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Innovative transport and disease control systems: Potato exports to Asia

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Innovative Transport and Disease Control Systems: Potato Exports to Asia

prepared by

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Purpose of this report

This report details the development of a fan-forced ventilated transport system for shipment of Australian potatoes at ambient temperature. This system includes a complete protocol for postharvest handling and transport of potatoes. Our report aims to stress that the container itself is not the key to successful ambient temperature transport. Rather it must be regarded as a single component of an integrated system that combines the container with a postharvest handling protocol. Only by following all steps in the prototcol from harvest to outturn can a successful result be expected.

We intend that the report, in particular the postharvest and ambient temperature shipment guidelines, will be a useful tool to assist the Australian potato industry achieve premium-quality exports without the need for expensive refrigerated transport.

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- Grower levies
- Food Into Asia

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Disclaimer

Media Summary

In the same way that fantainers were developed for shipping onions from Australia without the need for expensive cooling systems, we developed the Pot-Tainer to assist the growth of an export market for potatoes, particularly to Asia.

The aim was to develop a system whereby normal air (not cooled in any way) is used to keep the produce in peak condition throughout the shipping voyage, without the need for refrigeration.

Because potatoes store best at high humidity (90-95% Relative Humidity), compared to onions that store best at low humidity, they need a differently designed container than the fantainer.

Our team, comprising staff from Food Science Australia and the Sydney Postharvest Laboratory, came up with a system whereby the air is initially circulated through the container. Most of that air is then continually recirculated to maintain humidity, with just enough fresh air introduced to take away any gases produced by the potatoes.

For the Pot-Tainer to work properly it is essential that the potatoes be free of all but minor damage prior to export, properly cured and preferably treated with a fungicide. It is also necessary that the container be properly stowed so as to create uniform airflow as well as ideal airflow pathways throughout the produce.

The system was trailed, initially in simulated shipments at the container test facility at Food Science Australia, where the atmospheric conditions were varied as if on a real voyage. In the simulated shipments we introduced fungus and bacteria to the potatoes and placed them at various locations throughout the container. Importantly the disease did not spread and weight loss was very low.

Later, a real export shipment compared a Pot-Tainer with a conventional container. Part of the Pot-Tainer load was low in damage and treated with a fungicide and had little disease when it reached its destination. Another part was high in mechanical injury, without curing or fungicide prior to export and there was a lot of bacterial rot. This confirms the importance of ensuring high quality, properly treated produce is selected for export, because no container will improve quality, it can however maintain good quality.

TECHNICAL SUMMARY

Other than for short journeys, premium-quality potatoes have normally been exported from Australia in refrigerated containers. Like onions however, potatoes can be shipped to distant markets without refrigeration, provided they are handled appropriately, cured properly and kept dry during the journey. The challenge is to keep the surface of the produce dry during transport through changing climatic zones. As with onions, this can be done using fan-forced ventilation to ensure the load follows changes in ambient temperature during the journey. Unlike onions (that store best at low humidity), potatoes store best in the humidity range 90 – 95% RH. Our aim was to adapt the Fantainer transport system, developed for onions, to make it suitable, reliable and economical for the shipment of potatoes.

Since no container can improve product quality but rather maintain it, it is essential that the Pot-Tainer be used as part of an integrated system that combines a modified Fantainer with a postharvest handling protocol. The Pot-Tainer combines several innovative features utilising newly available control equipment and sensors to maintain a high rate of air circulation. This keeps a uniform temperature within the stow, but also creates a high humidity within the load-space. The postharvest handling protocol rejects other than minor surface damage, and includes curing and/or fungicide treatment.

During this and a previous project we simulated several shipments to Asia in a container test facility at Food Science Australia. In this facility the ambient temperature can be varied to simulate temperatures encountered during a shipment from Australia through the tropics to Asia. We also monitored a commercial export shipment between Melbourne and Hong Kong.

The results from most shipments were very good, with progressive improvements made in the technology. However the need to follow the postharvest protocol was graphically illustrated when potatoes with far higher levels of damage than were acceptable were shipped, and curing was not undertaken. The outturn from this shipment was not acceptable despite the Pot-Tainer technology working well. This poor outturn was the result of the quality of the potatoes being below acceptable limits with regard to damage and disease control. It cannot be emphasised too strongly that the Pot-Tainer needs to be used as part of the integrated export system not as a stand-alone component.

The export protocol is proposed as a complete system to help ensure that potatoes can be exported in large quantities without the use of refrigeration. This will enable expansion of the industry in Australia and enable Australia to capture a much larger share of the rapidly growing Asian market.

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1. INTRODUCTION

1.1 Potato production and export

In spite of competition from other staple foods (e.g. rice and pasta), potatoes are still the biggest horticultural crop in Australia, and are grown in all states. In 1995/96 the crop of 1,300,000 tonnes, as valued at the farm gate at $370 million [AHC 1998]. Production of potatoes, however, has varied little in recent years (see **Table 1.1**). Of this production a little over half the Australian potato crop is processed into chips/French Fries, or potato crisps [Prattley 1995].

Table 1.1: Australian potato production by State (by weight, and by percentage) [AHC 1998]

Season*	NSW	VIC	QLD	WA	SA	TAS	TOTAL
1991(ktonne)	120	377	119	110	175	235	1,136
1991 (%)	*11*	*33*	*10*	*10*	*15*	*21*	-
1992(ktonne)	123	369	113	98	199	250	1,150
1992 (%)	*11*	*32*	*10*	*10*	*17*	*22*	-
1993(ktonne)	137	309	125	108	179	270	1,129
1993 (%)	*12*	*27*	*11*	*10*	*16*	*24*	-
1994(ktonne)	139	322	118	112	203	291	1,187
1994 (%)	*12*	*27*	*10*	*9*	*17*	*25*	-
1995(ktonne)	127	280	109	108	247	256	1,127
1995 (%)	*11*	*25*	*10*	*10*	*22*	*23*	-
1996(ktonne)	162	336	104	122	283	302	1,308
1996 (%)	*12%*	*26%*	*8%*	*9%*	*22%*	*23%*	-

* Figures are to March of each year

Historically Australia has exported only a very small proportion of the crop, and this small quantity comprises a mix of fresh (ware) potatoes, seed potatoes, and potatoes for processing (mainly into crisps). In 1995/96 17,800 tonnes were exported, amounting to only 1.4% of the total crop (see **Table 1.2**).

Table 1.2: Australia's top ten export markets for potatoes [AHC 1998]

Country of destination	1995/96 (kilotonnes)	1996/97 (kilotonnes	1995/95 ($'000)	199697 ($'000)
Singapore	5.8	4.3	1.98	1.69
Malaysia	3.0	3.6	1.08	0.93
Republic of Korea	0.015	3.6	0.34	1.88
Mauritius	3.4	2.2	1.66	1.00
PHG	1.1	1.2	0.39	0.44
Hong Kong	0.23	0.95	0.23	0.39
Indonesia	0.36	0.79	0.34	0.55
Fiji	0.25	0.65	0.093	0.10
Seychelles	0.18	0.23	0.22	0.094
Sri Lanka	0	0.15	0	0.082
Other	2.4	0.24	0.59	0.23
Total	**16.6**	**17.8**	**6.93**	**7.38**

The four largest export markets, Singapore, Malaysia, Korea and Mauritius, account for 75% of all exports. These and other countries also import potatoes from other sources (see **Table 1.3**). Australia has a climate that allows potatoes to be produced year-round, but historically has not been a major exporter. While Australia can supply freshly harvested potatoes all year, many other producers, including the United States, grow exclusively during the summer, and can supply only stored potatoes during the rest of the year.

Table 1.3: Sources and quantity of imports (kilotonnes) into some of Australia's major export markets [AHC 1998]

Importing country	Australia	New Zealand	China	USA	Netherlands	Other	Total
Singapore	6.44	36.3	1.7	2.3	5.9	0	53.7
Malaysia	4.5	6.1	1.5	0.8	11.2	47.0	71.1
Indonesia	1.05	0	0.04	0.46	0.41	0	2.1

The demand for potatoes in Asia is increasing due to an increasing interest in Western foods. In particular there is a demand for fresh potatoes during the part of the year that countries in the Northern Hemisphere can supply only from coolstorage (about six months of the year). The potential quantities of potatoes that could be supplied by Australia are considerable, with the import market into Asia estimated at 4 million tonnes by the year 2000. Other major Southern Hemisphere producers are Colombia 3.1, Brazil 2.5, Argentina 2.1, Peru 1.9 and South Africa 1.5 million tonnes [FAO 1995]. Like Australia, most of these countries are major consumers, and export little of their production, though it is considered feasible for Australia to supply up to 500,000 tonnes into Asian markets within several years.

Other than for short journeys, premium-quality potatoes are normally shipped in refrigerated containers, to preserve quality and help prevent the development of rots. There is sufficient information available, however, to show that potatoes can be shipped without refrigeration (i.e. at ambient temperature) provided they are handled appropriately; they must be grown specifically for low disease levels and high storage quality, they must be cured correctly, and they require some form of postharvest disease control. While there will always be a premium market for potatoes shipped under refrigeration, it reasonable to suppose, that if handled correctly, the bulk of exports can be made at ambient temperature.

1.2 Other current potato research in Australia

During this project we worked closely with NSW Agriculture. This connection enabled research work to be done with potato growers and facilitated reporting of the work back to those growers. The major linkage in terms of research was with the Sustainable Potato Production in Highland NSW Project at Robertson, run by Sandra Lanz. Several collaborative trials were conducted to examine damage levels at various stages of harvesting and the effect on final postharvest rots. Other collaborative trials examined the effect of wound induced resistance sprays on leaf disease levels and final postharvest rots. Besides the potato growers, collaborative research was also conducted with Technico at Bowral; application of resistance inducing chemicals to potato plants growing minitubers produced very encouraging results.

In Victoria the main collaboration was with Agriculture Victoria, both with advisors at Ballarat and with Andrew Henderson and the team working at Knoxfield on ExpHort 2000 CQ Potatoes. In the first instance Agriculture Victoria advisors facilitated collaborative trials to examine damage levels at various stages of harvest, grading and packaging operations and the effect on final postharvest rots. The ExpHort 2000 CQ Potatoes program found the interaction especially helpful regarding the damage levels measured in our project and the type of damage found.

Considerable discussions were carried out with Western potatoes in WA and these were very helpful with design parameters for the PotTainer. However, fluctuations in international market conditions during later stages of this project meant that an export shipment in a PotTainer from WA was not possible in this project (particularly as most of the cost of the PotTainer export was to be paid by the commercial exporter).

1.3 Relationship of this study to previous CSIRO potato projects

This two-year HRDC project is the second stage of a series of Food Science Australia projects aiming to evaluate potential cultivars, postharvest treatments, and transport and container options for the export of potatoes. The first stage, *'Potatoes into Asia'*, was established with Green Triangle Growers Australia Pty Ltd (later Southern Choice Pty Ltd), and funded under CSIRO's *Food into Asia* scheme.

1.3.1 Relationship between injury and disease

Our previous Potatoes into Asia project showed that injury may create a convenient entry point for opportunistic organisms, and that under certain conditions both fungal dry rot and bacterial soft rot can proliferate rapidly, producing extensive tissue breakdown making tubers unsaleable.

A survey of potatoes from a Sydney wholesale markets showed that mechanical injury was widespread, irrespective of the type of packaging (jute or polypropylene bags or corrugated fibreboard cartons). The most common injury types were, (in frequency of occurrence):

- **splits:** characterised by rough fissures penetrating tuber flesh
- **skin grazes:** characterised by removal of the skin with no underlying tissue damage
- **scuffs:** characterised by rough breaks in the periderm containing crushed or bruised tissue

We determined the effect of injury type on disease development under storage conditions simulating a commercial export journey in a Pot-Tainer, through the tropics to Asia. Sites of severe tissue damage such as splits and scuffs readily developed extensive dry and soft rot infection, the latter developed in less than 48 hours. Injuries like scratches and skin grazes that involved less tissue damage developed less severe infection with bacterial rot being particularly sensitive to injury type. Tubers with intact skin and no damage did not become infected with either dry or soft rot.

Presence of free water on tuber surfaces also contributed significantly to the growth of disease organisms, being especially prevalent at elevated temperatures in the case of bacterial infection.

The work showed that injury types commonly found in commercial potatoes in Australia can contribute to disease development during storage and transport. It appears that prevention of injury during the harvest, postharvest, storage and transport chain would deny pathogens this important route to infection. Minimising of injury, should then, be an integral part of any disease control strategy for Australian potatoes.

To aid in the development of a disease control strategy we conducted a field survey of several potato growers in districts in NSW (Robertson), Victoria (Ballarat), and South Australia (Mt Gambier and Pinaroo). The aim of the survey was to develop an understanding of the type, level and place of occurrence of injury to tubers during harvest, grading and packaging. Growers of processing, fresh market and seed potatoes were included in the survey, which was made in the months of April and May 1998.

In practice of course, it is unrealistic to expect to eradicate injury entirely. Therefore a commercial disease control strategy must also include rot prevention in injured tubers. During the current project three classes of chemical treatment were investigated for their efficacy in preventing or reducing disease caused by *Fusarium* spp (dry rots) and *Erwinia* spp (bacterial soft rots):

- Fungicides
- Minimal-residue chemicals
- Common food preservatives

1.3.2 Shipment in fan-ventilated containers

During storage and transport potatoes sometimes suffer loss of quality through moisture loss and the development of fungal and bacterial rots. For some years people have contemplated the use of fan-ventilated 'Fantainers', developed for the export of onions. Indeed, some potato shipments have been made in onion Fantainers, with variable results. The onion Fantainer [Irving & Sharp 1985] generates a continuous, once-through flow of ambient air. This is appropriate to onions, which tolerate high temperatures but not high humidity [Irving & Sharp 1985], but not for potatoes, which store best at low temperature and high humidity [Morris, *et. al* 1989]. Although there is no agreed design for a Fantainer, and many variants of the Fantainer are in use, the shipping industry routinely ships onions in Fantainers, and is accustomed to providing electric power, monitoring their operation, and making repairs to ensure they continue to operate. It seems appropriate to build on this existing technology if a variant of the Fantainer can be made suitable for the shipment of potatoes.

During the *Potatoes into Asia* project we developed a modification of the onion Fantainer in which the air stream is recirculated within the container, with a humidity sensor and damper operated by an electronic controller to admit sufficient fresh air to maintain a desired high humidity within the container. We termed this a *'Potainer'*. This concept has been developed in the current project, and a patent application has been lodged for the improved technology (termed a '*Pot-Tainer*').

By maintaining a high relative humidity in the loadspace and by keeping temperatures uniform, the Pot-Tainer provides optimum conditions for potatoes. It alone however, cannot guarantee high quality outturn. To achieve this appropriate handling practices need to be implemented throughout the entire transport chain, including stringent control of harvest and postharvest handling practices. A high quality product can thus be loaded into the Pot-Tainer, which serves to maintain that quality throughout the export journey.

1.3.3 Current postharvest handling practices

There appears to be a belief that potatoes for direct distribution in Australia do not need careful postharvest handling. A recent study of potatoes purchased at retail (Choice 1998) found 20% showed signs of greening, and 25% had severe mechanical damage, as a result of careless handling, which is of course avoidable. Such a culture is unfortunate as a basis for an export industry.

Coupled with the idea that potatoes are a robust commodity, there is also a reluctance to use curing as a postharvest disease control treatment. Curing, a process of natural wound repair is a non-chemical treatment that utilises constant, moderate temperature and high humidity to increase the resistance of injury sites to infection. The process has been shown to entirely prevent infection by *Erwinia* spp and almost entirely prevent infection by *Fusarium* spp [Morris *et al* 1989]. Laboratory studies undertaken in the *Potatoes into Asia* project and in more detail in this project also indicated that curing was an effective tool in postharvest rot prevention.

European potato producers, who need to store their crop for several months of the year, use curing routinely to prevent storage rots. In Australia however, where potatoes are produced all year round, the general view is that curing does not benefit a product that will be consumed fresh. While this may be true of potatoes bound for local markets, those destined for export will undergo sufficiently long storage times for postharvest rots to pose a potential threat to final product quality.

Curing is an environmentally friendly postharvest disease treatment. The other benefit, identified in this project, is the possibility that for most of the year potatoes could be cured in the export container itself. Advantages are two fold, elimination of the need for special curing facilities and a time saving, since the load could be curing during the initial stage of its journey. This is made possible because ideal curing conditions are around 20°C and 95 – 98% relative humidity, an environment the *Pot-Tainer* is capable of delivering.

1.3.4 Simulation of an export voyage

While only an actual export voyage can test every aspect of a postharvest handling system, real export voyages suffer several disadvantages for research;

- Commercial constraints usually limit the measures that can be investigated,
- Any outturn of poor quality produce, whether or not the cause is attributable to the technology being trialled, and although it may be of scientific value, may be interpreted in commercial circles as showing that the entire concept is inappropriate; it is better to make such studies away from commercial scrutiny,
- Many aspects of the test cannot be controlled, and certainly weather conditions vary from one voyage to another,
- It is difficult to monitor the performance of the container,
- It can be difficult to arrange controls for all relevant aspects of the study, and
- It is not possible to remove samples during the voyage.

For these reasons it is often better to simulate a voyage in a Testroom. We found simulated voyages a useful tool in the previous *Potatoes into Asia* study, and again simulated a shipment in the Testroom of the Food Science Australia Container Test Facility in this study.

1.3.5 Trial shipments

Finally, when all laboratory studies indicate that commercial shipment should be successful, there must be actual trial shipments to demonstrate that the technology works. Such shipments are better termed 'trial shipments' than 'experimental shipments', because their purpose is not strictly experimental; their aim is not to find out whether a technology works, but to confirm that it does.

2. MATERIALS AND METHODS

2.1 Laboratory studies of the growth of disease organisms during storage

2.1.1 Effectiveness of chemical treatments for disease control in injured tubers

Several experiments were conducted; all had the same methodology except for storage conditions. Tubers were artificially injured with two light scuff wounds. A highly pathogenic strain of either *Fusarium* or *Erwinia* was inoculated into the wounds. The tubers were then held at room conditions (20°C, 67% RH), in jute bags for 6 to 18 hours before being dipped in solutions of the chemical disease control treatments:

- **Fungicides:** Imazalil, Guazatine, Carbendazim, SOPP (sodium ortho phenylphenate) and Prochloraz
- **Minimal residue chemicals:** chlorine and iodine
- **Common food preservatives:** citric acid, sodium benzoate and potassium sorbate
- **Control:** water

Tubers were left to dry then stored in commercial 20kg jute bags amongst healthy, untreated tubers. Two storage conditions were used:

- **Aggressive:** 20°C, jute bags completely wrapped in plastic to limit air flow or 20°C, jute bags completely wrapped in plastic, followed by 28°C, 90%RH without plastic. These were worst-case scenarios to vigorously test treatments.
- **Simulated shipment conditions:** jute bags, 3 days at 20°C, 90%RH, then 7 days at 18°C, 90%RH, then 7 days at 28°C, 90%RH; conditions based on the simulated shipment made in the *Potatoes into Asia* project 1997.

