a container on the wharf at each small port it would be possible to load or unload smaller quantities of produce and thus provide for the needs of smaller towns. This possibility was examined in a preliminary way for produce destined for Manus Island from Lae, but transport trials have not yet been carried out.

Commercialisation

The project was 'commercialised' in 1985 with the assistance of NZ Aid. This organisation hired 10 containers for a year. These were used by the small local organisations to send produce to Port Moresby, particularly from Wabag in Enga province. Although the investigators felt it might be necessary for a further injection of aid funds to re-hire the containers and provide infrastructure, a local transport company in the Highlands has accepted responsibility for re-hiring the containers and has placed a charge on users to cover their costs. If use of the process is to continue, collaboration of all parties involved will be needed, particularly the shipping companies whose rates are one of the major costs of the exercise.

Commercialisation has been assisted by the government placing bans on the importation of certain vegetables except when it can be shown that local supplies are not available. If further funds were available, the project could be expanded by the provision of simple packing houses in the production areas, and the employment of advisory staff to assist subsistence farmers in the choice of crop and cultivar to be grown. Ideally, the containers need to be loaded beside the traditional market as this would further reduce handling and make the venture attractive to more people. It is also suggested that the containers be unloaded at a traditional market in Port Moresby. This would allow both supermarkets and traditional sellers in the market to have access to the produce.

Economic Aspects of Vegetable Transportation in Papua New Guinea

K. Menz*

Socioeconomic Background

Why Vegetable Handling and Transportation in Papua New Guinea is Important

Papua New Guinea (PNG) and other Pacific Island agriculture has traditionally been heavily oriented towards subsistence food production with some export-oriented tree 'cash' crops. However, as in many other developing countries, there has been a trend towards urbanisation in PNG (Levine and Levine 1979). This has caused (or has resulted from) a break in the traditional pattern of subsistence agricultural production carried out by the majority of the population.

The traditional pattern has been described by Epstein (1982). The marketing arrangement associated with it features an absence of profit-maximising behaviour by sellers, the selling of incidental food surpluses only—with no attempt to systematically produce surpluses, and an absence of specialised agents providing food-marketing services.

Recently, increasing amounts of root crops and other foods have been for sale at local markets, with greater numbers of subsistence farmers aiming to sell their surplus food production on a regular basis in local markets (Goodman et al. 1985).

The various components of total food consumption have been estimated as follows (Goodman et al. 1985):

- marketed domestic production — 25%
- imports — 25%
- production–consumption — 50%

With these demographic and social trends leading towards greater market orientation for indigenously produced food in PNG, some additional development of a marketing infrastructure — such as better road access — is desirable, in order to further facilitate marketing of regular surplus production by smallholders (World Bank 1986). Marketing of export tree crop products and commercial pigs and poultry appears to be efficient now, with the major difficulties centred on perishable fruits and vegetables (World Bank 1986).

The call for development of a better food-marketing infrastructure was echoed by Epstein (1982, p. 103). Fleming and Hardaker (1986) found a similar neglect of government-sponsored food marketing initiatives (cf. export marketing) in the South Pacific. However, they cited the relative success of the export sector as a sign of hope for the emergence of entrepreneurial marketing agents in the food sector and of a more commercial approach by village producers of food, in line with that shown for export products. Indeed, the emergence of entrepreneurial marketing agents has been observed in PNG (Shepherd 1982) and is expanding.

The agroclimatic environment for vegetables in the Highlands of PNG is good, and a reasonable degree of knowledge and skill in vegetable production already exists there. However, traditional markets provide limited coordination information (Shaffer et al. 1985), particularly in PNG, where the domination of markets by producer–sellers has restricted the geographical scope of the coordination function. Active market coordination requires a series of product transformations, including assembly conditioning, processing, storage, transportation, wholesaling, and retailing. It includes functions such as identification of overall demand and supply, and organises resources to match the two. It offers information and incentives to producers and reduces uncertainty (Shaffer et al. 1985). The problem of coordination is exacerbated in PNG because major vegetable producing and consuming regions are widely separated, and are traditionally linked by air transportation.

The larger towns in PNG are on the coast,

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remote from the vegetable-growing centres in the Highlands. Import of vegetables from other countries for consumption in the coastal towns is thus feasible, but a series of import bans and tariffs manifests a desire by the government to promote the local supply of vegetables, albeit at some cost, at least in the short term, to consumers in terms of higher prices. Insofar as the consumers of fresh introduced vegetables tend to be expatriates or wealthy Papua New Guineans, import bans and tariffs may represent an appropriate distribution of the costs of developing the introduced fruit and vegetable sector.

However, potatoes in particular are widely consumed in both urban and rural PNG, and are grown almost exclusively in the Highlands.

Sending containerised vegetables from the Highlands is likely to impact heavily on women in PNG, since they are the primary producers and the traditional marketers of food. An expansion of the market for locally grown vegetables is likely to increase the cash flow to the women growers. Their role in marketing food is not likely to be significantly affected, since vegetables sent to Port Moresby, whether by air or refrigerated container, pass mainly through non-traditional markets.

The Approach: Adaptive Research

The vegetable transportation project represents a good example of adaptive field research. It could be regarded as an application of farming systems research methodology (Shaner et al. 1982). The latter has always encompassed marketing of farm output within its scope, but most implementation of the farming systems methodology to date has related to on-farm production. This project takes the philosophy of farming systems:

— problem identification at grass roots level
— scientific research in controlled environment
— application of the research in a commercial situation under supervision of research personnel
— application under totally commercial conditions with researchers monitoring progress

and applies it to a marketing problem. At all stages of the process, experience gained in the implementation phase was incorporated into an improvement in the technology.

It could not be said that the current stage of development of the transportation technology represents the 'final product'. Indeed, further changes are inevitable in the light of social, economic, and institutional changes relating to its use, and as the technical aspects themselves become more refined. Consequently, any judgment about the net economic benefits flowing from this technology is likely to be an interim one only. The analysis presented below should be regarded in this spirit.

Institutional Aspects

Clearly, the economic feasibility of the container transport operation is dependent upon satisfying consumer demand in the large coastal towns of PNG. Indeed, the matching of product flows with demand is probably more critical with the container transport system than with the currently used air freight system because of the relatively large quantities of vegetables transported per unit time with the container system (and thus the cost risks involved if the vegetables cannot be sold).

Good information on market demand is a critical ingredient in a successful transportation operation. The large retailers in the major towns are best placed to provide this information. This may lead them towards control of an integrated operation back through the marketing chain. A further factor suggesting that large retailers may become involved directly with the refrigerated container technology is their market power in negotiating transportation rates. This market power could extend to the point where the operators of the container transportation system gain most of the economic benefits of the technology. However, the market power of growers could also be considerable given the costs inherent in setting up the distribution system and thus its vulnerability to a reduction in supply of raw product.

To date, the major interest in the container technology has been shown by Highland producer groups. While the container system could be vulnerable to takeover by large transport–wholesale–retail conglomerates in PNG, such an event would not necessarily be to the detriment of Highland vegetable producers. An improved transportation–distribution system can generate economic benefits in three ways: by increasing output from a given set of inputs; by reducing the inputs necessary for a given output; or by increasing the economic return per unit of output. The three are not mutually exclusive, and it would be expected that the system under development would provide benefits in all three areas.

The groups involved in the marketing of Highland vegetable production are shown in

Figure 1. All groups have the potential to gain from an improved vegetable distribution–processing system. The actual winners (and losers) depend upon the supply and demand for the goods or services which each group provides. Unfortunately, the nature of the supply and demand situation facing the various groups is unknown. This uncertainty has little effect on the calculation of the aggregate benefits, but is critical to determining the distribution of such benefits between the groups involved.