After storage tubers were assessed for rot development. The width of the lateral spread and the depth of the internal spread of rot from the wound sites were measured.

2.1.2 The 'Spudrobe' Pot-Tainer simulation module

Preliminary studies showed that disease organisms are sensitive to many aspects of the way potatoes are packaged and stored, including the packaging material, the humidity of the air, the local rate of air movement, and the degree of contact between tubers. To study growth of such disease organisms during shipment it is necessary to simulate the conditions experienced during an export journey. In the current project we wished to study the spread of disease between potatoes in a bag, and between bags.

To conduct all studies in a full-scale simulated shipment (using 15 tonnes of potatoes in a 20' container, held in a Testroom) is costly and impractical. Hence we developed the 'Spudrobe', a storage module in which a single stack of bagged potatoes is ventilated and held at a desired humidity as it would be in a Pot-Tainer.

The Spudrobe consists of a cabinet with a hinged front door, exposing the storage space and an air-return duct. A fan recirculates air upwards through the stack, and a damper, operated by a humidity sensor, electronic controller and damper motor, controls the exchange of fresh air to maintain a high humidity. It is sized to facilitate easy movement in and out of controlled-temperature rooms. The Spudrobe is shown in **Photo 2.1.**

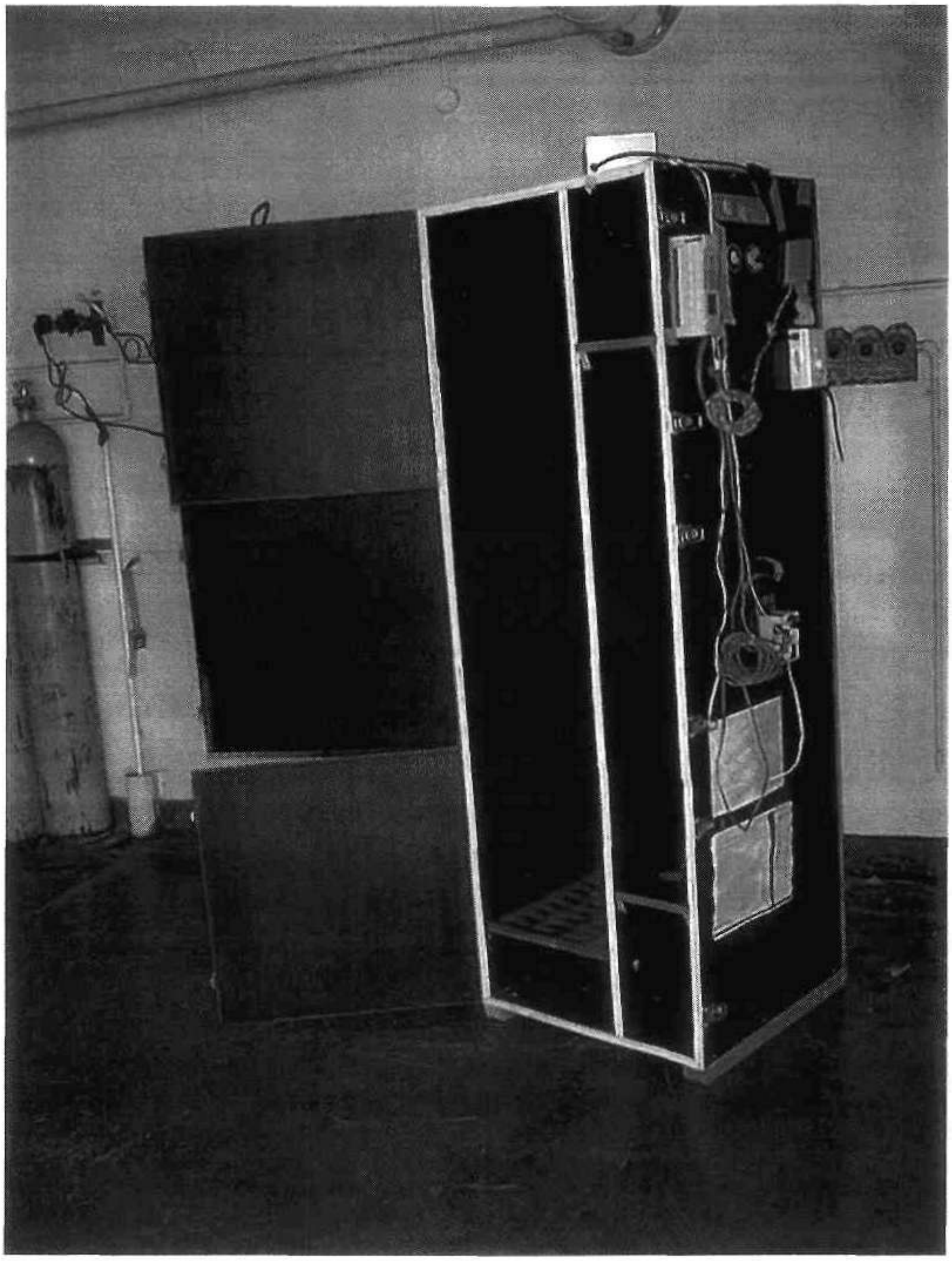


Photo 2.1: The 'Spudrobe', an experimental device that holds a single stack of bags of potatoes (seven bags) under the conditions they would experience in a Pot-Tainer.

Spudrobes were fabricated from 'Formply' (water-resistant, plastic-faced 18mm plywood), with:

- A storage chamber, in which a stack of bags (seven 20kg bags) sits on a mesh floor
- An air-return duct to return the air flow from the headspace to the floor
- A fan fitted into a 'shelf', which circulates air upwards through the bag stack
- A resistance 'shelf', with openings which can be covered or uncovered, to vary the rate of air circulation

- A humidity sensor (Vaisala Model HMD 50U) to sense the relative humidity within the storage chamber
- A damper motor (Landis and Stäfa Model SQE 65.12) and damper to regulate the inlet of fresh air
- An electronic controller (Landis and Stäfa Model RWX62.5030) to operate the damper, admitting fresh air when the relative humidity reaches the desired value

The humidity sensor, damper motor, damper and controller are similar or identical to those used in the full-size Pot-Tainer.

The Spudrobe has no temperature control system of its own, but was operated under constant temperature (in Controlled Temperature Rooms), and also used during voyage simulation in the Testroom, as a control for the Pot-Tainer.

2.1.3 Relative effectiveness of curing and treatment with fungicide

Spudrobes were used in a study to determine the relative effectiveness of curing and a common fungicide treatment for control of rot development in injured potatoes. Australian potatoes cv *Sebago* were used and conditions typically encountered during a summer journey from Melbourne to Singapore were simulated.

2.1.3.1 Treatments

Six treatments plus two pathogenic controls were used. The latter were included to test retention of pathogenicity to potatoes of the fungal and bacterial organisms normally used in our experiments. Potatoes from the six treatments were artificially wounded with a shallow split. This wound type was chosen since it typified injury sustained during grading and packaging operations as observed during our 1998 field survey. Half the pathogenic controls were similarly wounded. The rest were given a shallow scratch. The scratch wound was included to determine the effect of a less severe wound type.

The six treatments were inoculated with *Fusarium* (isolate FRR 5211 *Fusarium semitectum*). No co-inoculation with bacteria was included, since our previous studies showed that prevention of *Fusarium* infection also eliminates secondary bacterial infection. Half the pathogenic controls were inoculated with the same *Fusarium* isolate as the six treatments, the rest with E*rwinia* bacteria (isolate 98a E*rwinia caratovora*).

Four replicates of ten potatoes were used in each treatment. Treatments are summarised in **Table 2.1**. The curing process was carried out in the Spudrobe; potatoes were packed into 20kg hesian bags and placed in the Spudrobe for 5 days. The temperature was held at 17°C and the Spudrobe maintained an RH of 93%. The timing of application of curing was also tested **(see column 5 in Table 2.1)**

Table 2.1: Summary of treatments for study of relative effectiveness of curing and treatment with a common fungicide: four replicates of 10 potatoes per treatment

Sample	Cured[1]	Dip Treatment	Innoculation	Order of treatment[2]	Voyage simulation[3]
1	Yes	500ppm Carbendazim	*Fusarium* only	W-I-C-D	Spudrobe
2	Yes	Water	*Fusarium* only	W-I-C-D	Spudrobe
3	Yes	500ppm Carbendazim	*Fusarium* only	W-C-I-D	Spudrobe
4	Yes	Water	*Fusarium* only	W-C-I-D	Spudrobe
5	No	500ppm Carbendazim	*Fusarium* only	W-I-D	Spudrobe
6	No	Water	*Fusarium* only	W-I-D	Spudrobe
Pathogenic Control 1	No	Water	*Fusarium* only	W-I-D	Plastic bag
Pathogenic Control 2	No	Water	*Erwinia* only	W-I-D	Plastic bag

[1] Cured in a Spudrobe at 17°C, 93%RH for 5 days

[2] W-I-C = wound then innoculate then cure
W-C-I = wound then cure then innoculate
W-I = wound then innoculate

[3] After treatment, samples 1 – 6 were stored in the Spudrobe; Pathogenic Controls 1 and 2 were stored in plastic bags adjacent to the Spudrobe.

2.1.3.2 Treatment dips

Wound sites inoculated with the fungus or bacteria were allowed to dry before the treatment dip was applied. This ensured that inoculum would not be washed out of the wound site by the dipping process. To avoid cross contamination fresh dips were made up for each sample including the pathogenic controls.

2.1.3.3 Packaging

The potatoes in the six treatments were packed into commercial, 20kg hesian bags among healthy untreated potatoes that made up the bag weight of 20kg. No treatment was packed until the dip had completely dried on the potato surfaces. (Previous experiments showed that free water encourages disease development in wounded potatoes). One replicate group of ten potatoes from each treatment was packed into each bag. The potatoes once packaged, were loaded into the Spudrobe. Separating bags containing untreated potatoes were placed between treated bags to minimise the likelihood of cross infection.

2.1.3.4 Temperature profile for simulated voyage

The temperature and humidity to which a container is likely to be exposed during an export voyage from Australia can be predicted using the CSIRO 'Voyage Climate Predictor' software. This software marries the scheduled position of the container each day with a database of climate over the earth's surface to produce plots of temperature and humidity versus elapsed time. Typical climate regimes expected for departures at various times of the year, for a voyage from Melbourne to Singapore, via the west coast of Australia, are shown in **Fig 2.1**.

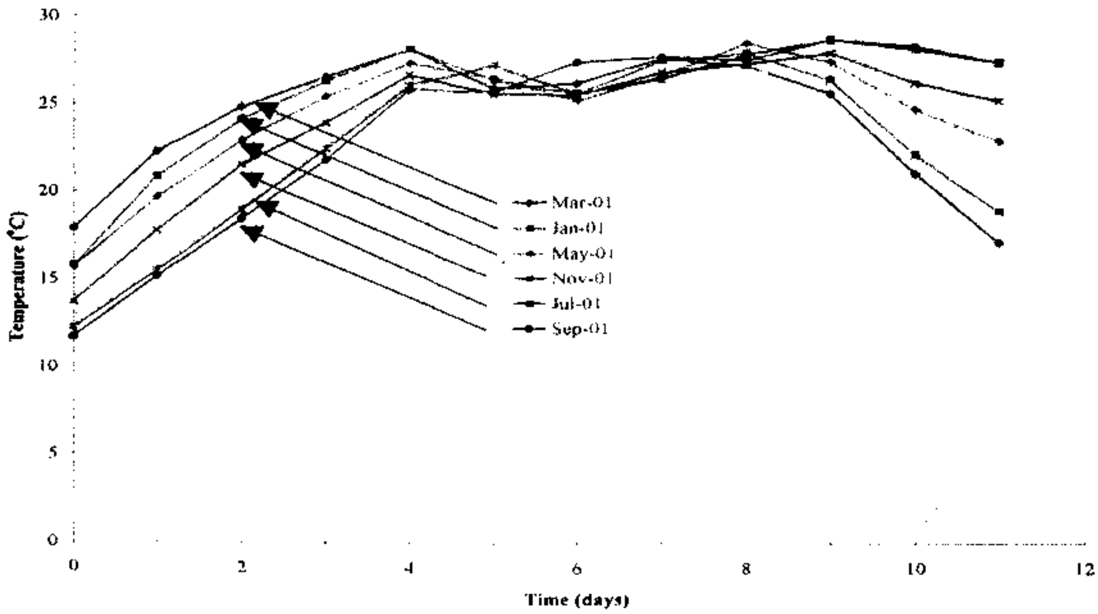


Fig. 2.1. Typical climate regimes expected for departures at various times of the year, for a voyage from Melbourne to Singapore, via the west coast of Australia

Since the Spudrobe is designed for use in a controlled-temperature room the temperature profile for a March 01 journey was approximated as follows:

- 3 days at 18°C, representing time on land in Melbourne
- 2 days at 16°C and 2 at 18°C, being the journey from Melbourne to Adelaide
- 3 days at 22°C, for journeying from Adelaide to Freemantle
- 4 days at 27°C, representing travel through the equator to Singapore
- 3 days at 30°C while the container is on land in Singapore.

2.1.3.5 Scoring levels of infection

At the conclusion of the simulated export journey rot development and sprouting were assessed. Rot development was determined using a rating scale, shown in **Table 2.3.** The spread of the infection beyond the wound sites and its depth below them were also measured.

2.2 Field survey of growing and postharvest handling practices

A field survey was made of several potato growers in districts in NSW (Robertson), Victoria (Ballarat), and South Australia (Mt Gambier and Pinaroo) as an aid to developing a disease control strategy. Its aim was to develop an understanding of the type, level and point of occurrence of injury to tubers during harvest, grading and packaging. Growers of processing, fresh market and seed potatoes were included in the survey, which was made in the months of April and May 1998.

Nine farms were studied. The soil condition on the paddock at harvest, the harvesting, washing, grading and packaging techniques were recorded. Where tubers were washed and rinsed, the level of bacteria (total count) in the wash water, and the chlorine level in the rinse water were determined. Where tubers were dried after washing, the degree of dampness was noted after the drier, and at the time of packing. The type of packaging materials, and the post-packaging storage procedure were also noted. In order to relate the incidence of mechanical injury to the severity of mechanical handling, wherever potatoes were observed dropping, the height of the drop was measured, and the nature of the impact surface noted.

Samples of tubers were collected at each operational stage: from the harvester, and from washing, grading and packaging operations (except that not all farms carried out all of these operations; some only harvested, some did not wash). Half of each sample was inspected immediately for occurrence, type and severity of injury. The other half was carefully placed in jute bags and returned to the Sydney laboratory for incubation over a period of 4 weeks, to determine the extent of rot development and bruising occurring during storage.

2.3 Testroom voyage simulation: Melbourne → Hong Kong

Knowledge gained from the laboratory studies and field survey allowed us to formulate a handling and treatment protocol for export potatoes. A testroom voyage simulation then evaluated the complete shipment protocol, including thiobendazole-type postharvest fungicides, used either alone or in combination with curing. For a direct side-by-side comparison of transport technologies, three types of transport were compared:

- the Pot-Tainer,
- a Spudrobe operating as an onion Fantainer (i.e. with once-through ventilation), and
- a Spudrobe operating as a Pot-Tainer (i.e. under humidity control), all operating alongside each other in the test room, experiencing the same simulated voyage conditions of temperature and humidity.

Various types of controls were used to compare with these transport technologies.

2.3.1 Description of the Pot-Tainer fan-ventilated container

2.3.1.1 General description of fan-ventilated containers ('Fantainers')

Our designs for container modifications to ship potatoes have built on the concept of the onion Fantainer [see Fantainer bibliography].

There are many variants of the onion Fantainer, the most common of which are now the Door-ajar Fantainer, and the P&O Fantainer (see **Fig. 2.2**). These each consist essentially of an unlined, steel General-Purpose freight container, usually 20' long, modified to allow a fan to draw fresh air through the cargo. The cargo of onions may be in net bags (either palletised or hand-stowed), in bins, or simply bulk-stowed (i.e. 'poured' into the container). With a palletised stow, the pallets create an air-flow floor to distribute incoming air beneath the stow, air passes vertically upwards through the stow to the headspace, and is extracted from the headspace by the fan. With a non-palletised stow, a slatted timber airflow floor is installed before the container is loaded. The fan is powered by a long lead from the three-phase power outlets normally used to run refrigerated containers. Since Fantainers consume very much less power than a refrigerated container, many may be supplied from a single outlet. It is usual to use three-phase fan motors, but each container must then be fitted with a reversing switch to ensure the fan runs in the correct direction (so that the fan exhausts from the headspace of the container). Finally, as an aid to monitoring that each container is connected to power and the fan is running in the correct direction, a tell-tale pennant is fitted to the fan outlet. At the end of the journey, the fan, cables and switches are removed from the container and shipped back to the exporter for re-use; the container can then be released for general cargo.

The function of ventilation in the onion Fantainer is to prevent the humidity from being raised by moisture released from the product (transpiration), and to prevent condensation of atmospheric moisture ('sweating') on either the interior of the container ('container sweat'), or on the surface of the cargo ('cargo sweat') during shipment through the tropics. A ventilation rate of approximately $0.5m^3/s$ has been found appropriate for this purpose.

The main difference between the two types of Fantainer is as follows:

- The P&O Fantainer was custom made for the shipment of onions. In addition to the normal features of a general-purpose container, it has a full-width, baffled air inlet built into the bottom rail at the far end of the container, and a housing for an exhaust fan built into the upper part of the left-hand door, with a 'hatch cover' which can seal the fan housing when not required.
- The Door-ajar Fantainer is a normal general-purpose container, modified for one trip by securing the right-hand door 100-150mm ajar, and fitting a bulkhead over the opening. An exhaust fan is fitted to the upper part of the temporary bulkhead, and a slot made in the lower part to allow the entry of fresh air.