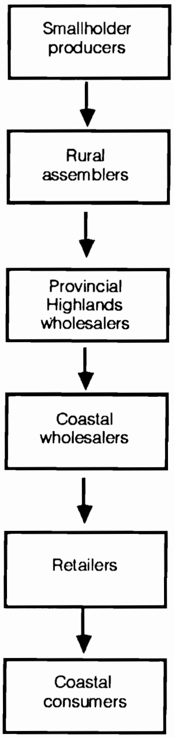

Fig. 1. Marketing channels for smallholder highlands vegetables to Port Moresby.

The initial impact of the technology is on the distribution–transportation part of the system. If the vegetable-growing sector were less responsive to the introduction of the technology (in terms of output change) compared with suppliers of transport services or with consumers, for example, then the growers would gain proportionately more of the economic benefits attributable to the technology [as discussed in Haynes et al. (1986) in relation to fishing]. Certain participants in the vegetable growing–marketing–consuming system may be able to gain a disproportionately high share of economic benefits from a new technology through the exercise of market power. However, the identification of market power is difficult. It might seem a priori that those who directly control the container system (especially if they also control the wholesaling–retailing sector) might be able to exercise market power in negotiations for procurement of vegetables from Highland growers. However, this is by no means clear cut. Political pressure could prevent the exercise of any market power that exists in the transportation sector; also, growers could possess significant bargaining power of their own.

This then, is the socioeconomic background to the postharvest vegetable processing technology developed by ACIAR. The technology represents a major thrust in overcoming a key internal transportation difficulty; provides a mechanism for active market coordination; and has favourable equity (rich–poor; male–female) implications.

Costs of Container Shipment of Vegetables

In this section, the costs of shipping vegetables from the Highlands of PNG to cities on the coast are examined. More specifically, the costs of using the refrigerated container system are compared with the costs of air freight for vegetables other than potatoes, and with palletised sea freight of potatoes. The calculations are based on transport from Wabag to Port Moresby. This is the route on which most commercial experience with the containers has been obtained. It is also typical of the general pattern of shipment envisaged for the refrigerated container system.

The cost components involved in the refrigerated container operation are shown in Table 1 and described on the next page.

Table 1. Cost categories and amounts.

Category	Items included	Amount* (kina)
Fixed	Container hire	315
	Container return	50
	Pre-tripping	50
	Electricity	24
	Transport at coastal centre	100
Mixed	Trucking	600
	Shipping	600
Variable	Wharfage	22
	Contents loss	295

*Per container load, with load assumed to be as shown in Table 2. For discussion of monetary amounts, see text.

A. Fixed Costs

(i) Container hire

One container-load of vegetables per week from a particular Highland centre is considered feasible. To achieve this, three containers are needed in order to allow for loading–unloading time, transportation, and return of the empty container.

Container hire costs 12 kina per day per container, or 252 kina per week for three containers. Therefore, to transport one refrigerated container-load of vegetables per week costs 252 kina for container hire.

Containers can be hired only on a year-round basis and the hire charge is paid regardless of whether or not they are used. Two scenarios are examined — one in which the containers are used year-round (equivalent to 252 kina per shipment per week) and another where containers are assumed to be used for 75% of the year — equivalent to a weekly hire charge of 315 kina per week for those weeks in which a container is used to transport vegetables.

(ii) Other 'fixed' costs

The preceding discussion on container hire cost indicated that it can be regarded as 'fixed' over a period, in that the cost will be incurred regardless of whether or not any vegetables are shipped.

The items listed in this section are 'fixed' in a somewhat different sense, viz. they are costs which will be incurred if a container-load of vegetables is to be transported during a given week, but do not vary in proportion to the amount or type of vegetables in a particular container shipment. Fixed costs include container return costs which are 50 kina per empty container per week. (Container return costs are all boat shipment costs. Trucks return containers to the Highlands at no cost because they are regarded by the trucking operators as convenient for packing of other materials.)

Other fixed costs are the transport of containers within Port Moresby at 100 kina (pick up and return to wharf), and 'pre-tripping' cost of 50 kina — for checking a container (mainly the electrics and refrigeration system) before each trip. Finally, electricity cost is 24 kina per load, comprising 12 hours of electricity supply at 2 kina/hour.

B. Mixed Costs

These are costs which include both a 'fixed' and 'variable' component. Trucking and shipping costs are in this mixed costs category. Both trucking and shipping are charged at a rate of 10 toea/kg for Wabag–Lae (by truck) and Lae–Port Moresby (by ship). There is a minimum charge per load of 600 kina for shipping and 500 kina for trucking. There is a maximum charge for shipping of 900 kina. In other words, costs are fixed up to a 6-tonne ship load and beyond 9 tonnes, and up to 5 tonnes per truck load respectively, but are variable outside those ranges.

C. Variable Costs

These are costs which vary more or less in proportion to the weight of vegetables in the container. The most straightforward charge is wharfage at 0.36 toea/kg. 'Risk of content loss' is somewhat complicated. It refers to the risk of losing the contents of a container due to mechanical breakdown, usually of the refrigeration equipment. This is estimated to occur once in every twenty loads, with a total loss resulting. This estimate is based upon experience with the containers. Insurance is currently taken to cover this item and could be included as a proxy for contents loss. However, we have chosen to include the estimate of losses, rather than the insurance premium, as a better reflection of the true costs. The calculation is based upon the following assumptions:

1. One container-load in 20 is lost due to spoilage (usually faulty refrigeration).

2. Faults are not discovered until the container reaches Port Moresby.

3. Economic losses thus consist of value of raw product plus transport cost. Clearly, raw product value is a function of total amount and type of vegetables included in the container.

Amount–Type of Vegetables in Container

Clearly, the cost per kg of transporting vegetables by container is a function of the weight of vegetables included, given the existence of fixed costs and mixed costs. A range of weights from 1–10 tonnes is examined. Potatoes would predominate in loads at the heavier end of this range.

The mix of vegetable types is also an important consideration in assessing the overall profitability of the system. However, in practice, only limited amounts of specific vegetables are usually available in different Highland centres, so that there is little flexibility with regard to this aspect in the short term. With increasing acceptance of the containerised system and with increased familiarisation by growers, the range of types and weights of various vegetables may increase. However, for the time being, containers consisting of an equal weight of mixed vegetables and potatoes are considered most feasible. For example, a typical 6-tonne container-load would consist of the mix of vegetables as shown in Table 2.

Table 2. Typical mix in a container (total weight 6 tonnes).

Vegetable	Weight (tonnes)	Price in kina/kg (ex Wabag)
Tomatoes	1.25	1.50
Carrots	0.75	0.60
Cabbage	0.50	0.40
Lettuce	0.30	1.00
Silver beet	0.10	1.00
Cauliflower	0.05	1.12
Broccoli	0.05	2.08
Potatoes	3.00	0.38

The ex-Wabag average price of the typical load shown in Table 2 is 69 toea. This value is relevant to calculations of contents loss. The weighted average price per kg of such a load excluding potatoes is one kina.

Results

Costs of Refrigerated Container Transport

Economies of Large Container Loads

The transport costs per kg of refrigerated container transport are shown in Figure 2.