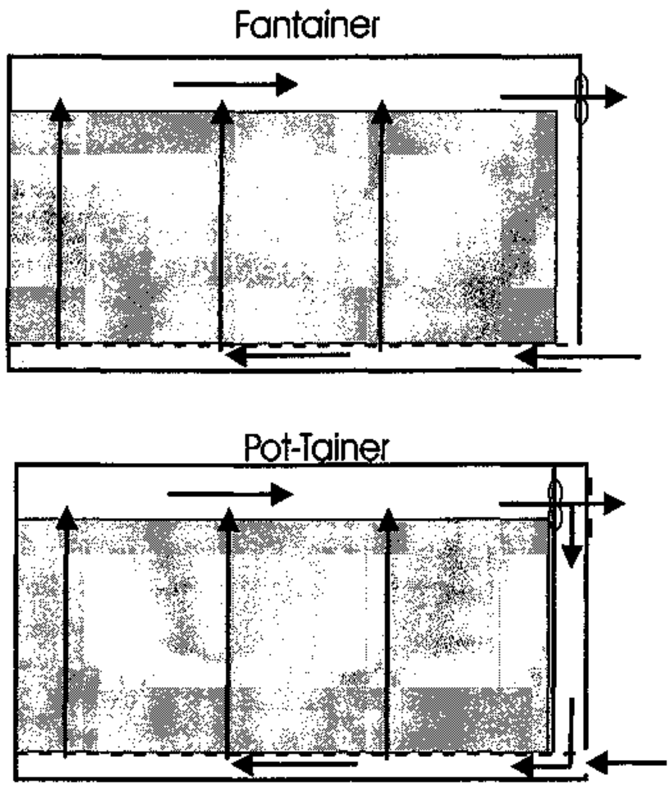


Fig 2.2 Diagrammatic representation of Door-ajar and P&O Faintainers, and Door-agar and their conversion to P&O Pot-Tainers

2.3.1.2 General description of a Pot-Tainer

Whereas onions require a low humidity, and store best under continual ventilation with fresh air, potatoes require a high humidity (as close as possible to 95%RH). To achieve this the Fantainer is modified to recirculate air, and additional components are added to admit just sufficient fresh air to maintain the humidity within the container at the desired level. An electronic humidity probe is used to sense the internal humidity, feeding to an electronic controller that drives a damper motor via a custom-made actuating arm (all three components can be sourced from the air conditioning industry). A description of the components, and an estimate of costs, is given in **Table 2.5**).

Table 2.5: Components and costing for Pot-Tainer conversion

Component	**Description**	**Characteristics**	**Approximate price (one-off)**
Fan	300mm axial flow fan	See Fig. F3	$150
Cable and plug	Three phase power cable with Wilco plug		$35
Humidity sensor	Vaisala, Model HMD 50U		$270
Electronic controller	Landis and Stäfa RWX62.5030		$400
Damper motor	Landis and Stäfa SQE 65.12		$130
Transformer to power RH sensor, controller and motor	RS Components 208-585	415v →24v	$30
Rotary valve Actuating arm	Valve cut from Formply Actuating arm custom made of stainless steel with ball joints at each end.		$100
Labour, mechanical and electrical installation			$75
P&O Pot-Tainer: Bulkhead (half-width) Labour			$50
Door-ajar Pot-Tainer: Bulkhead (full width plus half-width)			$100
Labour for installation			$100
Total cost	-	-	**$1300**

The airflow modifications consist of a full-width bulkhead; its function is to create a duct through which the greater part of the air stream leaving the fan is directed down to the airflow floor. The bulkhead carries only the weight of the fan, so need not be more substantial than is required to resist normal rough handling: it can be made of plywood or chipboard, with appropriate timber cross-bracing, the heavier the material, the less cross-bracing is required.

With both types of container, the bulkhead is spaced approximately 300mm in from the doors of the container. While this appears to represent a loss of 5% of the loadspace, the actual loss is negligible for palletised produce. The internal dimensions of a general-purpose container are approximately 2370mm wide x 5940mm long. These dimensions suit pallets 1100mm x 1100mm, leaving adequate side clearance for loading, and a surplus length of approximately 300mm, which is the size required for the return air duct.

Admission of fresh air is governed with a rotary valve driven by the damper motor via an actuating arm. The rotary valve can be made of 'Formply' (water-resistant plywood, the surface of which is finished with a low-friction plastic) and mounted on a custom-made bearing.

2.3.1.3 P&O Pot-Tainer conversion

This conversion requires a full-width bulkhead spaced approximately 300mm from the doors. The fan normally used in this container is relocated from the door to the upper, left-hand side of the bulkhead immediately behind its original location, and the rotary valve is fitted in its place. Fresh air enters as in the unmodified container

2.3.1.4 Door-ajar Pot-Tainer conversion

A fan is fitted to the inner, full-width bulkhead, high on the right-hand side. The rotary valve is fitted over a hole in the outer bulkhead aligned on the axis of the fan, and a fresh air inlet vent is cut low in the outer bulkhead

2.3.2 Potatoes, curing and fungicide treamtents

2.3.2.1 The potatoes

The majority of the stow in the Pot-Tainer was *Desiree* variety. White-skin *Sebago* variety was however chosen for the disease control experiment. This decision was based on a desire to have data for comparison with a proposed export shipment to Asia, planned to comprise of a white-skin variety.

The *Sebago* potatoes were freshly harvested in Victoria and packed, trucked to Sydney and delivered to CSIRO by Murphy's Produce at Flemington Markets, arriving three days after harvest.

2.3.2.2 Experimental design: wounding, curing and inoculation

Temperature profile for simulated voyage: The three transport systems were exposed to the temperature regime described in the earlier section of this report.(section 2.1.3.4)

Artificially wounded potatoes were used in the experiment since in any commercial handling and shipping protocol it is unrealistic to expect to entirely eliminate injured product.

In previous Spudrobe experiments potatoes were treated with the postharvest fungicide Carbendazim. In this experiment TBZ was selected. Both belong to the same family of thiobendazole chemicals. The latter was chosen because it is currently registered for postharvest use on potatoes.

Four treatments were replicated in each of the three transport systems. These were inoculated with *Fusarium* only (*Fusarium semitectum*). In addition, a further four treatments were incorporated into the Pot-Tainer. These were inoculated with *Erwinia* bacteria (*Erwinia caratovora*). These treatments were inoculated only with erwinia based on our previous finding that this bacteria does not readily infect wound sites in the absence of *Fusarium*. When *Fusarium* is present as a primary wound infection *Erwinia* enters as an opportunistic secondary infection. The incorporation of both *Fusarium* and *Erwinia* inoculated treatments into the Pot-Tainer was designed to further test this finding under simulated export conditions.

Two pathogenic controls, one inoculated with *Fusarium*, the other with *Erwinia*, were universal to the three transport systems. These were stored outside them, in the container test facility. The controls were exposed to the same temperature regime as the treatments contained within the transport systems.

Each treatment contained forty potatoes, divided as four replicate groups of ten potatoes. The treatments are described in **Table 2.6:**

Table 2.6: Summary of treatments for Test room voyage simulation

Transport Technology	Sample	Cured[2]	Order of treatment[1]	Innoculation	Dip Treatment
Pot-Tainer	1	Yes	WCI	*Fusarium* only	TBZ
	2	Yes	WCI	*Fusarium* only	Water
	3	Yes	WCI	*Erwinia* only	TBZ
	4	Yes	WCI	*Erwinia* only	Water
	5	No	WI	*Fusarium* only	TBZ
	6	No	WI	*Fusarium* only	Water
	7	No	WI	*Erwinia* only	TBZ
	8	No	WI	*Erwinia* only	Water
Spudrobe with humidity control	9	Yes	WCI	*Fusarium* only	TBZ
	10	Yes	WCI	*Fusarium* only	Water
	11	No	WI	*Fusarium* only	TBZ
	12	No	WI	*Fusarium* only	Water
Spudrobe with once-through ventilation	13	Yes	WCI	*Fusarium* only	TBZ
	14	Yes	WCI	*Fusarium* only	Water
	15	No	WI	*Fusarium* only	TBZ
	16	No	WI	*Fusarium* only	Water
Pathogenic controls	1	No	WI	*Fusarium* only	Water
	2	No	WI	*Erwinia* only	Water
Low temperature controls[a]	1	No	None	None	Water
	2	No	None	None	Water
	3	No	None	None	Water
	4	No	None	None	Water

[1] W-I-C = wound then innoculate then cure

W-C-I = wound then cure then innoculate

W-I = wound then innoculate (not cured)

[2] Cured in a Spudrobe at 17°C, 93%RH for 5 days

[a] Stored at 10C, 68%RH (average weight loss 1.5% over the duration of the trial)

2.3.2.2.1 Curing

Where potatoes were cured, the process was carried out in the Spudrobe. The potatoes to be cured were packed into 20kg hesian bags and placed in the Spudrobe for 5 days. The temperature was held at 18°C and the relative humidity inside the Spudrobe was maintained at 98%.

2.3.2.2.2 Wound Type

The wound type chosen for the experiment was a scratch. Though this is not a severe injury laboratory results have indicated that *Fusarium* will, under favourable conditions, readily infect sites of minor tissue damage. It can be assumed therefore that any infection seen in a scratch wound would be amplified in more severe wound types, thus illustrating the importance of minimising all injuries to tubers intended for export at ambient temperatures.

2.3.2.2.3 Inoculation

Wound sites were inoculated with 30µl of either:

- a four day old *Fusarium* hyphal suspension in sterile water or
- an 18 hour old *Erwinia* nutrient broth.

2.3.2.2.4 Treatment Dips

After inoculation wound sites were allowed to dry before treatment dips were applied. This ensured that the inoculum would not be washed out of the wound or diluted by the dipping process.

There was no reuse of dips; a fresh dip was prepared for each treatment, including the controls. In this way the chance of cross contamination between treatments was minimised. The potatoes were dipped for sixty seconds.

2.3.2.2.5 Packaging

Treatment dips were allowed to dry fully before the potatoes were packed and loaded into the transport systems; previous laboratory studies indicated the presence of free water on potato surfaces is a strongly predisposing factor in soft rot development.

All treated potatoes were packed in commercial 20kg hesian bags. Each bag contained only forty treated potatoes so to make up the bag weight to 20kg healthy, undamaged, untreated potatoes were added.

2.3.2.2.5.1 Pot-Tainer

The Pot-Tainer contained both *Fusarium* and *Erwinia* inoculated treatments. To minimise the risk of cross contamination the two were packed into separate bags. There was a total of eight bags.

The eight bags were loaded onto pallet 8, the second pallet back from the door end, on the left hand side of the Pot-Tainer. The *Erwinia* inoculated bags were stacked into layer 5 and the *Fusarium* inoculated bags into layer 6 above. This was a deliberate packing arrangement; if the *Erwinia* inoculated potatoes became infected with bacterial soft rot it was important to prevent them dripping onto, and contaminating, other treatments below.

2.3.2.2.5.2 Spudrobe Fantainer

Potatoes inoculated with *Fusarium* only were used in the Spudrobe and Fantainer. One replicate group of ten potatoes from each treatment was packed into each bag, making a total of four bags each for the Spudrobe and Fantainer.

Treatment bags were spaced equally throughout the depth of the Spudrobe and Fantainer; if differences arose due to location they would be detected. Bags of untreated potatoes were used to separate treatments, thus reducing risk of cross infection. The packaging arrangement is shown in **Fig 2.3**

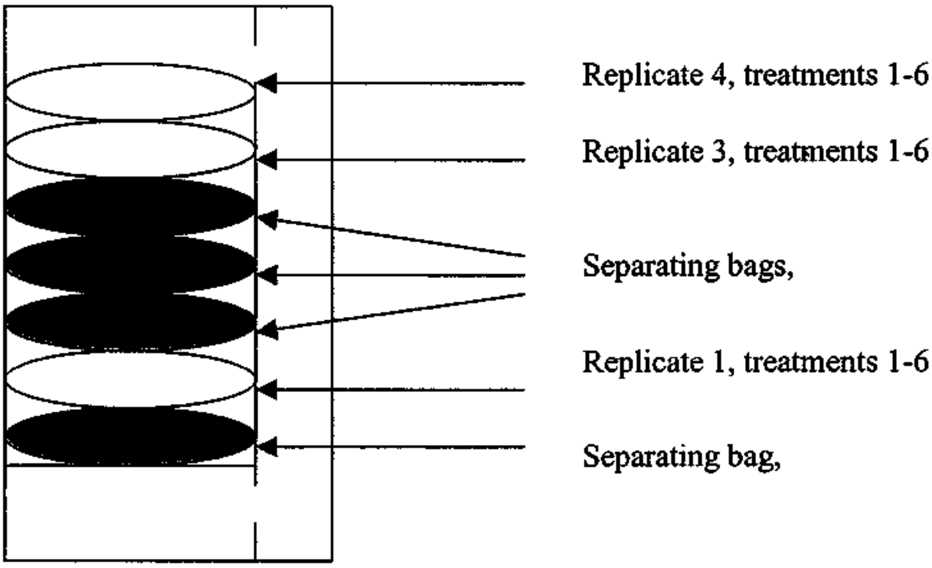


Fig 2.3 Loading pattern of treated potatoes in the Spudrobe

2.3.2.2.6 Scoring levels of infection

At the conclusion of the simulated export shipment the treated bags were removed from the Pot-Tainer, Spudrobe and Fantainer and examined for rot development and sprouting. Rot development was measured using a rating scale. The scale ran from 0, representing no rot development to 7, representing severe infection and tissue necrosis. The entire rating scale is shown in **Table 2.7**. The spread of the rot laterally beyond the original wound was also measured.

Table 2.7: Scoring scales for *Fusarium* and *Erwinia* infections

Fusarium infection			*Erwinia* infection		
Score	Percentage of wound site infected	Mycerial growth absent, ceased or active[1]	Score	Percentage of wound infected	Mycerial growth absent, ceased or active
0	0	Absent	0	0	Absent
1	< 25%	Ceased	1	< 25%	Ceased
2	> 25%	Ceased	2	> 25%	Ceased
3	1 – 25%	Active	3	1 – 25%	Active
4	26 – 75%	Active	4	26 – 75%	Active
5	> 75%	Active	5	> 75%	Active
6	> 100%	Active + [1]	6	> 100%	Active + [3]
7	> 100%	Active ++ [2]	7	> 100%	Active ++ [4]

[1] mycelial growth active, tissue necrosis extends laterally and vertically 0 – 10mm beyond the wound site

[2] mycelial growth active, severe hyphal growth and severe necrosis of tissue laterally and vertically >10mm beyond the wound site

[3] active rot extends laterally and vertically beyond wound

[4] extremely severe tissue necrosis extends laterally and vertically far beyond wound.

2.4 Trial shipment: Melbourne → Hong Kong (April/May 1999)

The aim of this trial was to evaluate the performance of the Pot-Tainer system for non-refrigerated transport of potatoes from Melbourne to Hong Kong, under conditions recommended for handling and export of Australian potatoes (developed during this project).

2.4.1 Description of containers and their loads

The trial involved two 6m (20') container loads of potatoes, comparing a Pot-Tainer based on a P&O Fantainer with a conventional refrigerated container ('reefer') (see **Table 2.8.)**

Table 2.8: Description of containers used for export trial

Container (container number)	Temperature & humidity setpoints	Description of stow	Total weight of potatoes (nominal)
Pot-Tainer (OCLU 904 302 8)	**Temperature**: not controlled **Humidity**: 92% RH	Potatoes packed in 20kg jute bags, palletised on pallets 1000x1200mm square, stretch-wrapped with highly perforated plastic film.	720bags x 20kg = 14,400kg
Refrigerated container (GCEU 201 077 1)	**Temperature:** 8°C, **Humidity:** not controlled	Potatoes packed in 20kg jute bags, Eleven layers hand-stowed onto pallets placed on the T-bar floor of the container	640 bags x 20kg = 12,800kg

This was a commercial shipment made by Southern Choice. The potatoes were grown in the Mt Gambier region of South Australia, mechanically harvested, washed, bagged in jute, palletised on Australian Standard pallets, and trucked to Farm Fresh, near the wharves in Melbourne where they were re-palletised on export pallets, and 'stuffed' into the containers. They were then trucked to the wharf and held on power in the refrigerated container holding area while awaiting shipment.

The shipping company agreed to monitor both containers twice daily to ensure they were on power and operating throughout the time the containers were in their care. Spare parts and instructions for the Pot-Tainer were supplied to the vessel in case they were needed for repairs (ships always carry spare parts and manuals for refrigerated containers). The containers were loaded in Melbourne then shipped to Hong Kong (see **Table 2.9**). After the shipment, no shipment records were made available to us because of a claim made by the exporter against the shipping company.

Table 2.9: Details of voyage from Melbourne to Hong Kong

Shipping line	:	P&O Nedlloyd
Vessel	:	Aramac
Place containers were 'stuffed'	:	Farm Fresh Distribution, Footscray
Date containers were 'stuffed'	:	27 April 1999
Date of sailing from Melbourne	:	30 April 1999
Route	:	via East Coast
Date of arrival in Hong Kong	:	17 May 1999
Place of outturn	:	PARKnSHOP, Sheung Shui, NT, Hong Kong
Date of outturn	:	18 May 1999

2.4.1.1 Potato Variety

The bulk of the load for the two containers was made up of Nardin variety, packaged in 20 kg jute bags. These were neither cured nor treated with fungicide. The remainder consisted of thirty 20 kg bags of red-skin Pontiac variety, which had been dipped in TBZ fungicide 500ppm immediately after grading.

2.4.1.2 Initial assessment of mechanical damage

The handling and export protocol sets strict limits on the type and level of damage that is acceptable for export under non-refrigerated conditions. All mechanical damage other than skin grazes should be graded out since it predisposes potatoes to rot development. Damage levels were assessed prior to loading the containers.

A random sample of the stow was examined for mechanical damage prior to loading. One hundred potatoes were randomly selected from each of fifteen bags and examined for mechanical damage and other defects. Potatoes from five bags of fungicide-treated red-skin Pontiac and five of white-skin Nardin, from the Pot-Tainer load were inspected. The other five bags were taken from the Reefer load.

Mechanical damage was assessed under three categories:
- Skin grazes
- Cuts and splits
- Shatter bruises

The total bag weight before and after assessment was recorded. The weight of potatoes in each damage category was also recorded so that the damage as a percentage of total bag weight could be calculated for each category. The level of mechanical damage in each category is shown in **Table 2.10**. Each figure is an average of five bags.

Table 2.10: Mechanical damage present at time of loading

Container	Potato variety	Damage level %				
		none	skin graze	cuts/splits	shatter bruise	other
Pot-Tainer	*Pontiac*	28.6	38.5	15.5	14.7	1.8
Pot-Tainer	*Nardin*	37.7	0.6	14.3	43.6	3.8
Reefer	*Nardin*	46.9	0.8	14.5	34.6	2.4

The level of mechanical damage was higher in Nardin than in the Pontiac variety, though both had unacceptably high damage levels with regard to the export protocol. Skin grazes are the only type of mechanical damage permissible in the protocol. The combined level of cuts/splits and shatter bruises in the Nardin variety was 53.5% and in the Pontiac variety 15.1%. Such high levels of mechanical damage potentially create many easy entry points for disease organisms. Rot development may ensue, particularly if elevated temperatures occur during non-refrigerated transport. Since the bulk of the load in both containers was the Nardin variety, we were concerned about the potential for rot development in the Pot-Tainer as it encountered high ambient temperatures in the tropics. The exporter arranged an independent damage assessment of the load and decided to continue with the shipment.