The economies achieved via larger loads are obvious, being most significant in the 1–6 tonne range, but continuing up to the maximum load capacity of the container. For loads greater than 3 tonnes, container transport is cheaper per kg than air (e.g. refrigerated container average cost for a 6 tonne load is 32 toea/kg, compared with air freight at 55 toea/kg).

For a given weight in a container, these values change only slightly (in the order of 1–2 toea/kg) if a load contains a different mix of vegetables, arising from the different raw product cost of potatoes, and thus different product losses. There is therefore little point in distinguishing between vegetable types for a given weight of produce for currently feasible container-loads, and no such distinction will be made in the remainder of the paper.

For loads containing potatoes only, non-containerised sea freight (on pallets) is feasible and slightly cheaper than the refrigerated container system for container loads under 7 tonnes, as shown in Figure 2. The cost of palletised sea shipment of potatoes (non-refrigerated) is calculated at 10 toea/kg for shipping, 10 toea/kg for trucking, and 0.4 toea/kg for wharfage, with minimum weight loads also applying. In addition, losses are thought to be substantial: 20% of the sum of the raw product (ex-Wabag) price of 38 toea and the transportation cost. The total cost of transporting large loads of potatoes is thus just above 30 toea/kg, when sent by palletised non-refrigerated sea freight. In general, the palletised sea freight costs for transporting potatoes and the refrigerated container costs are similar, except at very low tonnages.

Adding weight to light container loads is economically attractive even for a relatively low value crop, such as potatoes. The total transportation cost of the 3 tonne load (no potatoes) is 1816 kina, or 61 toea/kg. The total

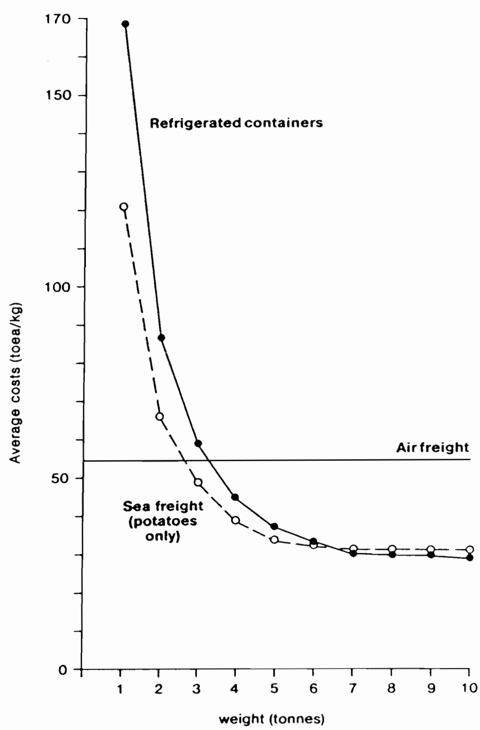

Fig. 2. Economies of large loads in refrigerated containers.

costs of transporting the 6 tonne load with 3 tonnes of potatoes is 1989 kina or 33 toea/kg. The additional 3 tonnes of potatoes can be transported at a cost of only (1989 – 1816) = 173 kina, or 4 toea/kg. Thus, the cost of adding 3 tonnes of potatoes to a 3 tonne container-load of vegetables is substantially less than the average cost of shipping pallets of potatoes (at around 31 toea/kg for a large load). The principle of adding several tonnes of potatoes to lightish (1–3 tonne) loads of other vegetables generally appears to be an attractive economic proposition, being cheaper than sending separate loads of potato pallets by sea freight.

In summary, it does pay to 'make up the weight' with potatoes or other vegetables in refrigerated containers, where the cost in the example above is effectively about 4 toea/kg of items added. This is cheaper than shipping separate palletised loads of potatoes which have an average cost of around 31 toea/kg, and clearly cheaper than air freight which costs 55 toea/kg.

The overall economies of adding weight to containers are substantial, especially in the range up to 6 tonnes, as shown in Figure 2, where refrigerated container-loads in the 6-tonne range cost just over 30 toea/kg, similar to the non-refrigerated sea freight cost of potatoes but well below air freight costs of 55 toea/kg.

Less than Year Round Usage of Containers

If a container load is not sent in a particular week, the container hire charge is effectively increased per load sent. Container hire is the only inescapable cost (i.e. the only cost which is incurred regardless of whether there is any use of the container). In order to determine the effects of less than full usage of containers throughout the year, a calculation of transportation costs was made on the basis of a 75% usage rate (per year) of containers. As explained earlier, this effectively increases the container hire cost by 25% per week. However, container hire costs are a minor proportion of total costs. Thus, the direct economic consequences of 75% usage of containers per year (cf. 100%) are minor for the most likely range of actual usage volumes, as indicated in Figure 3. It is not expected that less than a 75% usage rate of containers per year would be experienced for a particular supply centre.

Sensitivity Analysis Regarding Losses of Content

All of the preceding discussion has been based upon a loss (risk) factor of one load in twenty for the refrigerated container system. This is the best

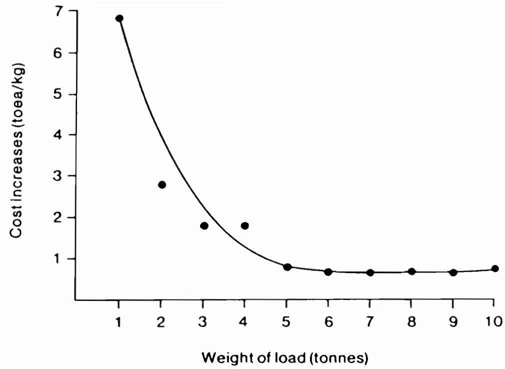

Fig. 3. Cost increases per kilogram resulting from reduced annual usage of containers (100% to 75%).

estimate available, based upon actual experience. However, it is probably the least certain of all of the parameters in the calculation. Some sensitivity analysis around the figure of 1/20 was performed, ranging from 1/100 to 1/5. Figure 4 shows results for a mixed (50–50) potatoes–vegetables container-load of various risks. The significance of the loss factor can be seen, for example, with an 8-tonne load showing a cost variation of 18 toea/kg (i.e. from 28 to 46 toea) for loss factors 1/100 to 1/5. Because of the significance of this figure, the minimisation of losses is a key management variable in the container system.

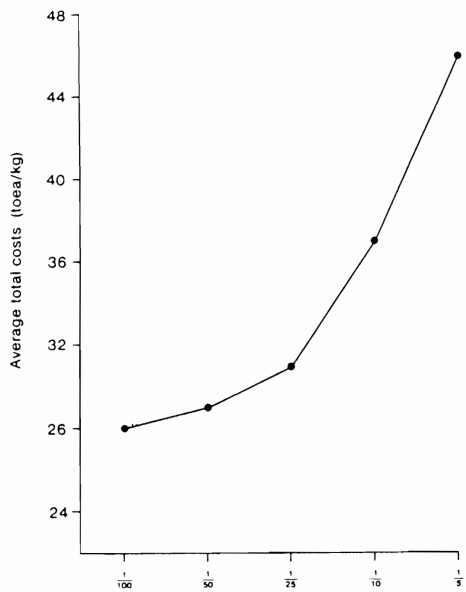

Fig. 4. Average total costs of transportation for various risk levels of contents loss (refrigerated containers).

Aggregate Net Benefits of Research

The tonnage of vegetables shipped from various Highland centres is shown in Table 3.

Table 3. Tonnage of vegetables shipped from various Highland centres (data from a private consultant report to the PNG Government)

Centre	Tonnage
Wabag	386
Kundiawa	220
Mt Hagen	201
Goroka	1083
Lae*	1204
Total	3094

*Not a Highland centre, but Lae vegetables are sourced from Highlands and not otherwise included.

Approximately 50% of the anticipated total Highland vegetable shipment using containers is thought to be potatoes. Assuming a 50% mix, vegetables and potatoes are sent by containers in 8-tonne loads, with 75% container usage per year, average transport costs would be 32 toea/kg.

The equivalent cost of sending such a load by alternative methods, viz. air (vegetables other than potatoes) and sea (potatoes) would be: $(0.5 \times 55) + (0.5 \times 31)$, or 43 toea/kg. Therefore, the total saving per kilogram would be 11 toea. If all vegetables currently transported from the Highlands (Table 3) were shipped by refrigerated containers, the total saving per year would consist of 3094 tonnes transported at a saving of 11 toea/kg, or 340 000 kina per year.

Current transport cost savings (700 tonnes being shipped by refrigerated containers per year) are 790 000 kina per year.

The internal rate of return based on a 3-year investment of 0.33 million kina in the project, and assuming a constant adoption rate from the present level of 700 tonnes to a maximum of 90% of all vegetables transported from the Highlands by containers in 1995 (the latter being 3094 tonnes) would be approximately 40% for the investment in the project.

Potential product flows using the containers are more than 3094 tonnes per year. A large-scale development project for the vegetable sector in PNG is mooted in a private consultant's report to the PNG Government. It would involve investments on a whole spectrum of activities from production to wholesaling if implemented, and an increase in vegetables transported from the Highlands of the order of 50% would be expected. Clearly, the benefits of refrigerated container transport would be correspondingly greater than those calculated alone.

Concluding Comment

Transportation of vegetables by refrigerated container from the Highlands of PNG to major consuming regions on the coast is cost-effective, relative to the alternative air freighting (or non-refrigerated sea freight for potatoes).

The major 'constraints' to increased adoption and use of refrigerated containers lie in logistics, such as with vegetable assembly, rather than costs. A proposed broad-ranging plan to develop the vegetable sector in PNG could ease these logistical problems substantially and result in a potential usage of refrigerated containers beyond that envisaged here.

The refrigerated container technology has positive implications for both income and equity.

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Effect of Curing on Storage and Transport of Vegetables in Papua New Guinea

S.C. Morris* and M. Forbes-Smith*

Introduction

A simple and effective means of considerably improving the marketable life of certain vegetables is by encouraging the natural defence mechanisms of the produce to seal over or 'cure' any injuries. Two crops in which curing is particularly effective are potatoes and sweet potatoes. Since these crops are very important in the agricultural economy of Papua New Guinea (PNG), this part of the ACIAR project studied the curing process with the aim of greatly reducing losses during transport between the growing areas and final markets.

This part of the project is reported under four headings:

- Survey of postharvest pathogens of potatoes and sweet potatoes
- Study of optimum curing conditions required for potatoes
- Study of optimum curing conditions required for sweet potatoes
- Development of a humidity control system for containers and curing rooms.

A. Survey of Postharvest Pathogens of Potatoes and Sweet Potatoes in PNG†

Potatoes

The most common fungi identified in this survey belong to the *Fusarium* genus (42% of all isolates), followed next by *Rhizopus arrhizus* (3% of all isolates). Only *F. oxysporum, F. solani,* and *Geotrichum candidum* have been identified previously in association with potato tuber decay in PNG (Shaw 1984). New records for PNG from this survey are *Cylindrocarpon destructans, Cylindrocladium ilicola, F. moniliforme, F.* m. pv. *athophilum, F. sambucinum, Monilia sitophila, Phoma* sp., and *R. arrhizus.*

Pathogenicity testing was carried out on only a small subsample of those fungi identified due to quarantine problems and of these *F. oxysporum, F. sambucinum,* and *Phoma* sp. proved pathogenic. Nevertheless, previous reports of pathogenicity are found for most of the fungi identified, namely: *F. sambucinum (F. sulphureum)* and *F. solani,* causing dry rot, found worldwide (Logan 1983); *F. oxysporum,* causing fusarium wilt, found in hot climates (Hooker 1981); *G. candidum,* causing rubbery rot, found in U.K. (Logan 1983); *Phoma exigua,* causing gangrene, found in cool growing conditions worldwide (Hooker 1981); *Rhizopus arrhizus,* causing rhizopus soft rot, mainly in the tropics (Hooker 1981); and *Cylindrocarpon tonkinesis,* causing a dry rot, found in India (Hooker 1981). These previous reports of pathogenicity would indicate that most of the fungi identified are pathogenic given the right infection conditions, except for *Monilia sitophila,* a common culture contaminant (Alexopoulos 1962).

The most common bacteria identified in this survey belong to the *Enterobacter* genus (28% of isolates), followed by the *Erwinia* (5%) and *Pseudomonas* (6%) genera, with the *Bacillus* genus (5%) next. Only *E. carotovora* pv. *carotovora* has previously been identified in PNG associated with potato tuber decay (Shaw 1984). New records for PNG from this survey are *Enterobacter liquifasciens, Erwinia carotovora* pv. *atroseptica, Bacillus pumilus, B. subtilis, P. fluorescens* bv C, *P. fluorescens* bv G, and *Micrococcus lutens.*

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Pathogenicity testing was carried out on only a small subsample of isolates from the *Enterobacter, Erwinia,* and *Pseudomonas* genus; no isolates were positive. However, often the presence of other pathogens is required for pathogenicity of bacteria on potatoes (Hooker 1981). Previous reports of pathogenicity have been found for most of the bacteria identified in this survey, namely: *E. carotovora* pv *atroseptica* and *E.* c. pv *carotovora,* causing bacterial soft rot, found worldwide (Hooker 1981); *P. fluorescens,* causing pink eye (Lund 1983); and *B. subtilis* causing a soft rot, found above 28°C (Lund 1983). The bacteria belonging to the *Enterobacter* and *Micrococcus* genera would be unlikely to be pathogenic (Buchanan and Gibbons 1974).

The relative importance of *F. oxysporum* as a pathogen was clearly demonstrated in this survey. This had not been obvious from the small number of potato postharvest pathogens previously identified in PNG. This finding means that control of *F. oxysporum* is of major importance to the PNG potato industry. Due to the aggressive nature and rapid development of this fungi, it is important that control measures be applied as soon as possible after harvest.

Control measures against both *F. oxysporum* and *Erwinia* sp. would include curing by holding at high humidity (greater than 85% RH at 20°–25°C) for 5–7 days before transport. This curing period is important since potatoes are capable of forming protective barriers against infections. The hot temperatures of the PNG lowlands create conditions ideal for the development of various postharvest diseases, resulting in heavy losses during transport and sale.

Both *Fusarium* and *Erwinia* grow very slowly at temperatures below 15°C. If potatoes can be held at below 15°C, and preferably below 10°C after curing, the very heavy losses currently occurring can be largely eliminated.

Additional control measures could include use of chemical dips such as Benlate® solutions. This chemical is generally very effective against *Fusarium* sp. (Wade and Morris 1982). Dipping in calcium hypochlorite solutions would also be effective in controlling *Erwinia* sp. (Morris 1985). However, the feasibility and economics of these treatments would need to be carefully assessed for each grower and/or packer.