2.4.1.3 Conversion of P&O Fantainer to Pot-Tainer

In its unaltered form a Fantainer consists of an unlined steel container fitted with inlet vents, a bulkhead, an air flow floor (often consisting of pallets), and an exhaust fan. The P & O purpose-built Fantainer is permanently fitted with openings for air supply and a fan. When configured properly, onion Fantainers provide once-through circulation of ambient air at a rate of approximately half a container volume per minute (empty basis), uniformly distributed beneath the air flow floor.

The electric exhaust fan normally mounted in the left-hand door of the Fantainer was removed and mounted in a full-width bulkhead, directly behind, and 230mm back from its original position. This is shown in **Photo 2.2**.

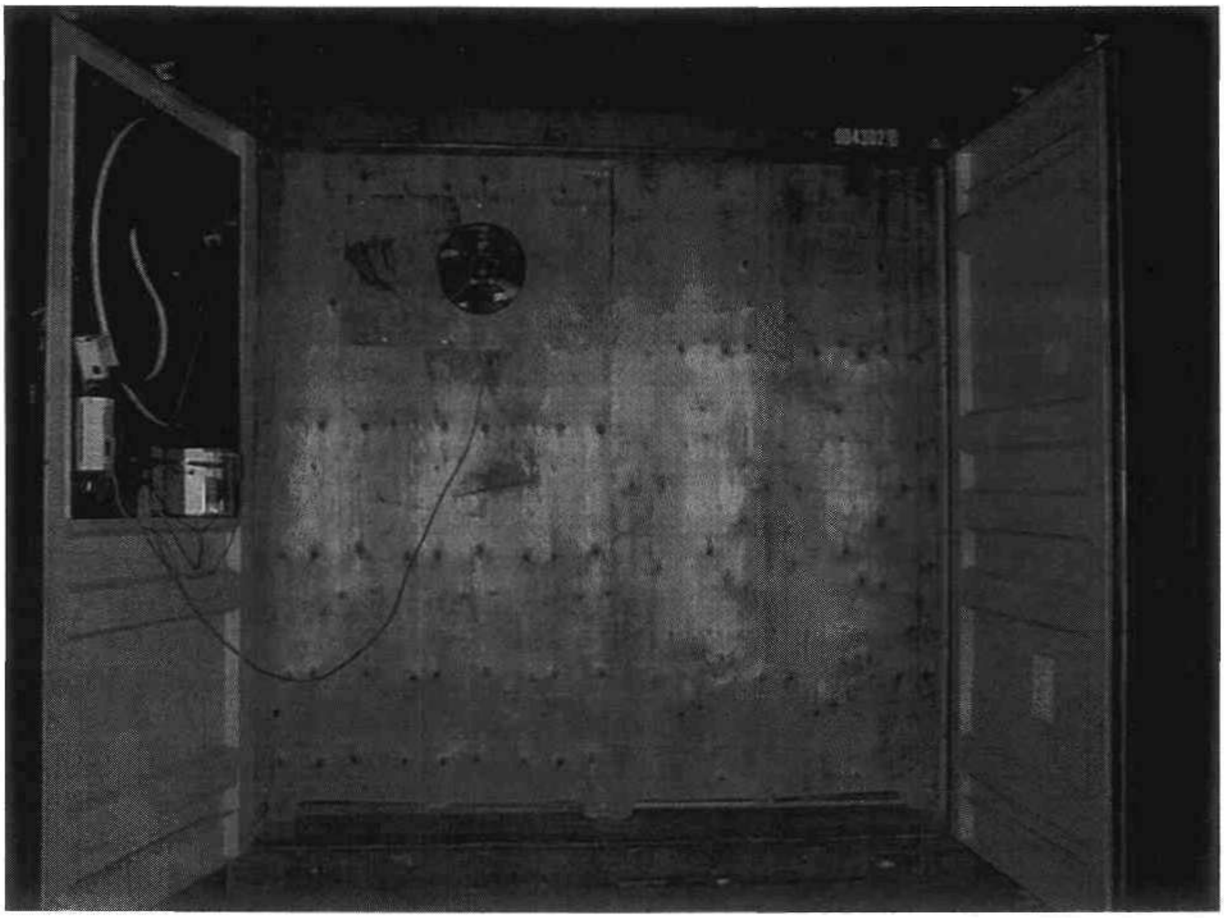


Photo 2.2 The fan and bulkhead configuration in the Pot-Tainer

The fan provides recirculation of air within the container and supplies fresh air when necessary. Telltale ribbons were located on the outer grill of the fan to indicate whether it is operational. If the vent is closed and there is uncertainty about the fan operation or the venting system itself, a waterproof switch was mounted in the fan grill and can be operated from outside the Pot-Tainer. This opens the vent, starting the telltales fluttering if the fan is operational.

The bulkhead was constructed of second-hand marine plywood. It ran from the ceiling to 100mm above the floor. When the load is stowed on pallets creating a false floor, the 100mm gap allows air to move along the pallet gap and up through the stow. The bulkhead was secured in position by horizontal bracing, locked into place against the convolutions of the container walls with wooden wedges.

The air freshening/humidity control system was identical to that used in the Testroom Simulation. The essential elements of the system are shown in **Fig 2.4**

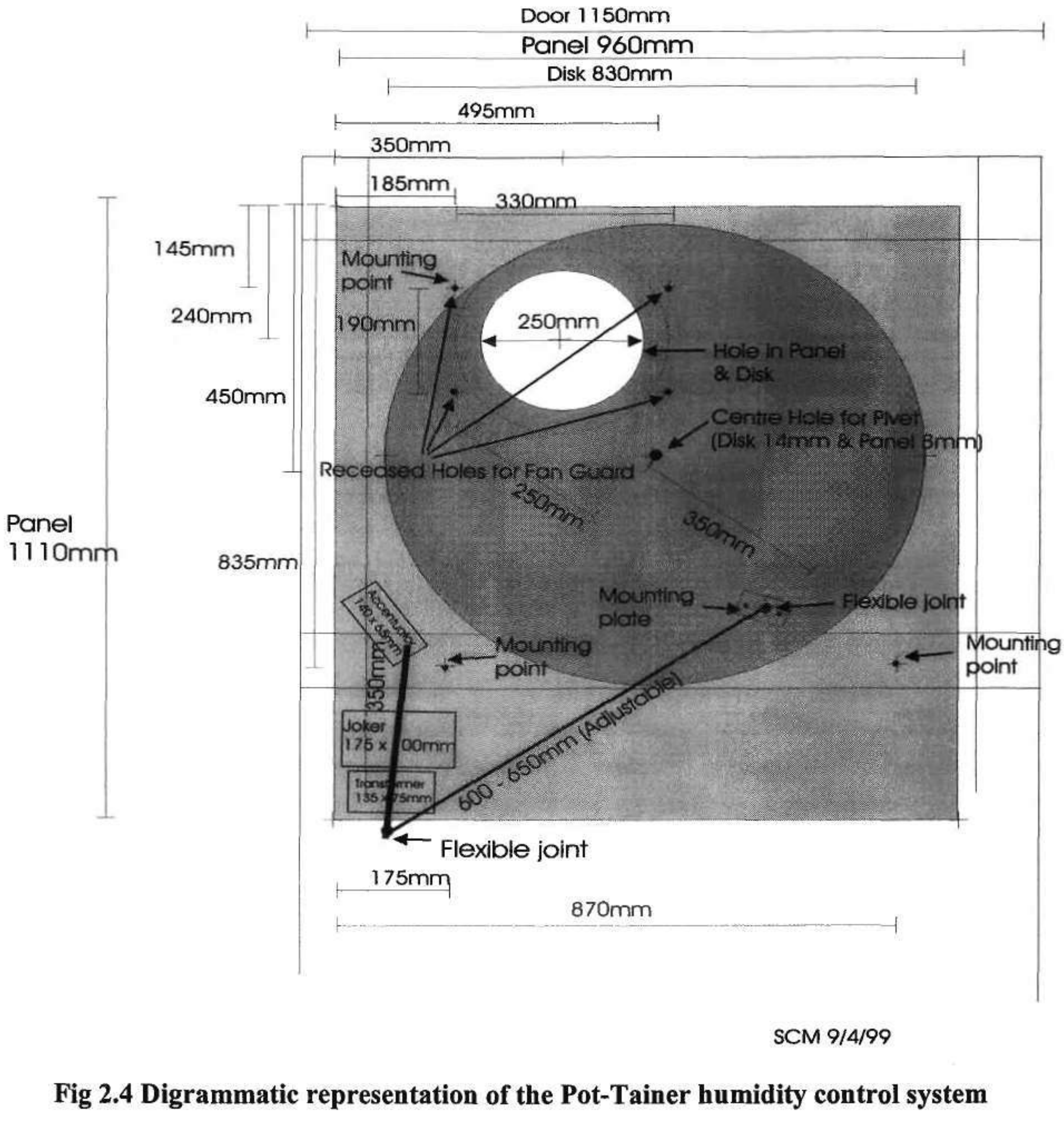


Fig 2.4 Digrammatic representation of the Pot-Tainer humidity control system

All elements of the control system were mounted on a form ply panel attached to the left hand door of the Pot-Tainer. The panel contained a circular hole of the same diameter and which aligned with the hole in the door left after removal of the fan.
A form-ply disc, attached to the door panel via a central pivot, contained a tear-drop shaped hole which was the air freshening vent. A humidity sensor (Vaisala Model HMD 50U) was mounted near the lower left corner of the form ply panel. The sensor was linked to an electronic controller (Landis & Stäfa Model RWX62.5030) that drove a damper motor (Landis & Stäfa Model SQE 65.12). This extended a pivoted arm to rotate the disc containing the air freshening vent, aligning it to varying degrees with the circular hole in the door panel.

When the RH in the Pot-Tainer was below the setpoint of 90% the vent was fully closed and the air within the Pot-Tainer was fully recirculated. When the RH was above the setpoint the controller signaled the disc to rotate, opening the air freshening vent. The fan expelled humid air from the Pot-Tainer and fresh air was drawn in through the fresh air inlet. The controller was set to maintain a relative humidity of 90% within the loadspace. The vent opened proportionally between fully open and fully closed to maintain this humidity. In this way the humidity in the loadspace could be maintained at a higher value than that of the ambient air.

2.4.2 Container loading and unloading

2.4.2.1 The refrigerated container

Temperature: Air temperatures were measured at twelve locations within the container using single-point dataloggers (Tinytag Model 12, Hastings Data Loggers). The loggers were positioned in three sections across the container. All measurements were taken on the left side of the container **(see Fig 2.5)**. Air temperature in the top and bottom layers of the stow and the delivery and return air temperatures were recorded at sixty minute intervals. The delivery air temperature was set at 8°C.

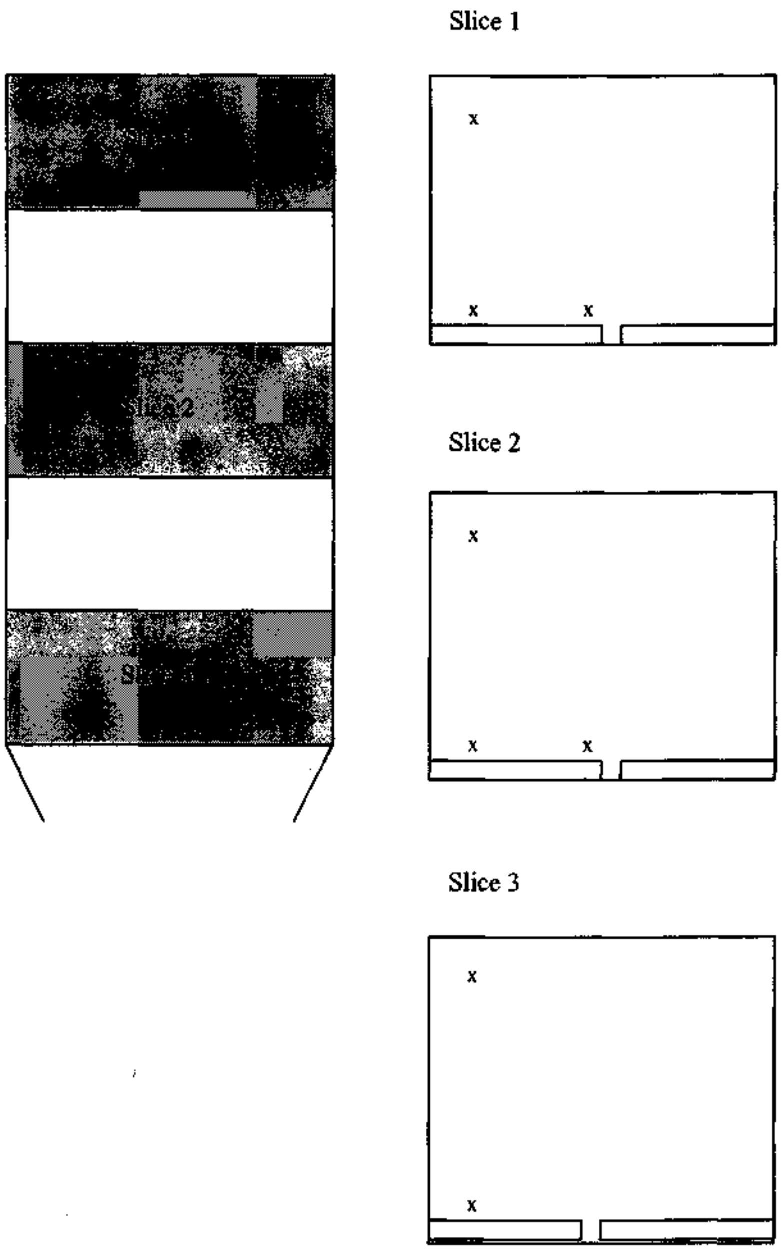


Fig 2.25 Location of air temperature measurements in the reefer

Weight loss: Five bags of Nardin were weighed prior to loading the reefer and again at outturn to assess weight loss during the journey. A further five bags were also weighed before and after loading. These bags were opened and examined at outturn to assess loss in quality and rot development. The bags were distributed throughout the stow as shown in **Fig 2.6.**

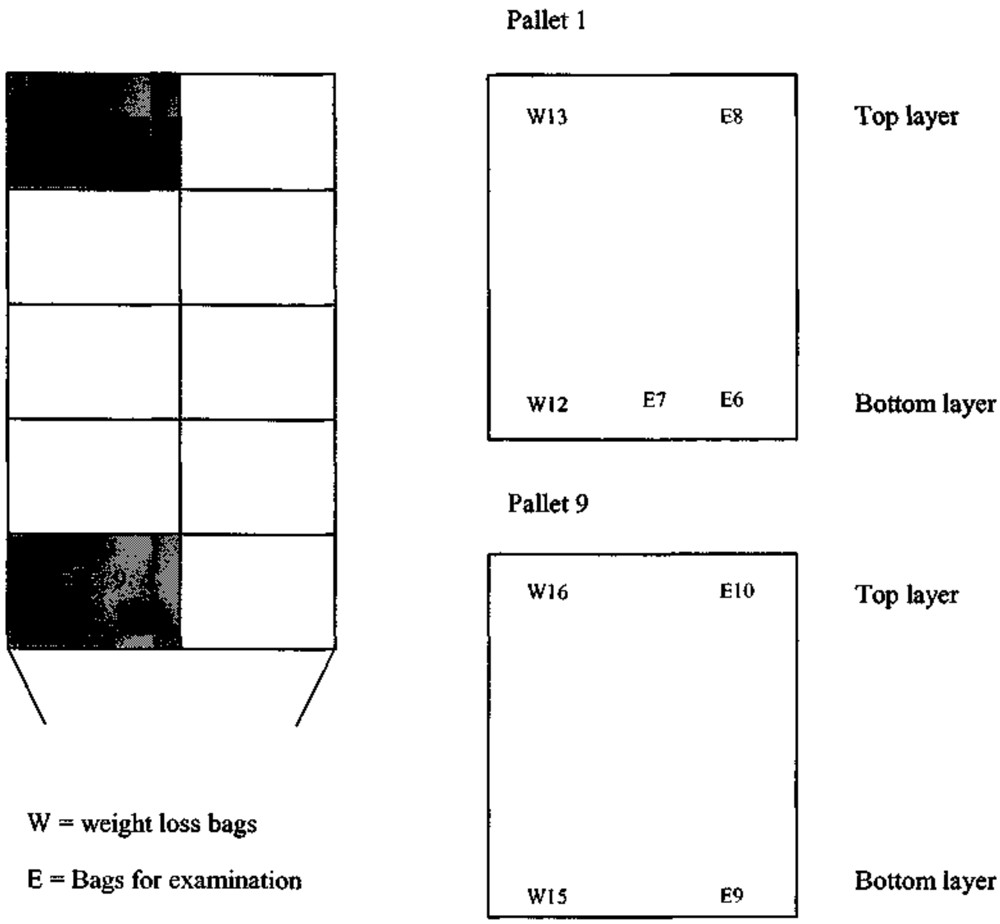


Fig 2.6. Distribution of experimental bags of potatoes in the Reefer

On arrival in Hong Kong the reefer was unstowed by hand in a refrigerated loading bay, air temperature 17°C. The bags required for weighing and examination were removed from the load and held at 10°C until they were examined the following day.

2.4.2.2 The Pot-Tainer

2.4.2.2.1 Stowage of potatoes into the container

Direction was provided to the packer that both the reefer and Pot-Tainer loads were to be hand stowed on pallets. However, at the request of the exporter the potatoes for the Pot-Tainer were palletised using a rig normally used for Fantainer palletisation of onions. The pallets themselves posed a problem. The pallet gap was only 75mm not the requested 100mm. The latter is required for good air flow along the entire length of the container. The reduced pallet gap is likely to limit this flow, possibly leading to restricted circulation through the load. The pallets contained twelve layers of potatoes in 20 kg jute bags. The loaded pallets were wrapped in ventilated plastic. This is shown in **Photo 2.3**.

Photo 2.3 Palletised potatoes with ventilated plastic wrap

The palletised potatoes were stowed in the Pot-Tainer using a forklift. Ten pallets were loaded. It was observed at the time of loading that pallet 5 contained two bags with bacterial rot, indicated by damp patches on the bags. Had the loads been hand stowed it would have been possible to remove these contaminated bags.

Palletisation of the bags restricted the spreading that would normally occur in a hand stowed load. This resulted in a gap of approximately one bag width between adjacent pallets along the centre line of the Pot-Tainer. In order to prevent short circuit of the air flow this gap had to be filled with loose 20 kg bags of potatoes.

Because the gap was uneven from top to bottom it was impossible to fill it completely. However at no point was there a complete gap from the floor to ceiling. This is shown in **Photo 2.4**.