Sweet Potatoes

The most common fungi identified infecting sweet potato in this survey belong to the *Fusarium* and *Rhizopus* genera (each 17% of all isolates), followed by *Ceratocystis fimbriata* and *Monilchaetes infuscans.* Only *C. fimbriata, F. oxysporum, Phomopsis batatas,* and *Rhizopus nigricans* have been identified previously in association with sweet potato decay in PNG (Shaw 1984). New records for PNG from this survey are *Geotrichum candidum, F. solani, M. infuscans, Monilia sitophila, Pythium splendens, Rhizopus oryzae, R. stolonifer,* and *Trichoderma neolongibrachiatum.* Various *Aspergillus* and *Trichoderma* sp. previously reported on sweet potato roots in PNG (Shaw 1984) were not found in this survey.

Pathogenicity testing was carried out on only a small subsample of fungi identified, due to quarantine problems. Of those tested, *Ceratocystis fimbriata, F. oxysporum, F. solani, Pythium splendens,* and *Rhizopus stolonifer* proved pathogenic. However, there are previous reports of pathogenicity for many of the fungi identified in this survey, namely: *Ceratocystis fimbriata,* causing black rot, reported in USA (Elmer 1960); *Fusarium oxysporum,* causing surface rot, found in USA, Asia, and Australia (USDA 1971; Morris 1981); *Monilchaetes infuscans,* causing scurf, found in USA and Australia (USDA 1971; Morris 1981); *Phomopsis batatas (Diaparthe phaseolum)* causing dry rot, in USA and Australia (USDA 1971, Morris 1981); *Pythium splendens,* causing pythium soft rot, found in Australia (Morris 1981); and *Rhizopus nigricans* and *R. oryzae,* causing rhizopus rot, found widely (Daines 1970; Morris 1981). These reports would indicate that only *Monilia sitophila* and *Trichoderma longibrachiatum* are unlikely to be pathogenic on sweet potatoes under favourable conditions.

The most common bacteria identified belong to the *Enterobacter* genus (19% of all identifications), followed by *Erwinia, Micrococcus,* and *Pseudomonas* genera (7% each). No records for bacteria associated with sweet potatoes exist for PNG, therefore all these records for *Erwinia chryanthemi, Pseudomonas fluorescens* bv A, and *P. fluorescens* bv G are new for PNG.

Pathogenicity tests were carried out on two *Erwinia* sp. isolates and both were negative. However, as mentioned previously, often more than one organism may need to be present to start a bacterial infection. Only *Erwinia chryanthemi* has been previously reported as a postharvest pathogen, causing bacterial soft rot. It has been found before only in Georgia, USA, and is favoured by temperatures exceeding 32°C (Martin and Dukes 1977). *Pseudomonas* sp. have not previously been reported as a pathogen on sweet potatoes, although bacteria from this genus are pathogenic on a wide range of vegetables (Lund 1983). For the reasons discussed previously, it is unlikely that bacteria from the *Enterobacter* and *Micrococcus* genera are pathogenic on sweet potatoes.

Control measures against these fungal and bacterial pathogens would firstly involve 'curing' by holding at high humidity for up to 7 days at temperatures of 25–30°C. This process leads to healing of wounds which occur at harvest and results in much lower losses due to rotting. No single protective fungicide could be recommended against such a wide range of pathogens.

The best treatment after curing would involve cool storage, with the best temperature for transport being 13°–15°C. It is very important that sweet potatoes are not exposed to temperatures below 12°C, which may cause severe damage and *Rhizopus* rot infections. In fact, severe chilling of sweet potatoes was observed during this survey at Nuigini Produce, Lae, and very heavy losses resulted.

B. Study of Optimum Curing Conditions Required for Potatoes*

Several methods for measuring curing were assessed. The first of these involved measuring the resistance of the skin to abrasion by a water jet. Unfortunately, the results were very variable and desiccation could not be distinguished from suberisation. The next method used was a rapid lignin sensitive staining technique. While this method was quick, it was precise enough to distinguish only major differences in suberisation and could not be used to measure wound periderm formation. The only accurate method was to prepare freeze-dried sections of the 'cured' area and use various staining techniques to quantify lipid, lignin deposition, etc. in the cells below the wound surface.

Development of a satisfactory humidity control system proved difficult and after testing several methods a new technique using split airflows was developed.

To determine the optimum conditions for curing Irish potatoes they were wounded and then held under a series of temperature (10°–30°C) and humidity (50–98% RH) combinations for 7 days. The active physiological processes which occur during suberisation, lipid and lignin deposition, and wound periderm formation were found to be maximal at 25°C and 98% RH. The effect of temperature was of greater consequence than humidity for these factors.

* F.M. Scriven, School of Food Science and Technology, University of New South Wales, Sydney, Australia cooperated in this work.

The development of the three factors was found to be highly correlated. The depth at which the suberised layer formed below the wound surface was affected far more by humidity than temperature, with 98% RH resulting in the suberised layer being produced almost at the wound surface. The two major postharvest pathogens found in PNG, *Fusarium oxysporum* and *Erwinia carotovora* were used to assess the resistance of the suberised layer to infection. The resistance to infection was also maximal at 25°C and 98% RH. Resistance to *Fusarium* infection was found to be more influenced by humidity than temperature, while resistance to *Erwinia* infection was relatively more sensitive to temperature changes. The rate of weight loss during curing was not influenced by humidity, with the lowest weight loss at 98% humidity.

Once the optimum conditions of 25°C and 98% RH were established, the effect of duration of curing was studied for periods of up to 14 days. Lignin and lipid deposition and wound periderm formation were found to be rapid during the first three days of curing with the rate of suberisation gradually decreasing with time.

A major difference between the time of curing required to control infection by *Fusarium* and *Erwinia* was apparent. Three days curing was required for effective reduction of *Fusarium* infection. However, only one day was required for effective reduction of *Erwinia* infection.

The relative thickness of the lipid, lignin, and wound periderm layer was correlated with resistance to infection. The thickness required for effective control of *Fusarium* was found to be two and a half times that required for *Erwinia.* A relative difference of the effectiveness of different physiological factors was also apparent, with lignins and the wound periderm being approximately three times more effective at controlling both *Erwinia* and *Fusarium* infection than an equivalent layer of lipids.

These results indicate that major changes are required to existing temperature and humidity recommendations for curing. Current recommendations are for temperatures of about 15°C (Dearborn 1978; Ryall and Lipton 1979; Nnodu et al. 1982). As regards recommendations for humidity levels, there is a great deal of disagreement, with levels of between 75% and 95% recommended (Ryall and Lipton 1979; Nnodu et al. 1982) and more commonly only 'high relative humidity' as the recommendation (Dearborn 1978; Knowles et al. 1982).

If curing is performed under the optimum conditions described above, as little as three days curing will result in major reductions in subsequent rotting of potatoes, with seven days curing giving the best results. In order to minimise weight loss after curing the potatoes should be stored at cooler temperatures, ideally in the range 5°–10°C.

The simplest method of obtaining curing conditions in PNG using containers or controlled-temperature rooms is by setting the room to 25°C and splashing several buckets of water on the floor three times a day. The potatoes should be kept off the floor on pallets. The best long-term method of obtaining curing conditions in PNG is to install a humidity control system for the room or container, such as the simple system described elsewhere in this report.

C. Study of Optimum Curing Conditions Required for Sweet Potatoes*

The methods assessed for curing sweet potatoes were the same as those used for potatoes. The best method of monitoring curing was again found to be preparation of freeze-dried sections of the 'cured' area and use of various staining techniques to quantify lipid, lignin deposition, etc. in the cells below the wound surface.

The humidity control system used was also the same as for potatoes with a split-flow system combining 'wet' and 'dry' in various ratios.

To determine the optimal conditions for curing, sweet potatoes were wounded and then held under a series of temperature (20°–40°C) and humidity (50–98% RH) combinations for 7 days. The active physiological processes which occur during suberisation, lipid and lignin deposition, and wound periderm formation were found to be maximum at 30°C and 98% RH for lipid and lignin deposition, and 35°C and 98% RH for wound periderm formation. These values are much higher than those observed for potatoes and reflect the warmer climate required to successfully grow sweet potatoes. The three factors were highly correlated, with temperature having a greater effect than humidity. This was largely due to virtually no suberisation occurring at 20°C.

When the largely physically mediated factors of weight loss and depth of desiccated cells between the wound surface and the suberised layer were examined, a different picture emerged. When average temperatures are considered, these two factors are minimal at 20°C. Similarly, when average humidities are considered, 98% is the lowest. However, 98% RH, with the effect of varying temperature, is non-significant between 20° and 30°C for weight loss, and between 20° and 40°C for depth to the suberised layer. Unlike physiological factors, humidity has a larger relative effect than temperature.

For the critical factors of resistance of the wounded surface to infection by *Fusarium* and *Erwinia*, a similar pattern to weight loss and depth of the desiccated layer occurs. Humidity has a very much greater effect than temperature on resistance to infection. When individual combinations of temperature and humidity are considered, the lowest infection occurs as a result of curing at 98% RH and temperatures of either 25°C or 30°C.

While the optimum conditions for suberisation occur at 30°–35°C and 98% RH, the optimum conditions to minimise weight loss and infection by *Fusarium* and *Rhizopus* spp. are 25°–30°C and 98% RH. These results indicate that changes are necessary to existing recommendations for curing conditions. While there is currently a range of recommendations, most lie in the range of temperatures from 30°–35°C (Kushman and Pope 1972; Gull and Duarte 1974; Bueschar 1980; Walter and Schadel 1982) and humidities from 80–90% (Kushman and Pope 1972; Gull and Duarte 1974; Buescher 1980; Walter and Schadel 1982). The optimum temperature range for minimising postharvest losses would instead be 25°–30°C with a humidity as close as possible to 98% RH.

This result means that curing of potatoes and sweet potatoes under the same conditions is not only feasible but also highly desirable. A single curing room or container could therefore be used for both potatoes and sweet potatoes. This finding validates a major objective of the project.

D. Development of a Humidity Control System for Containers and Curing Rooms†

This research was initiated due to a need to control humidity in refrigerated containers. Since these are often the only cooling or temperature control facilities in PNG, any holding of potatoes or sweet potatoes under curing conditions would invariably involve their use. After the curing period of 5–7 days, the condition of the produce after subsequent transport at 3°–5°C would be greatly improved by storing under a high humidity regime (Van de Berg and Lentz 1978).

* F.M. Scriven, School of Food Science and Technology, University of New South Wales, Sydney, Australia cooperated in this work.

† Tom Hayworth, Brambles Container Division, Sydney, N.S.W., Australia cooperated in this work.

A major problem with humidity control systems in containers is that water must be continually returned to the atmosphere of the container to maintain a high humidity level. The problem has previously been tackled by adding a large reservoir of water to a container. This, needs continual replenishment, however, and has been found to be unsatisfactory.

By monitoring shipments of refrigerated containers of vegetables from Goroka to Port Moresby it was found that weight losses of about 5% could be expected, especially from leafy vegetables. Since a fully loaded container weighs 10–12 tonnes, this represents a loss of 500–600 litres of water. This large quantity of water is removed from the container air by the cooling coils and leaves the container through the defrost water drainage tube.

Several methods of using this water to increase the humidity of the air were tested. These included running the water into a tank into which a large absorbent cloth had been suspended. It was hoped that the water would rise up the cloth and rapidly evaporate. Unfortunately, this did not happen because of problems with inadequate capillary action due to excessive air flows and a lack of porosity of the various cloths used.

Another alternative was to simply run the waste water into the airflow channels beneath the cartons in the container. Two problems were encountered. Firstly, the water usually trickled down only one or two channels and provided virtually no evaporative surface for humidifying the air. Another major problem was the continual trickle of water from the doors of the container. This is generally regarded in the container industry as a certain sign of a load of rotting produce. Various dripper and spreader sponge systems did not improve matters.

The best solution was to dam the defrost drainage tray to provide a reservoir of 5–6 litres of water. A small pump was used to spray the water through a microjet into the delivery air stream to the container after it had passed through the cooling coils. This resulted in a rapid increase in the humidity level in the container. An inexpensive control system was added so that water was added to the air stream only when the humidity level dropped below a critical set point (Fig. 1). A tube to the exterior of the container was provided to enable the water reservoir to be topped up at the beginning of each shipment. This system was tested in several static trials in Australia and humidity levels were kept within the range 85–95% RH during curing. During rapid cooling, levels dropped well below 85%. However, they were 20–40% higher than without humidity control and the produce temperature was within 2°–4°C of the required temperature, then humidity levels approached 85% again. The system was also tested in PNG during curing and transport from Goroka to Port Moresby. The curing achieved by the potatoes and sweet potatoes was quite acceptable using the humidity control to maintain conditions at 25°C and greater than 85% RH. After curing, the potatoes were cooled to 4°C and a full load of precooled other vegetables (cabbages, carrots, zuchinnis, tomatoes, celery, and lettuce) was added. Transport to Port Moresby produced exceptionally good results for leafy vegetables such as lettuce.

The humidity control system worked well for containers with bottom air delivery. However, the most recent containers used in PNG for vegetable transport are top air delivery and a problem was encountered with excess water dripping onto the top of the coils. This problem was considerably alleviated by using the spray heads from Ultra-Low-Volume spray units which produced a much finer droplet than the previously used microjet irrigation spray head. Generally, however, the system is more successful with bottom air delivery containers. The system could also be used to control humidity in standing cool rooms or curing rooms.

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High Humidity Storage in ISO Containers and Cool Rooms and Its Effects on Horticultural Produce

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THIS research was commenced as part of an ACIAR project with the aim of providing a practical solution for the transporting of fruit and vegetables in Papua New Guinea (PNG). Due to the extremely mountainous terrain in the centre of PNG, transport difficulties are the major constraint on fruit and vegetable production. Air freight was the only successful method of transport between production centres and major markets. Transport by road to the coast and thence by ship took up to 10 days and losses of produce were very high. After examining the problem, the best method of successfully transporting vegetables (especially potatoes) seemed to be by refrigerated container. This method has the advantages of flexibility, maintenance of high quality in vegetables and, most importantly, avoidance of damage through rough handling during transport.

During the course of this investigation it became obvious that maintenance of a high humidity environment was necessary, both for 'curing' of potatoes and sweet potatoes and for preventing excessive weight loss during transport. It is known that 'curing' of potatoes after harvest can substantially improve their postharvest storage life (Schippers 1971; Booth and Shaw 1981). The same phenomenon can also improve the storage life of sweet potatoes (Kushman and Deonier 1972). After a thorough investigation of curing conditions for potatoes and sweet potatoes it was found that optimum conditions for curing potatoes occurred at 25°C and 98% RH and at 25°–30°C and 98% RH for sweet potatoes. These results indicate that curing of both commodities in the one container or room is feasible. The benefit of these curing conditions for potatoes is highlighted in Figure 1, which shows that the depth of the protective suberin layer that forms after curing for 7 days at various temperatures and humidities is maximum at 25°C and 90–98% RH. The effect of curing conditions on reducing subsequent infection is described in Figure 2. The importance of high humidity conditions during curing is

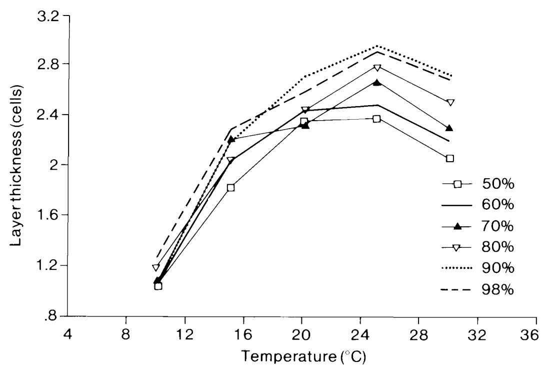

Fig. 1. Effect of curing temperature and humidity on the depth of the protective suberised layer formed over wound sites during curing.