Photo 2.4 The gap left between adjacent pallets as a result of palletisation

Palletisation of the load created a further problem. When the Pot-Tainer was fully loaded a gap of around 200mm remained between the door end pallets and the bulkhead. Left unpacked this gap would create a path for air to short circuit the rest of the stow, resulting in recirculation at the door end of the Pot-Tainer only. The gap was packed with pieces of polystyrene foam. While this left no obviously visible air channels it is unlikely that it fully sealed the space. This is shown in **Photo 2.5**.

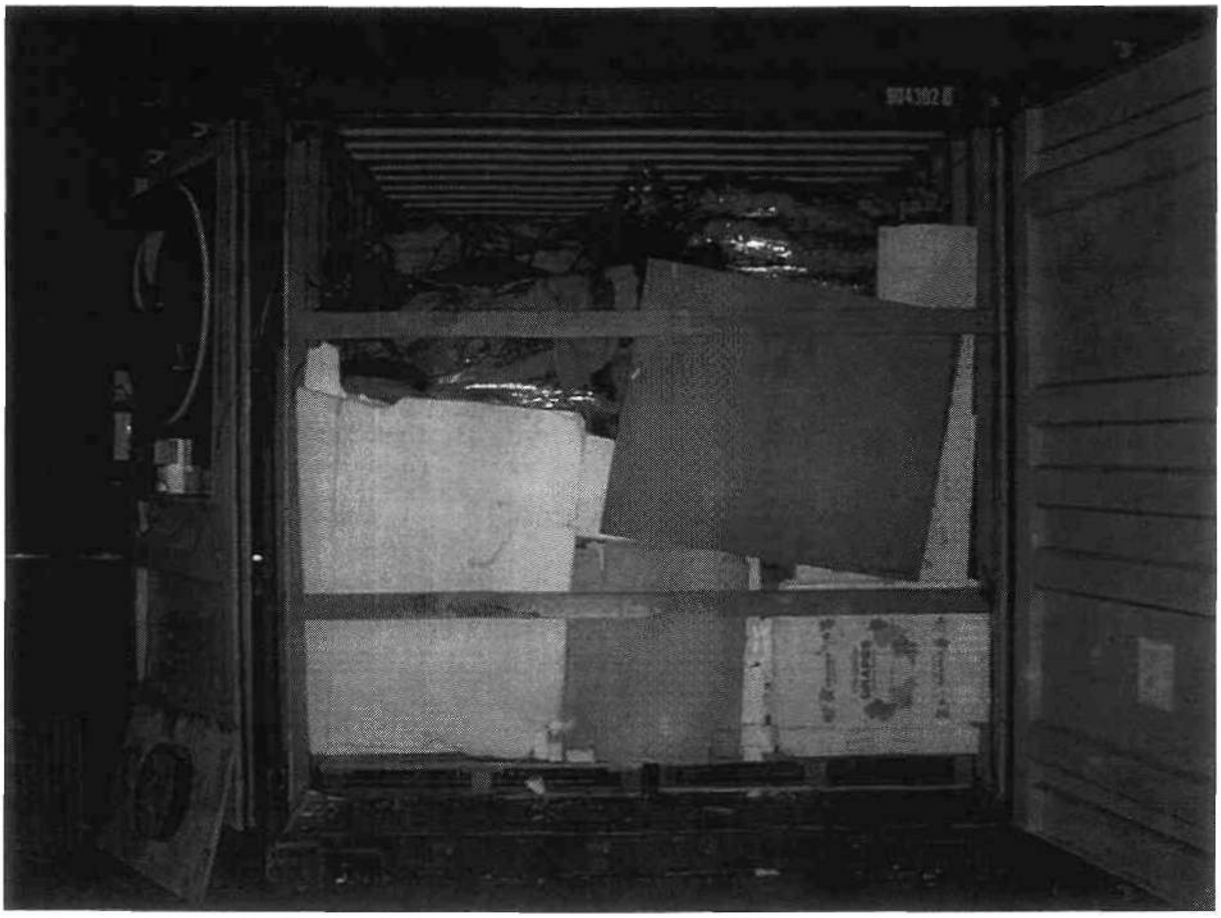


Photo 2.5 Packing of the gap between the bulkhead and the door end pallets

2.4.2.2.2 Monitoring of container and product

Temperature: Throughout the shipment product temperatures were measured in thirty positions using Type T thermocouples. The thermocouples were located in five sections across the container on the left side (see **Fig 2.7**). Each section contained 6 sensors in a 2 x 3 grid, with sensors located in layers 1, 6 and 12. The thermocouples were checked in on ice-pot (i.e. at 0°C) prior to the journey.

Ambient air temperatures outside the container were measured using two thermocouples located in the air space of the door channel adjacent to the door hinge on either door.

All thermocouple readings were recorded at sixty minute intervals throughout the shipment using multi-channel, battery-powered data loggers (Grant Squirrel 1200 series).

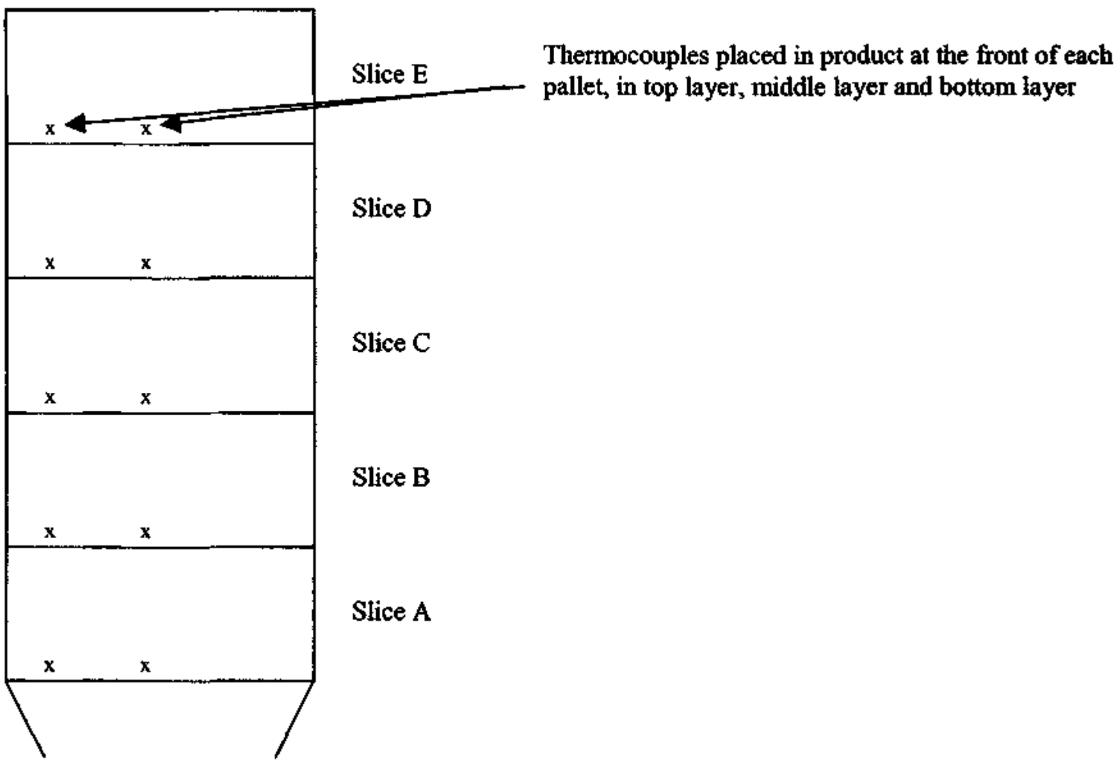


Fig 2.7. Location of thermocouples for product temperature measurement in the Pot - Tainer

Relative Humidity: Relative humidity was measured at two positions using HMP 31UT humidity probes. The humidity sensors were positioned on top of the load on the centre line, three quarters of the way along the container from the door end and at the door end. The probes were calibrated against saturated salt solutions prior to the journey. Humidity was recorded at sixty minute intervals throughout the journey using a battery powered data logger (Grant Squirrel 1200 series).

Vent opening and output from the humidity sensor: The opening of the air freshening vent and the output from the Vaisala humidity probe that controlled its operation were recorded as voltage outputs using a battery powered data logger (Grant Squirrel 1200 series). Measurements were recorded at sixty minute intervals throughout the journey.

Weight loss: The weight of eleven bags of Nardin were recorded prior to loading the Pot-Tainer. These bags were re-weighed when the container was unstuffed in Hong Kong. The weight loss during the journey was then calculated.

A further five bags of Nardin were weighed prior to loading and again at outturn. These bags were also examined at outturn for loss of quality and rot development. Five bags of fungicide treated Pontiac variety were also weighed prior to loading and again at outturn. These bags were also examined for loss of quality and rot development. These bags were distributed throughout the stow as shown in **Fig 2.8**

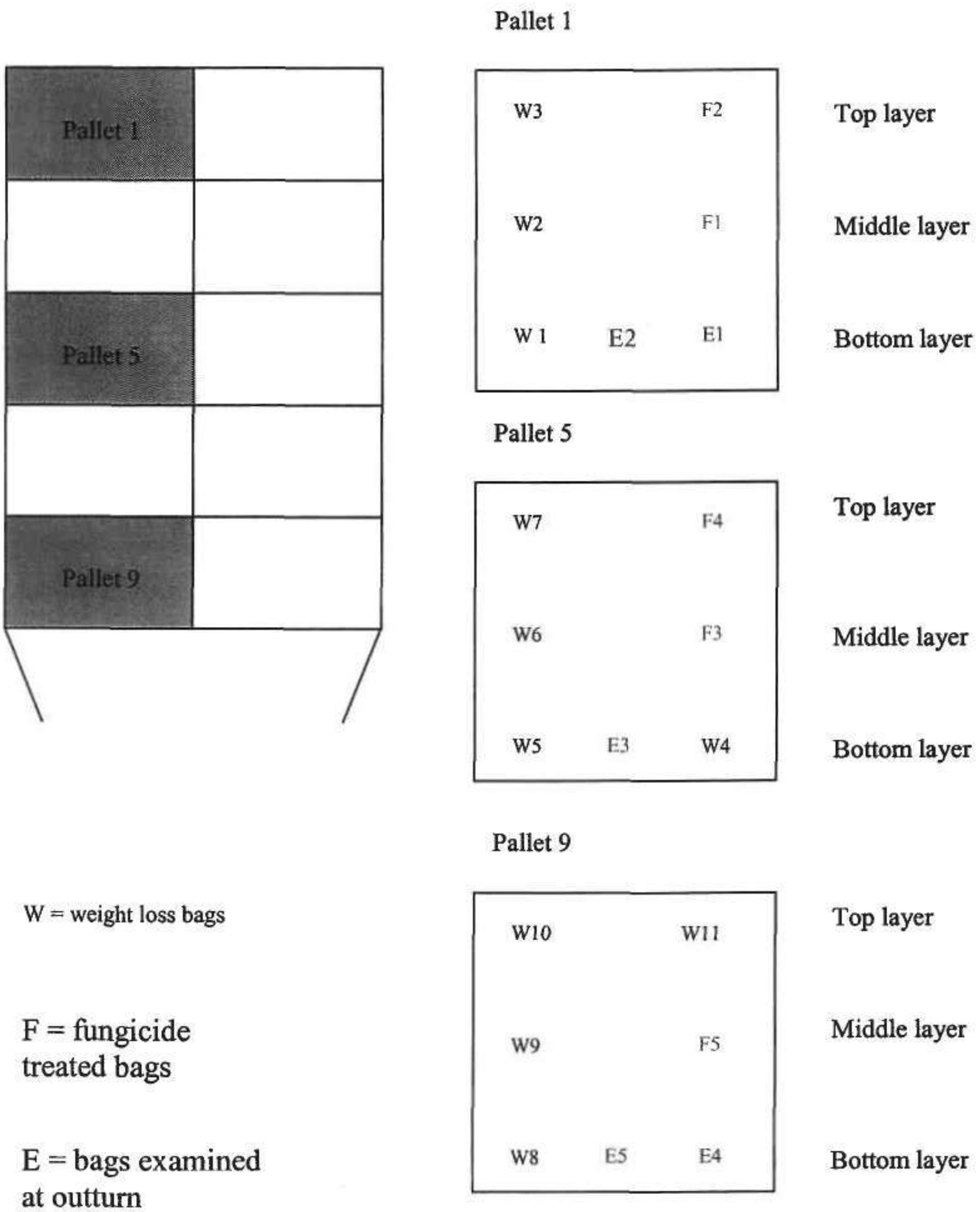


Fig 2.8 Location of experimental bags in the Pot-Tainer

On arrival in Hong Kong the Pot-Tainer was unstowed by hand. It would have been simplest to remove each pallet intact by forklift but the unusually small pallet gap (75mm) was too small to allow the tines of the forklift access. The bags required for weighing and examination were held at 10°C until the following day when they were examined.

3. RESULTS

3.1 Laboratory studies of the growth of disease organisms during storage

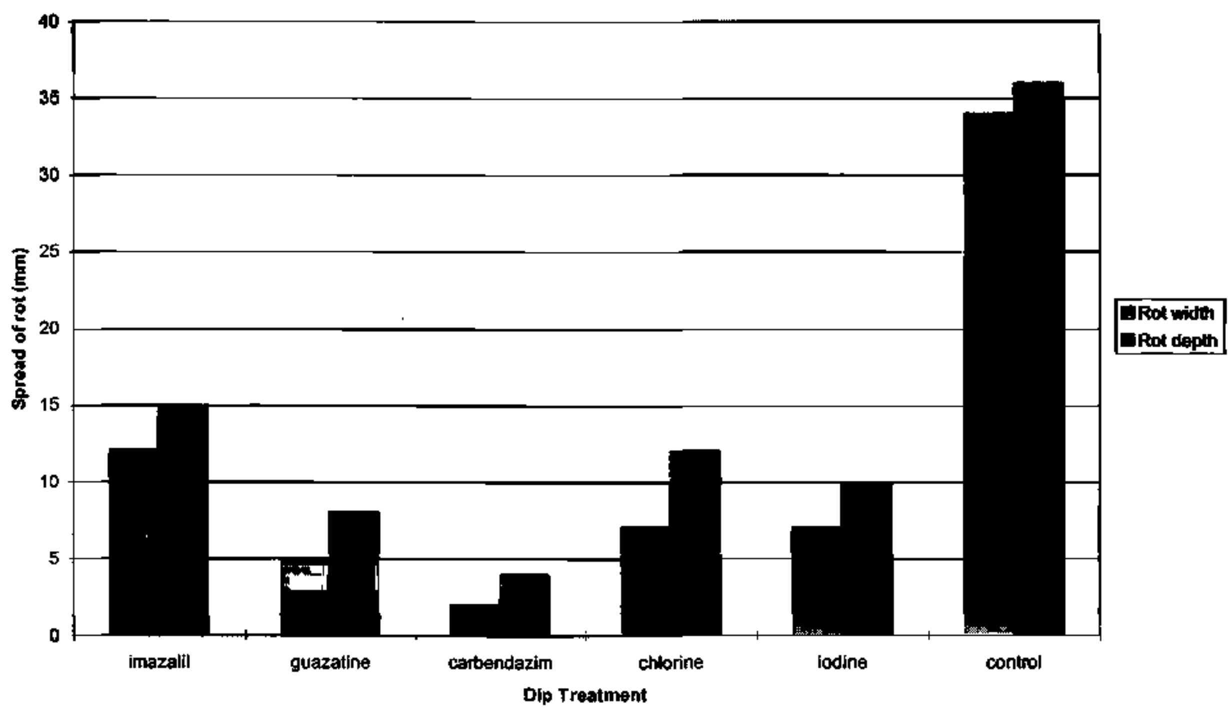
3.1.1 Effectiveness of chemical treatments

3.1.1.1 Experiment 1: fungicides and minimal residue chemicals

3.1.1.1.1 Erwinia infection

The fungicides Imazalil, Guazatine and Carbedazim, and the minimal residue chemicals chlorine and iodine were tested in Experiment 1, and the development of *Erwinia* soft rot that resulted is shown in **Fig. 3.1**.

Fig 3.1: Lateral and vertical development of Erwinia soft rot in wounded, inoculated potatoes stored in hesian sacks under conditions simulating shipment to Asia



Every treatment was highly effective in controlling soft rot infection compared to the control. Very few inoculated wounds had active soft rot present. Carbendazim gave the greatest reduction (91%), followed by Guazatine (80%). Chlorine and iodine had a similar control capacity, (around 75%) with iodine marginally superior.

The control contained a higher proportion of completely soft-rotted potatoes (66%) than any of the treatments, the highest of which was 23% (for Imazalil). A control potato completely infected with *Erwinia* soft rot is shown in **Photo 3.1**.

Photo 3.1 A potato from the control infected with *Erwinia* soft rot

Interestingly, though rotted tissue from control potatoes became smeared across wound sites of other treatments, no infection resulted, indicating that the treatments effectively prevented soft rot.