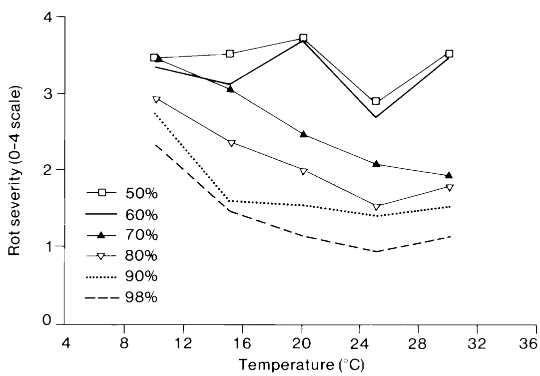

Fig. 2. Effect of curing temperature and humidity on the severity of *Fusarium* infection occurring after inoculating cured potatoes (assessed using a 0–4 severity scale).

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especially important for controlling decay, with 98% RH being significantly better than 90%.

As containers are often the only cooling or temperature control facility available in developing countries such as Papua New Guinea, it was obvious that the production of curing conditions within containers was necessary. A further advantage of producing high humidity conditions in a container is that after the curing period of 5–7 days at 25°C, the container load can be cooled to 3°–5°C and then other vegetables can be progressively added to the load. When the temperature within the container reaches the target, it can be transported to the final markets. It has been reported that use of high humidity conditions during cool storage can greatly improve the subsequent condition of produce (Grieson and Wardowski 1975). Thus, use of the humidity control system developed for curing to maintain high humidity in the container at 3°–5°C during transport should be of considerable benefit to the quality of the produce at outturn.

In the last few years considerable work has been done by container companies (such as Mitsubishi and Diakon) on the design (Anon 1986; Blacker and Parker 1985) of high humidity containers. Unfortunately these systems are extremely expensive (costing up to five times more per day to hire) and are not yet readily available. Both these reasons make their use totally impractical in countries such as PNG. A further problem with humidity control systems in containers is that water must be continually returned to the atmosphere of the container due to removal of water by the cooling coils. This problem has previously been tackled by adding a sizable reservoir of water to the container, e.g. the Mitsubishi, Hyo-on container [see also Blacker and Parker (1985)]. However, this reservoir needs to be continually topped up for the container to run effectively.

Monitoring of shipments of refrigerated containers of vegetables (ca 50% potatoes, 25% cabbages, and 25% mixed vegetables) between Goroka and Port Moresby in PNG, a distance of about 1200 km by road and sea taking 5–10 days, found that weight losses of about 5% could occur. Since a fully loaded container weighs 10–12 tonnes, this weight loss represents 500–600 L of water. This large quantity of water is removed from the container air by the cooling coils and trickles out of the container through the defrost drainage tube. A large loss of water is inevitable in conventional containers especially since space problems restrict the size of the cooling coil. The dehumidification of the container atmosphere and consequent extra water loss results in reduced produce shelf life and appearance (Blacker and Parke 1985).

Several methods of using this defrost water to increase the humidity level in the container were tested. These included channeling the water into a long tank running down one side of the container into which a large absorbent cloth was suspended. It was hoped that water would rise up the cloth and be rapidly evaporated thus raising the humidity level in the room. Unfortunately, this did not happen because of inadequate capillary action caused by excessive airflows within the container and also a lack of porosity of the various cloths used. Another alternative was to simply run the defrost water into the airflow channels beneath the cartons in the container. This method was recommended by Rath (1971), who claimed the increased humidity achieved by this method prevented dehydration by reducing mass transfer from the produce, with negligible effect on heat transfer. However, two major problems were encountered with this method. Firstly, the water usually trickled down only a few of the channels and provided virtually no evaporative surface for humidifying the air. Secondly, excess water continually trickled from the doors of the container; this is generally regarded in the container industry as a sure sign of the presence of rotting produce within. The use of various irrigation tubing, dripper, and spreader sponge systems did not significantly improve the evenness of spread of water across the container or prevent the excess trickling from the door.

A more successful solution was to build up the defrost drainage tray to provide a reservoir of 20–25 L of water (Fig. 3). A small pump was used to rapidly drip the water through fine irrigation tubing into the delivery air stream to

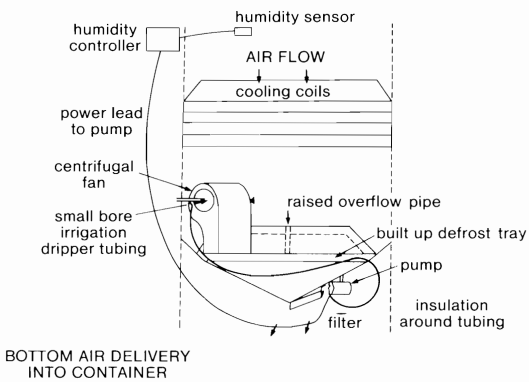

Fig. 3. Humidity control system for bottom delivery container using an irrigation 'dripper' to add water to the delivery air system.

the container (in this instance into a centrifugal fan) after it had passed through the cooling coils. A flow rate of about 30 mL/min was used, resulting in a rapid increase of the humidity level in the container. An inexpensive control system (Austratherm Pty Ltd, Sydney) was used so that water was added to the air stream only when the humidity level dropped below a critical set point, usually about 92% (the upper limit of accuracy for the Phillips capacitance humidity sensor). A tube to the exterior of the container was provided to enable the water reservoir to be topped up at the beginning of each shipment, while excess defrost water could still drain away from the defrost tray through a raised drainage tube. This system was tested in several static trials in Australia and humidity levels kept in the range of 80–100% RH during curing at 20°–25°C. During rapid cooling relative humidity dropped to around 50%; however, after the drop during initial rapid cooling, humidity levels were considerably higher than without humidity control.

Temperature and humidity were recorded using an 18-channel MISER datalogger (Northern River Industrial Electronics, Lismore, Australia) with LM335 temperature sensors (accuracy tested at ±0.2°C) and capacitance relative humidity sensors (Phillips, Netherlands). These humidity sensors are accurate up to 92% RH (tested at ±2% RH) but give a spuriously high value above 93% RH. Weight loss during cooling was recorded with a balance (Mettler PE16, Mettler, Zurich, Switzerland) fitted with a serial output accessory to allow continual recording of weight loss.

This 'dripper' humidity control system for containers was tested in PNG using a Luke Model 2000–100 (Luke Pty Ltd, Melbourne), during curing and transport from Goroka to Port Moresby. The temperature and humidity results for part of this experiment are given in Figure 4. The curing achieved by the potatoes and sweet potatoes was quite acceptable after using the humidity control to maintain conditions at 22°C and >90% RH. After curing for 5.5 days the potatoes were cooled to 3°C and other vegetables — cabbages, carrots, zucchinis, tomatoes, celery, and lettuce — were added to make a full load (this took 6.5–6.75 days). These were then cooled for 36 hours prior to transport to Port Moresby. The outturn quality of leafy vegetables at Port Moresby, particularly lettuce, was exceptionally good, with reductions of weight losses about 50% of those in equivalent containers without humidity control.

The humidity control system worked well for containers with bottom air delivery (both for

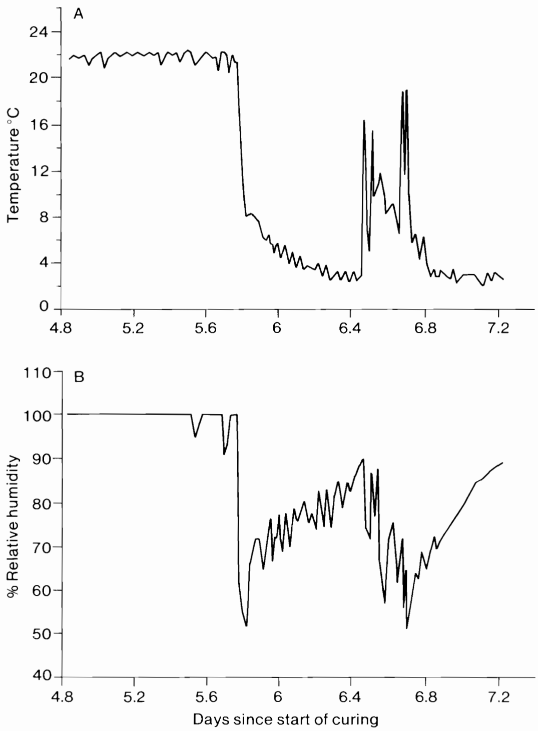

Fig. 4. Results from a combined potato curing and then cool-down of mixed vegetable transport trial in PNG: (A) Temperature of return air; (B) Relative Humidity in centre of the container.

centrifugal and axial fans) since any excess water could simply drop back into the defrost tray or onto the container floor. However, many recent containers are top air delivery with fans above the coils and problems were encountered in latter trials in Papua New Guinea with these styles of containers (Model 3200–100, Luke Pty Ltd, Melbourne). Small amounts of excess water dripping onto the top of the coils freezes and thus slows the cooling rate. This problem was partially alleviated by using the spray heads from Ultra-Low-Volume spray units (Micro Herbi, Model 77, Micon, London), which produced a much finer droplet than the previously used microjet irrigation spray head or dripper irrigation tubing. Unfortunately some water still dripped onto the coils even with these improvements.

A more satisfactory method of dispensing the water evenly into the air was using an Air Atomizing spray nozzle (Model 1/4JH/2A, Spraying System Co., Illinois) and a small 250 W compressor (Big Beaver, CIG, Sydney). This system worked equally well with either top or bottom air delivery systems and the compressor could either be located in the outside control part of the container, or internally if space were available. A flow rate of 40 mL/min of water was used and 35 L/min of air. If the distance between water level of the reservoir and the spray nozzle exceeds 400 mm then a small pump may be necessary to help lift the water.

Results were obtained for cooling (20° to 3°C) and holding tests in containers (Luke Model 2000–100: Luke Pty Ltd, Melbourne), with the spray nozzle method of humidity control compared with no humidity control. These tests used a small load of 500 kg of Navel oranges in boxes and half a box of large lettuce spread on top of the Navels. Trials were done in pairs with boxes of lettuce split between each pair of runs, with runs with and without humidity control. The results from three parts of tests were averaged and are presented in Figure 5A. The temperature results are given only for the control changes. While the return air dropped to the set point within 3 hours, it was 4–6 hours before the variance between the average difference between the return and delivery air was less than 2°C. The seven-eights cooling time for the lettuce averaged 13.5 hours. However, there was a substantial effect of humidity control on relative humidity content in the container (Fig. 5B). There were only marginal humidity increases during rapid cool down (as occurred for the 'dripper' system); however, after the first 1.5 hours relative humidity levels were kept substantially higher by the humidity control system compared with the uncontrolled container.

These humidity differences are reflected in the average weight loss differences for lettuce stored with and without humidity control (Fig. 5C). Initially, weight losses are very similar, but the weight loss in the control lettuce continued at a steady rate, while the weight loss of lettuce with humidity control slowed rapidly. At 18 hours the average rate of weight loss in the control lettuce is 0.056% per hour, while the average rate of the lettuce in the container with humidity control is 0.0095% per hour, a reduction of about 80% in the rate of weight loss.

The container modification described here [turning the defrost draining tray into a water reservoir, adding a humidity control, small compressor and air atomising spray nozzle (or Ultrasonic nozzle)] is simple to perform and relatively inexpensive. It enables containers to be used to 'cure' potatoes and sweet potatoes and also help to maintain the quality of produce (in particular, valuable leafy vegetables) during cool storage. The basic humidity control system proposed here has been tested in conventional cool rooms, with similar increases in produce quality. The system would usually be simpler to install in cool rooms since existing water and often existing compressed air lines can be used.

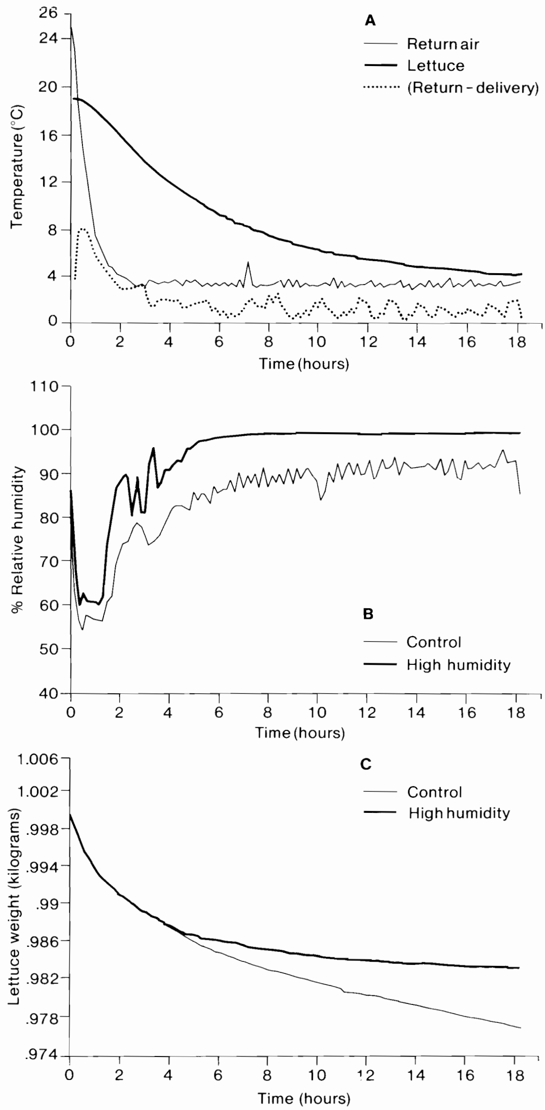

Fig. 5. A. Temperatures (no humidity control). Average results from cooling tests done with lettuces in containers, with or without humidity control (using atomising spray nozzles). B. Relative humidities (centre of container). Average results from cooling tests done with lettuce in containers, with or without humidity control (using atomising spray nozzles). C. Weight loss of lettuce. Average results from cooling tests done with lettuce in containers, with or without humidity control (using atomising spray nozzles).

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