3.1.1.1.2 Fusarium infection

The extent of *Fusarium* dry rot development in Experiment 1 is shown in **Fig. 3.2**. In comparison with the control, none of the treatments gave effective protection. The best were the fungicides Carbendazim and Guazatine, which reduced the incidence of dry rot by around 20%. The development of dry rot, externally and internally, is shown in **Photos 3.2 & 3.3.**

Fig 3.2: Lateral and vertical development of Fusarium dry rot in wounded, inoculated potatoes, stored in hesian sacks under conditions simulating shipment to Asia

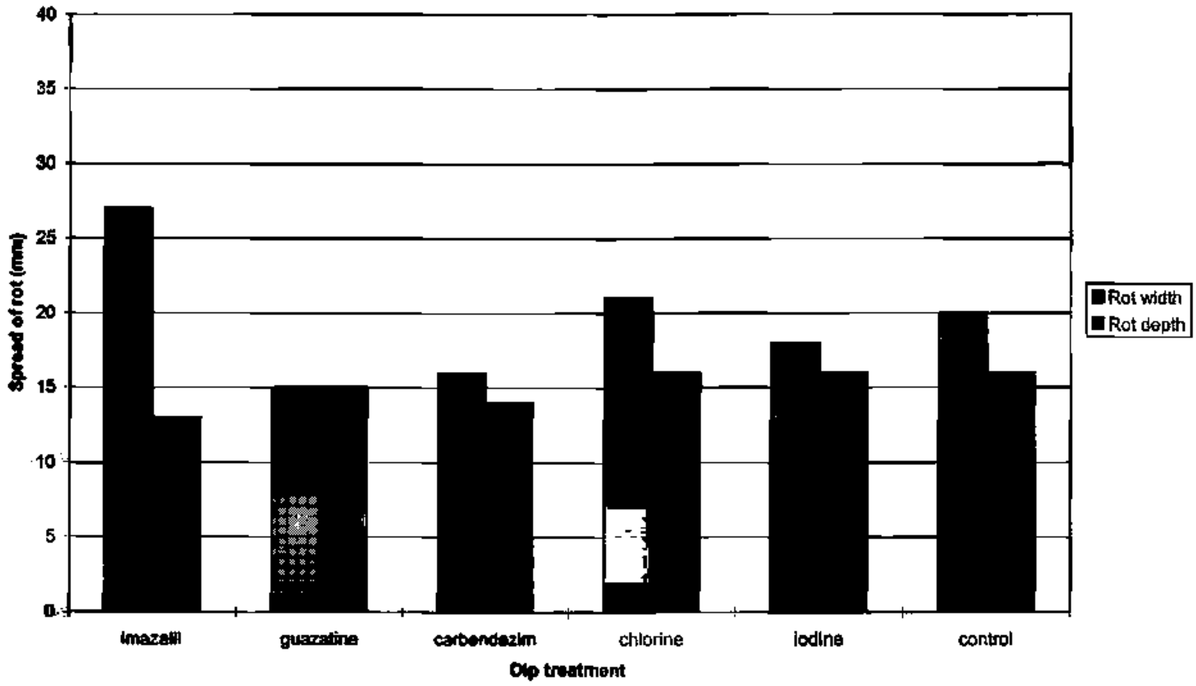


Photo 3.2 External development of dry rot

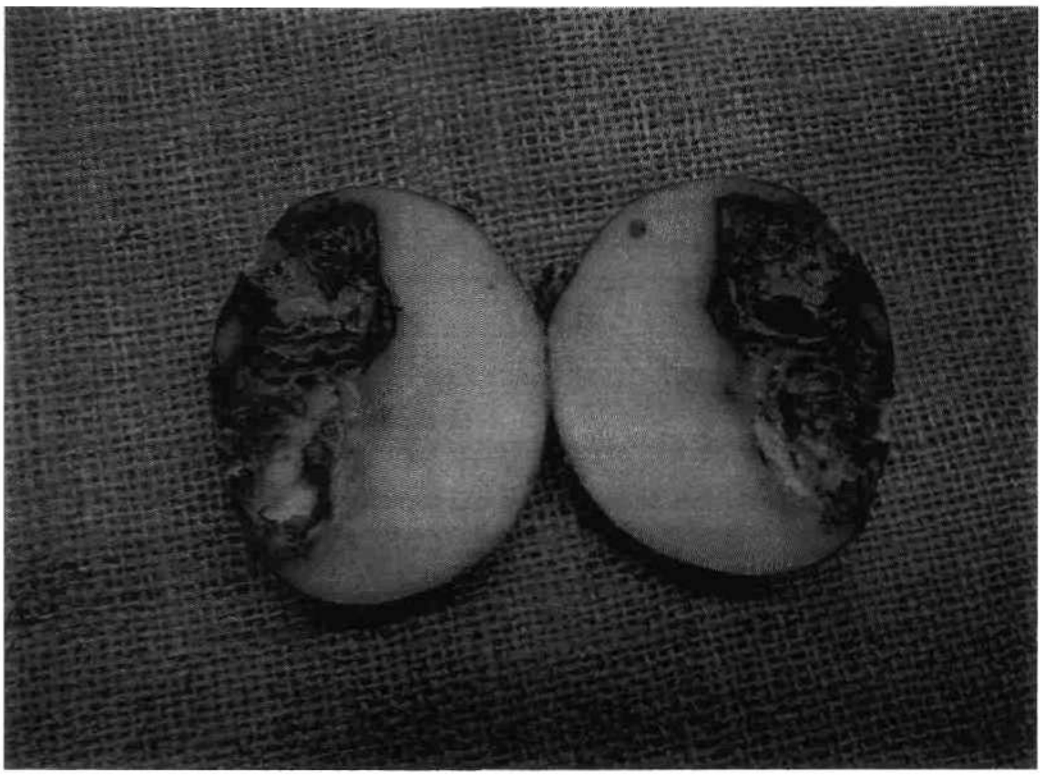


Photo 3.3 Internal development of dry rot

Extensive bacterial soft rot was observed in the potatoes that had been inoculated with *Fusarium*, indeed more than in those inoculated with *Erwinia*. 42% of *Fusarium*-

inoculated potatoes developed *Erwinia* soft rot infection, while only 22% of the *Erwinia*-inoculated potatoes subsequently developed soft rot. Cross-contamination can be ruled out as a cause, since stringent measures were taken to avoid it. Rather, as shown in **Photo 3.4**, the soft rot developed as a secondary infection, invading around the margins of the primary fungal dry rot. This suggests a synergy between the fungus and bacteria; first the *Fusarium* invades tissue that has been mechanically wounded, and later *Erwinia* enters the weakened tissue as a secondary, opportunistic infection. *Fusarium* infection appears to be a strong precursor for bacterial infection.

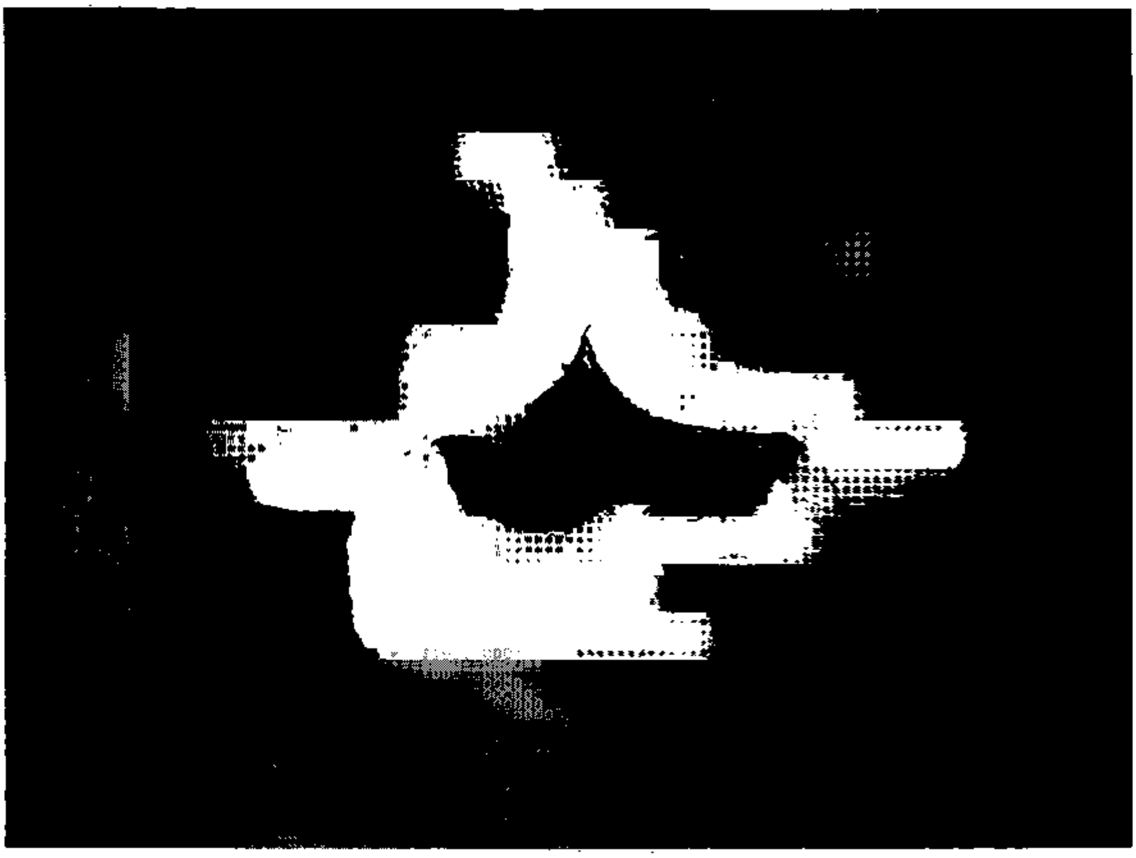


Photo 3.4 Soft rot developed as a secondary infection

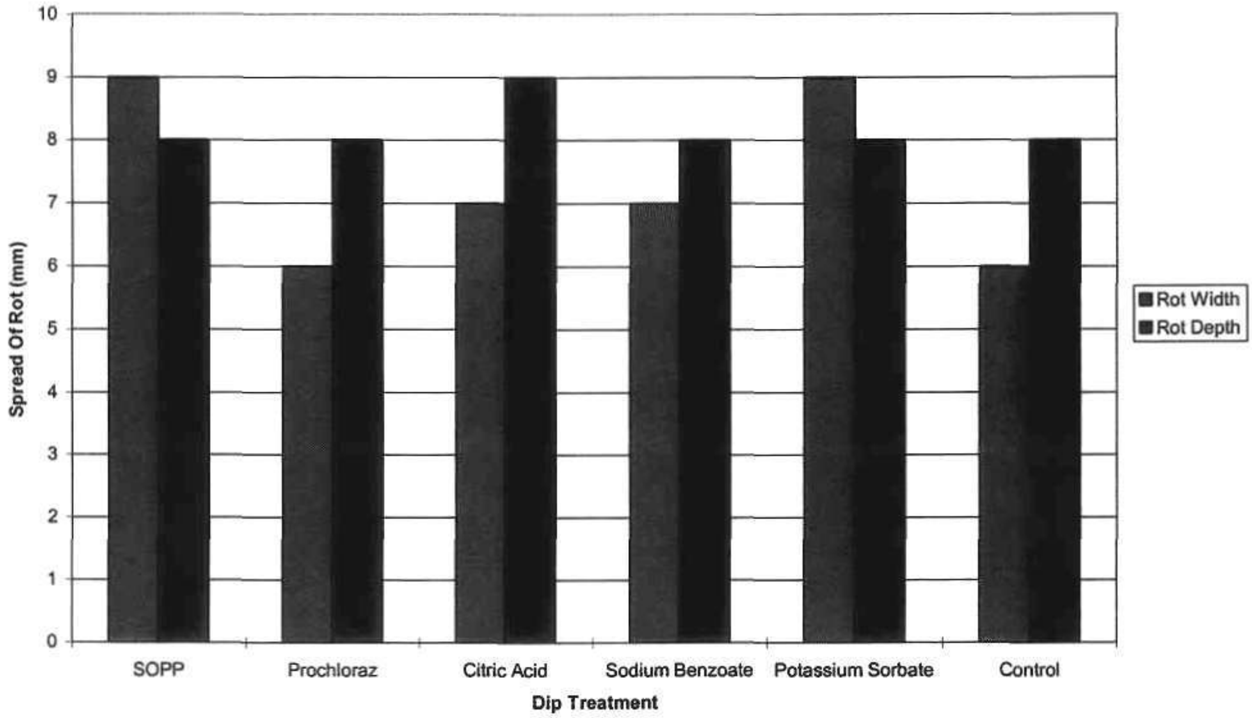
3.1.1.2 Experiment 2: fungicides and common food preservatives

The fungicides SOPP and Prochloraz, and the commonly used food preservatives citric acid, sodium benzoate and potassium sorbate, were tested in Experiment 2.

3.1.1.2.1 Erwinia infection

Incubation in conditions expected during shipment in a Pot-Tainer produced no active soft rot in any wound site, in any treatment, including the control - see **Fig.3.3**. Minor levels of rot initially detected in most wounds did not develop further. All treatments gave similar results. In terms of rot depth, the two fungicides and two of the food preservatives, sodium benzoate and potassium sorbate were identical to the control and citric acid was slightly higher. In terms of rot width, the fungicide Prochloraz was the same as the control and all other treatments were slightly higher.

Fig 3.3: Lateral and vertical development of Erwinia soft rot in wounded, inoculated potatoes, stored in hesian sacks under conditions simulating shipment to Asia.



In can be argued from these results that Erwinia soft rot is unlikely to develop in wounded potatoes under the temperature and humidity conditions expected in a Pot-Tainer shipment to Asia. A possible barrier to soft rot development is the conditions in the early part of the journey (18°C and 90% RH) that encourage natural wound healing ('curing'). This conclusion is supported by the results of the 1997 simulated 'Potainer' shipment, in which wounded potatoes inoculated with *Erwinia* and loaded as part of the stow showed no development of soft rot at outturn.

If curing prevented the rot development, then the experiment was unable to assess the effectiveness of the dip treatments. This was addressed in Experiment 3, in which the same treatments were used, but incubation conditions were more extreme to encourage *Erwinia* growth.

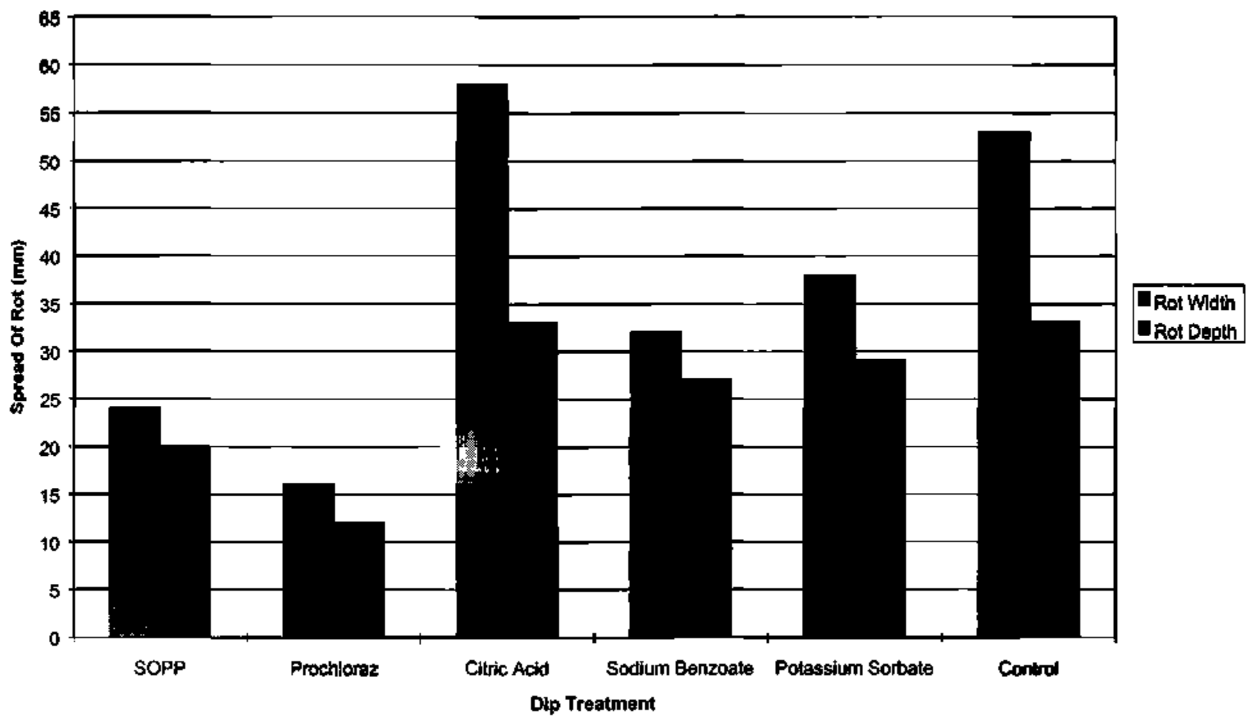
3.1.1.2.2 Fusarium infection

The development of *Fusarium* dry rot is shown in **Fig. 3.4**. All treatments except the citric acid lowered the level of *Fusarium* dry rot in comparison with the control, but the fungicides provided better rot prevention than the food preservative treatments. Prochloraz (66% reduction) was more successful than SOPP (47% reduction). Sodium benzoate was the best food preservative treatment, (34% rot reduction, compared to 15% with potassium sorbate).

Depth and width of rots were equal for most treatments, except the citric acid and control treatments where the rots were comparatively wider due to the higher incidence of secondary soft rot development.

More secondary soft rot developed in the food preservative treatments than the fungicide treatments. 38 % of tubers in the food preservative treatments showed soft rot, compared to 12% in the fungicide treatments. This again lends support to the concept of a synergism between *Fusarium* and *Erwinia*; where dry rot is prevented or reduced, so too is the incidence of secondary soft rot.

Fig 3.4: Lateral and vertical development of Fusarium dry rot in wounded, inoculated potatoes stored in hesian sacks under conditions simulating shipment to Asia

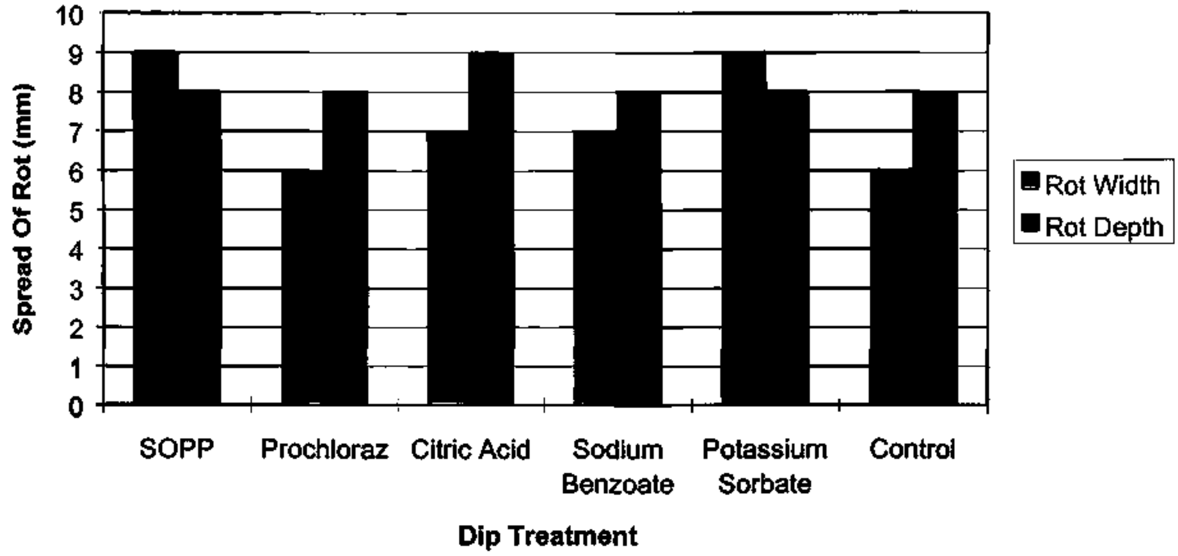


3.1.1.3 Experiment 3: aggressive incubation conditions

Incubation conditions in Experiment 3 were designed to be extreme in order to encourage *Erwinia* soft rot, and thus determine whether any of the dip treatments used in Experiment 2 may be effective in its prevention. See materials and methods 2.1.1 for incubation conditions.

The resulting development of *Erwinia* soft rot is shown in **Fig. 3.5.** All treatments except the potassium sorbate gave greater control of soft rot in comparison to the control. Both fungicide treatments were more effective than the food preservatives; Prochloraz reduced rot development by 52% and SOPP by 38%. Citric acid and sodium benzoate reduced rot development by 17% and 16% respectively.

Fig 3.5: Lateral and vertical development of Erwinia soft rot in wounded, inoculated potatoes, stored in hesian sacks under conditions simulating shipment to Asia.



Under extreme conditions of storage, when curing of mechanical injury may not be sufficient alone to prevent the development of bacterial soft rot a reduction of up to 50% can be achieved by treating tubers with fungicides prior to storage. A lesser level of protection can be achieved by treating them with citric acid or sodium benzoate.

3.1.2. Spudrobe comparison of curing and fungicide treatments

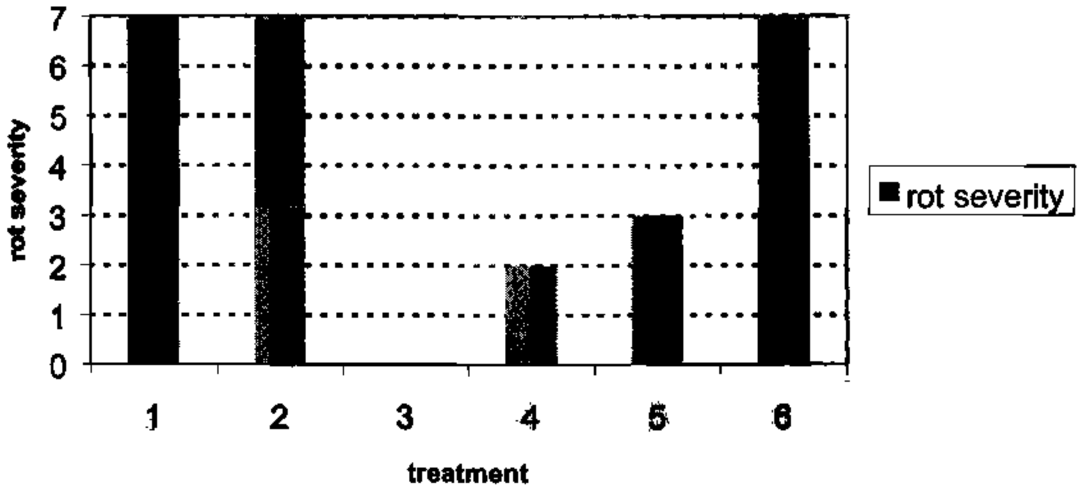
3.1.2.1 Severity of rot development

The rot severity for the six treatments described in **Table 2.1 (see materials & methods)** is shown in **Fig 3.6**. The rot severity for each treatment represents an average of the values for the eighty wound sites in each treatment. Treatment 3, the combination of curing followed by carbendazim fungicide was the most effective at preventing *Fusarium* dry rot development, with an average rot development rating of 0. This indicates total prevention of dry rot development.

Treatments 4 and 5, the cured only and carbendazim fungicide treated only were also very effective at *Fusarium* dry rot prevention. Treatment 4 had a slight edge over Treatment 5 though the two were similar. Their respective rot development values were 2 and 3.

Treatments 1 and 2 both failed to prevent *Fusarium* dry rot infection. Average rot development scores were 7 for both treatments, indicating severe rot development. These treatments were inoculated with dry rot fungus before they were cured. This indicates that once an infection takes hold curing cannot reverse it, even when as in Treatment 1, the curing is followed by a fungicide treatment. Hence, to be effective, curing or fungicide application must be carried out as soon after harvest as possible. Treatment 6, which had no curing or fungicide treatment gave as equally bad a result as Treatments 1 and 2.

Fig 3.6 Effect of postharvest curing and fungicide treatments on severity of fusarium dry rot development during a simulated summer export journey from Melbourne to Singapore



The *Fusarium* inoculated pathogenic controls were both highly infected with *Fusarium* dry rot regardless of wound type. Both had an average rot development score of 7. The *Erwinia* inoculated pathogenic control was not infected with *Erwinia* soft rot, which at first glance may appear as though the *Erwinia* isolate had lost its pathogenicity to potatoes. Based on previous laboratory studies however, the more likely explanation is that the incubation conditions were not severe enough to promote bacterial invasion.

3.1.2.2 Spread of rots

The spread of the rot infection both laterally from the wound and vertically below it mirrored the trend shown in the rot severity ratings, as would be expected. The results for the six treatments are shown in **Fig. 3.7**. Each result represents the average of eighty measurements from the forty potatoes in each treatment.

Fig 3.7 Width and depth of fusarium dry rot development in cured and fungicide treated potatoes during a simulated summer voyage from Melbourne to Singapore

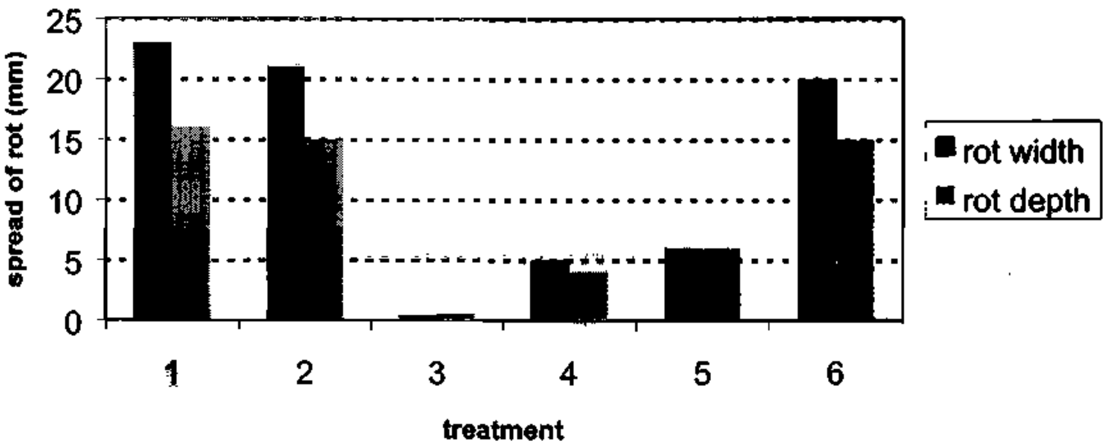
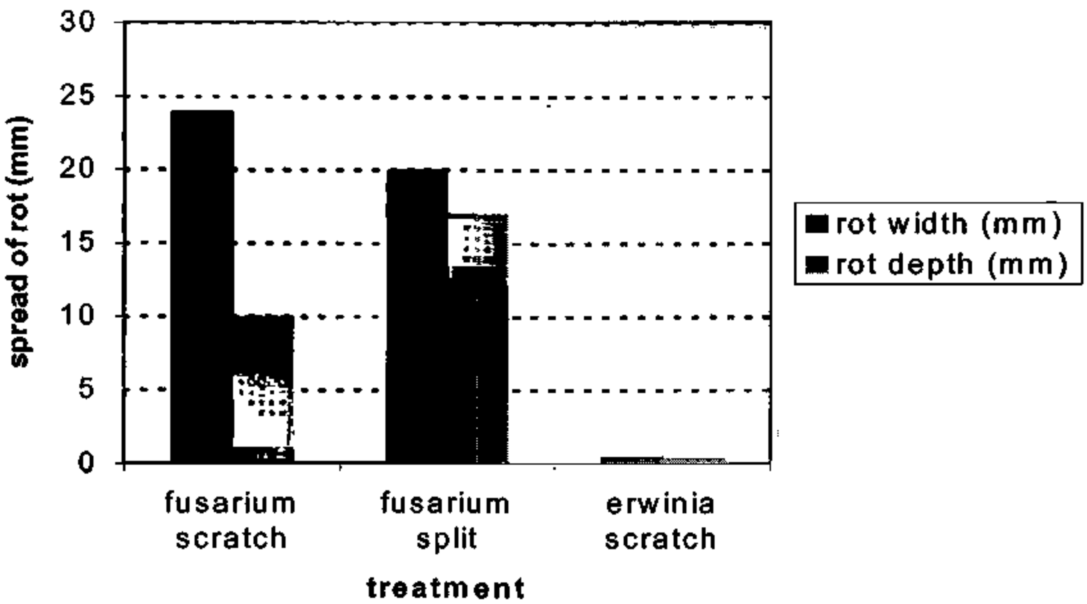


Fig 3.8 Width and depth of rot development in pathogenic controls



The spread of rot in the pathogenic controls is shown in **Fig 3.8.** The difference in rot development between the *Fusarium* and *Erwinia* controls is clearly evident. Rot development was all but absent as outlined in the previous section

3.1.2.3 Secondary Infection

Treatments 1, 2 and 6, the treatments that developed severe *Fusarium* infection also developed severe bacterial soft rot, despite the fact that these treatments were not inoculated with bacteria. Treatment 3, the curing plus fungicide treatment that almost entirely prevented dry rot development, had no bacterial infection. The remaining treatments 4 and 5, the curing only and fungicide only treatments, had very little soft rot development. Where soft rot was present it was always in potatoes with *Fusarium* infection. The soft rot was clearly a secondary infection invading tissue around the margins of the dry rot. This is shown in **Photo 3.5.** The bacteria enters the wound site as a secondary, opportunistic infection only after the *Fusarium* has macerated the potato tissue. The fact that potatoes inoculated with *Erwinia*, in the absence of *Fusarium*, developed no soft rot, lends further support to this supposition.

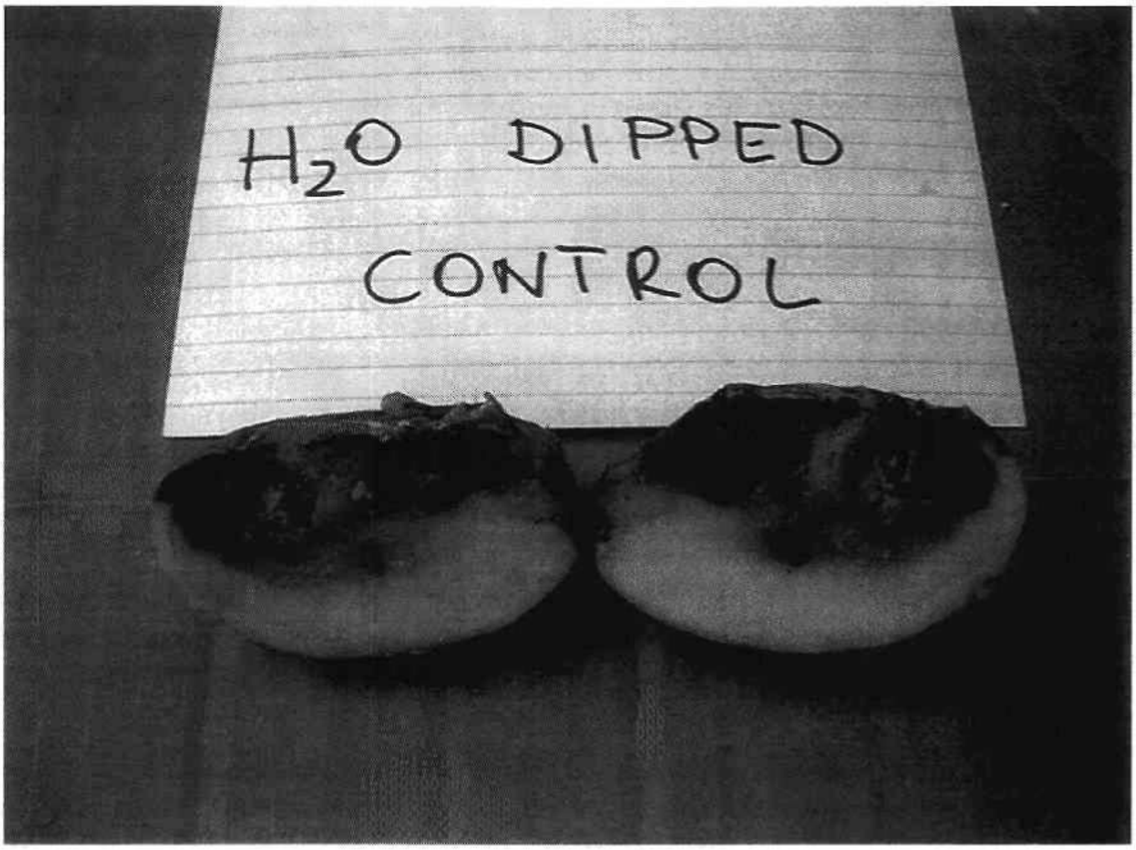


Photo 3.5 Secondary soft rot around the margins of primary dry rot

3.1.2.4 Sprouting

Sprouts had begun to emerge in every treatment by the end of the fifteen day experiment. Most potatoes in every treatment showed some sprout development. There were no differences between treatments in the number or length of the sprouts.

3.2 *Field survey*

3.2.1 District Averages

Four types of injury were found to be common to all the districts sampled as part of the field survey of harvest and postharvest handling practices. These were:

- **Skin graze**
- **Split**
- **L-shaped puncture**
- **Bruise**

The level of damage for each injury type, which includes mechanical injury and development of soft and dry rots, observed in each State, is shown as the average for farms in the State. This is shown in **Figs 3.9 - 3.11**. The stage of harvest/ grading operation at which a moderate to severe level of the four most common injury types was found for each State is shown in **Figs 3.12 – 3.14**.

Fig 3.9: Type and level of damage in New South Wales tubers during harvest and grading/packaging operations

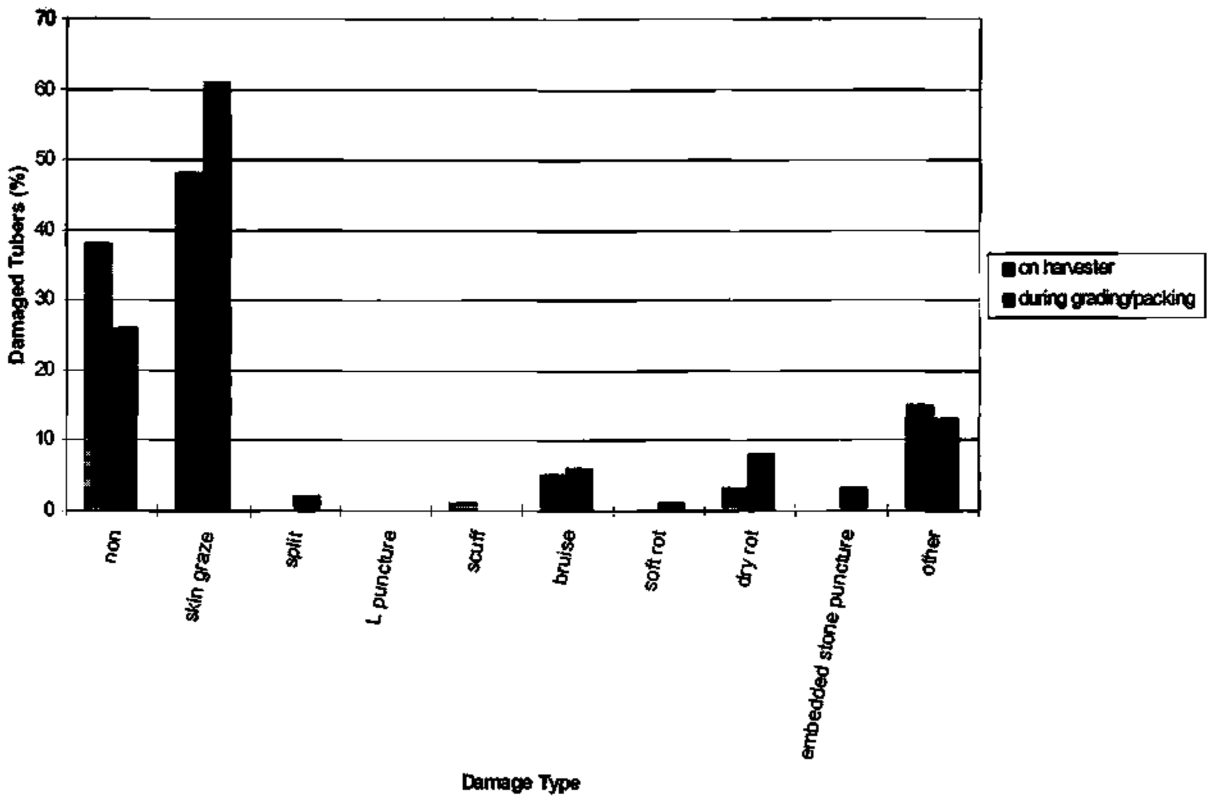
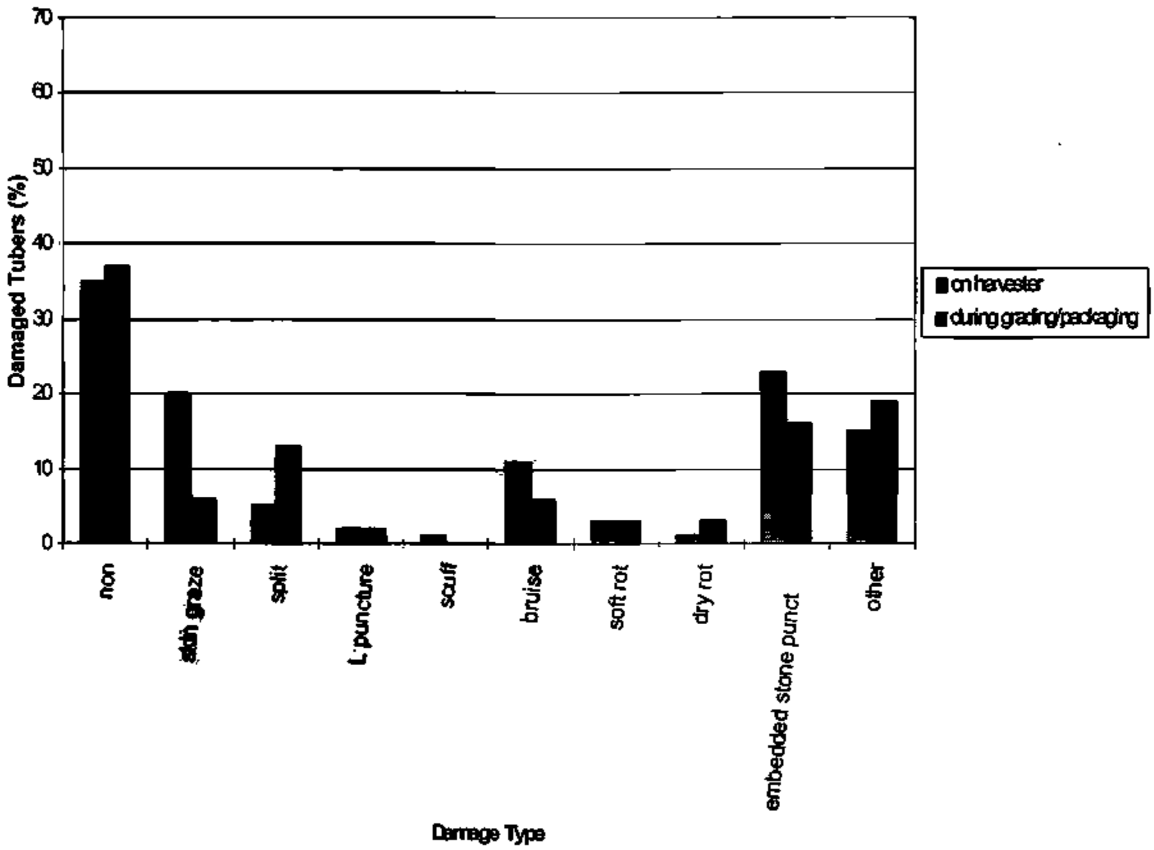
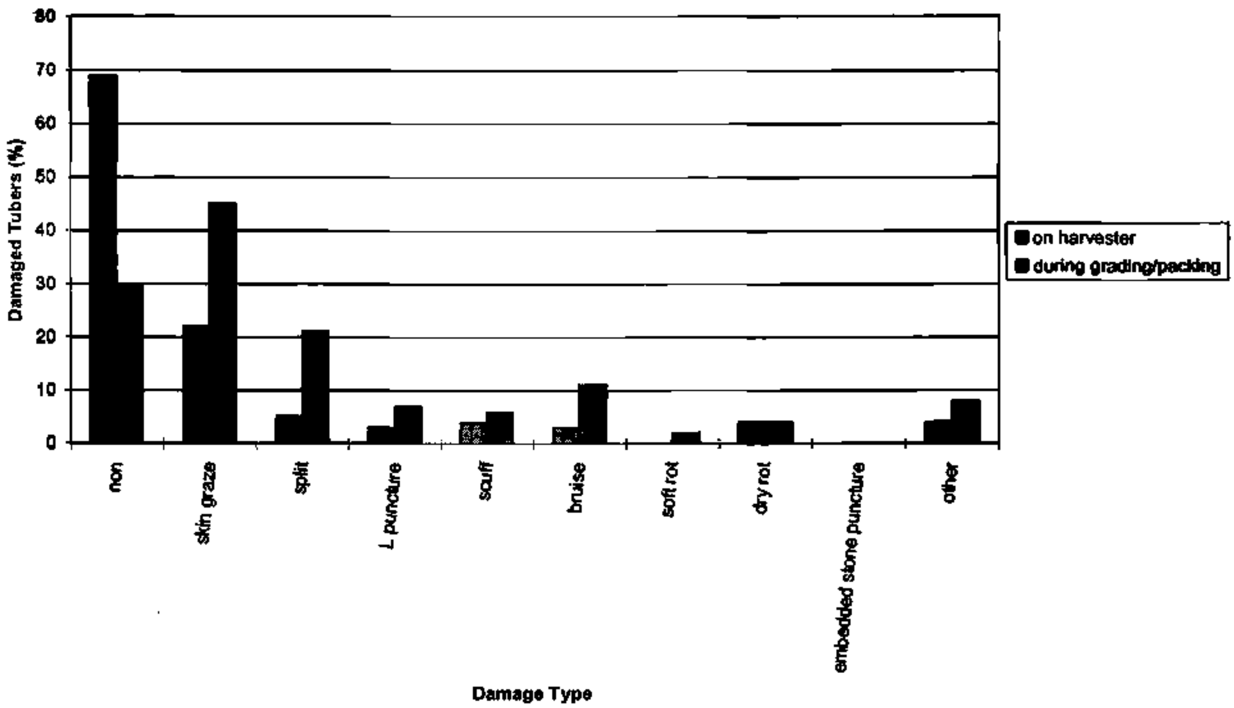


Fig 3.10: Type and level of damage found in Victorian tubers during harvest and grading/packaging operations



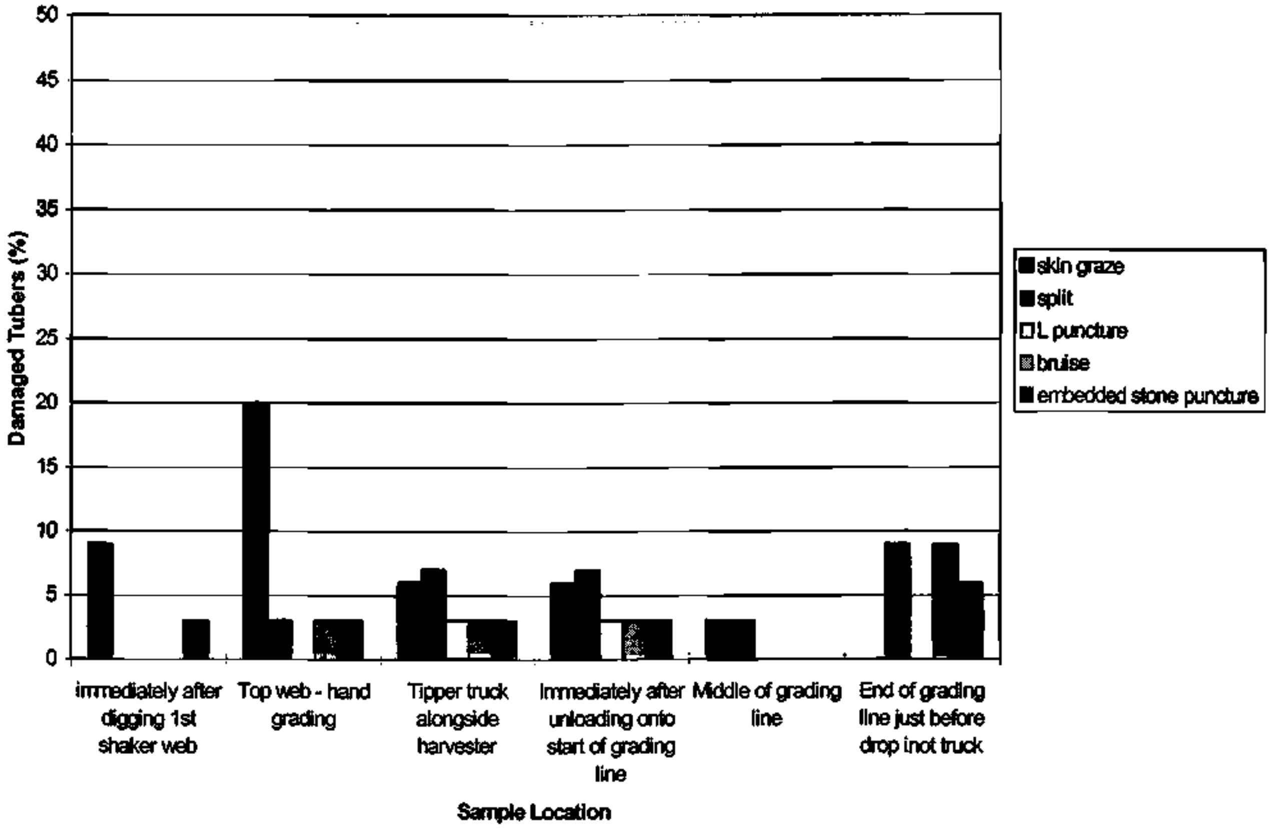
The 'others' category includes injuries that occur infrequently such as scratches, clean cuts, insect damage and also other defects such as greening and sunburn which may be of economic importance in an export market.

Fig 3.11: Type and level of damage found in South Australian tubers during harvest and grading/packaging operations



At farms in New South Wales and South Australia injury levels were higher in potatoes sampled during grading than on the harvester, indicating that after harvest additional damage can be attributed to this operation. This was particularly marked in South Australia, where 32% of tubers showed some injury at harvest, with this figure increasing to 70% during grading. At the Victorian farms around 64% of tubers showed some level of injury at harvest, with no increase occurring during grading.

Fig 3.12: Degree of moderate to severe injury occurring in the most common types of injury found during harvest, grading and packaging in New South Wales



Skin grazes were the most common injury in New South Wales and South Australia. In Victoria, where the paddocks visited had a high percentage of stone fragments, embedded stone punctures were as prevalent as skin grazes. The particularly high level of skin grazes in New South Wales is explained by the fact that the district had its driest season in one hundred years; with little soil adhering to tuber surfaces there was scant protection from abrasion as they travelled over the harvester webs.

Fig. 3.13 Degree of moderate to severe injury occurring during harvest, grading and packaging in Victoria

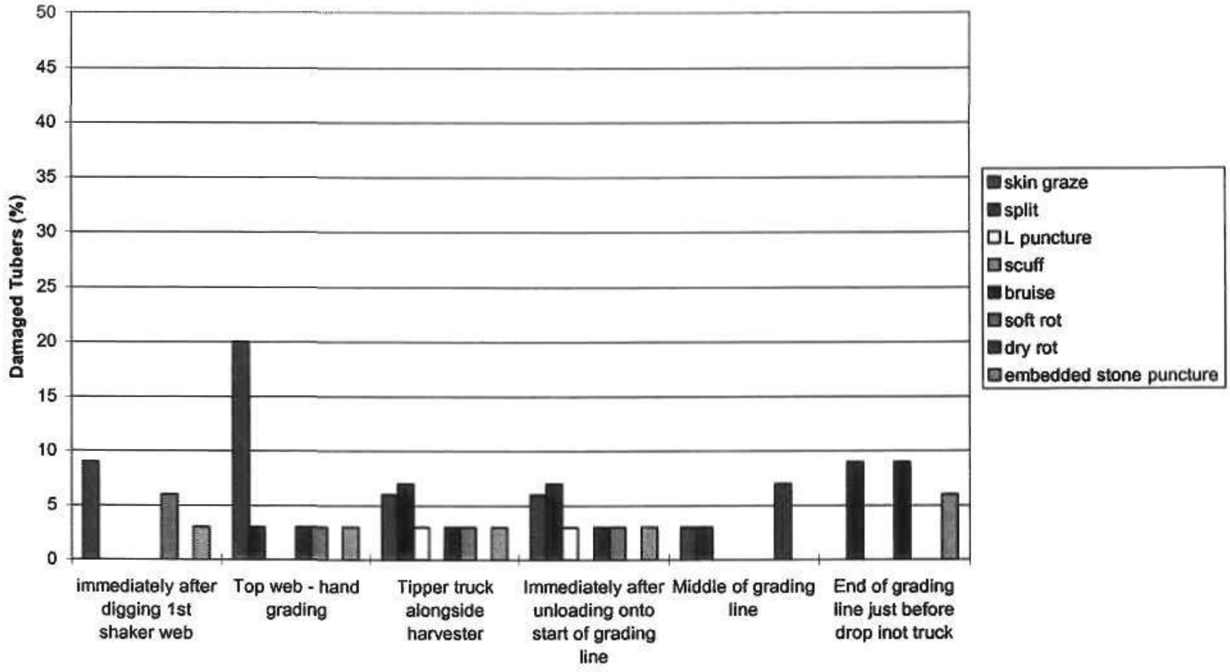
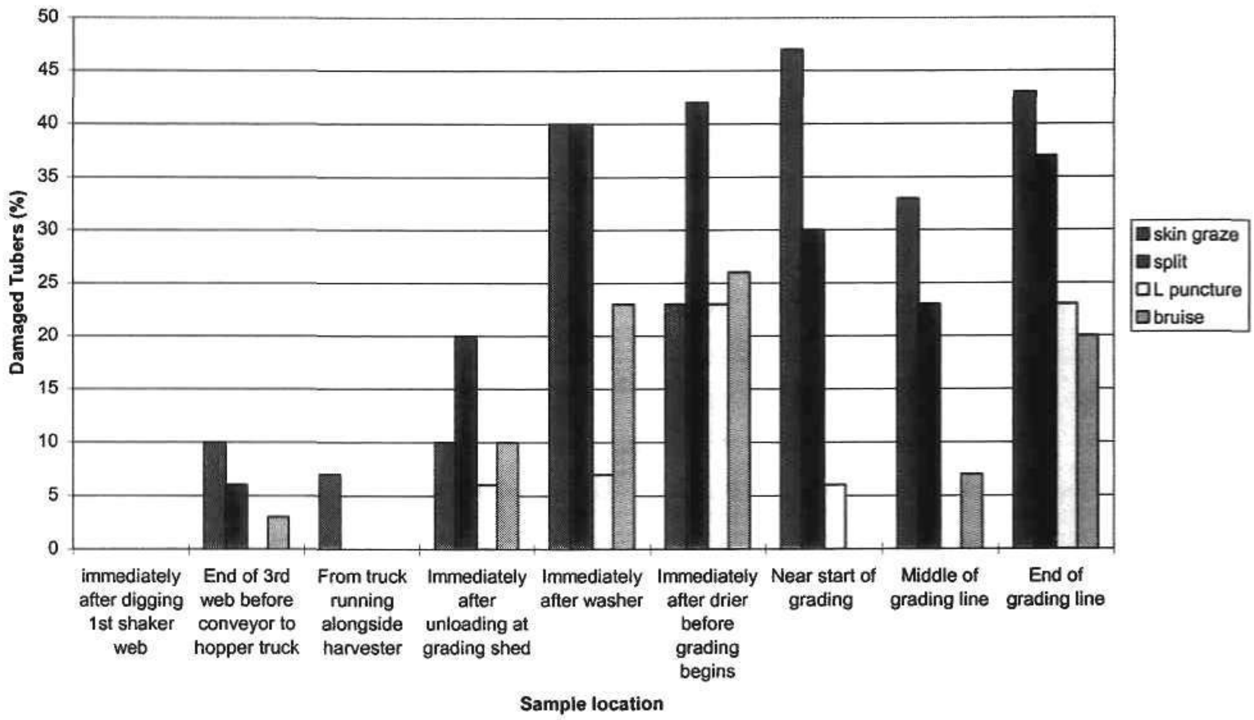


Fig. 3.14 Degree of moderate to severe injury occurring in the most common types of injury found during harvest, grading and packaging in South Australia



3.2.2 Where injury occurs

The classification scheme used to describe injury level is detailed in **Table 1**.

Table 1: Classification scheme used to describe the level of injury

Injury type	Classification		
	Light	**Moderate**	**Severe**
Skin graze	< 1% of surface area	1-2% of surface area	≥ 3% of surface area
Split	≤ 10mm long & ≤ 2mm deep	10-35mm long or 3-4mm deep	> 35mm long or > 4mm deep (or ≥ 3 moderate splits)
L shape puncture	≤ 10mm long & ≤ 2mm deep	10-35mm long or 3-4mm deep	> 35mm long or > 4mm deep (or ≥ 3 moderate L shape punctures)
Scuff	≤ 50mm^2 & ≤ 2mm deep	50-150mm^2 or 3-4mm deep	> 150mm^2 or > 4mm deep (or ≥ 2 moderate scuffs)
Bruise	≤ 50mm^2 & ≤ 2mm deep	50-150mm^2 or 3-4mm deep	> 150mm^2 or > 4mm deep (or ≥ 2 moderate bruises)
Stone puncture	1 present	2 present	≥ 3 present
Rot	≤ 50mm^2 & ≤ 2mm deep	50-150mm^2 or 3-4mm deep	> 150mm^2 or > 4mm deep (or ≥ 2 moderate rots)

3.2.2.1 Incidence of injury for each farm

Overall there were two important trends:

- The range and level of injury was low at harvest,
- The range and level of injury increased substantially during grading.

Skin grazes were the most common injury on the harvester, and the level of skin graze injury increased as tubers travelled along the harvester webs. Immediately after digging, as tubers enter the first shaker web, the incidence of skin grazes was very low (around 7%), but the level doubled as the tubers travelled over the rest of the harvester.

It can be seen from **Figs 3.12 to 3.14** that the level of injury was low during harvesting, but increased in severity and level during grading. For example the percentage of tubers with moderate to severe splits increased from an average of 5 % on the harvester to 30% during grading, and the number with bruises increased from 3% to 23%. The incidence of skin grazes also increased early on the grading line. This increase in injury started as early as unloading at the grading shed, in the form of splits, bruises, skin grazes and L-shaped punctures.

Figs 3.13 and 3.14 show that the washing process was a source of increase in the type and amount of moderate to severe injury observed. **Photo 3.6** shows one type of washer used to remove soil from tubers. This increase may be dramatic, as shown in **Fig. 3.14** where skin grazes, splits and bruises increased substantially during washing.

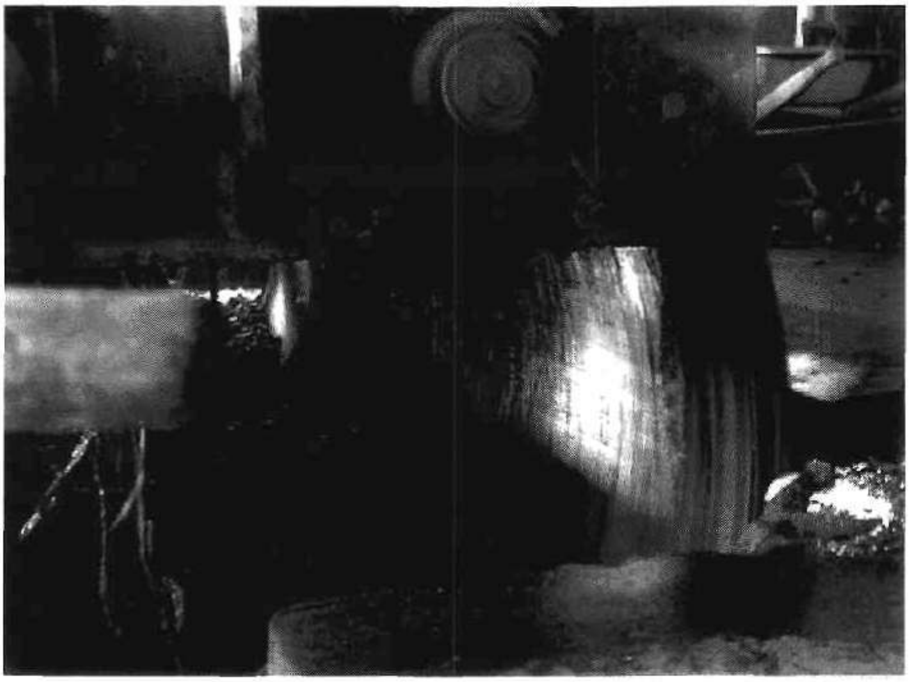


Photo 3.6 One of the washers used to remove soil from tubers

Samples of wash water and rinse water were taken from two grading sheds. At both the rinse water was reported to be routinely chlorinated. Chlorine levels in the rinse water were measured as 12.5ppm and 90ppm respectively, and bacterial counts in the wash water at these two sheds were found to be 2.3×10^6cfu/ml and 1.9×10^6cfu/ml. The chlorine level in the first shed was probably too low to be effective in preventing the growth of bacteria, but the level at the second should have been sufficient. The high bacterial count in the second shed may be due to the fact that once bacteria increase to a high level in wash water it is difficult to remove them from the surface of the tuber, even with further washing in fresh or chlorinated water. At the second shed, samples of tubers collected prior to washing did not develop infection during storage but all samples taken after washing developed severe bacterial infection of the lenticels (see **Photo 3.7**).

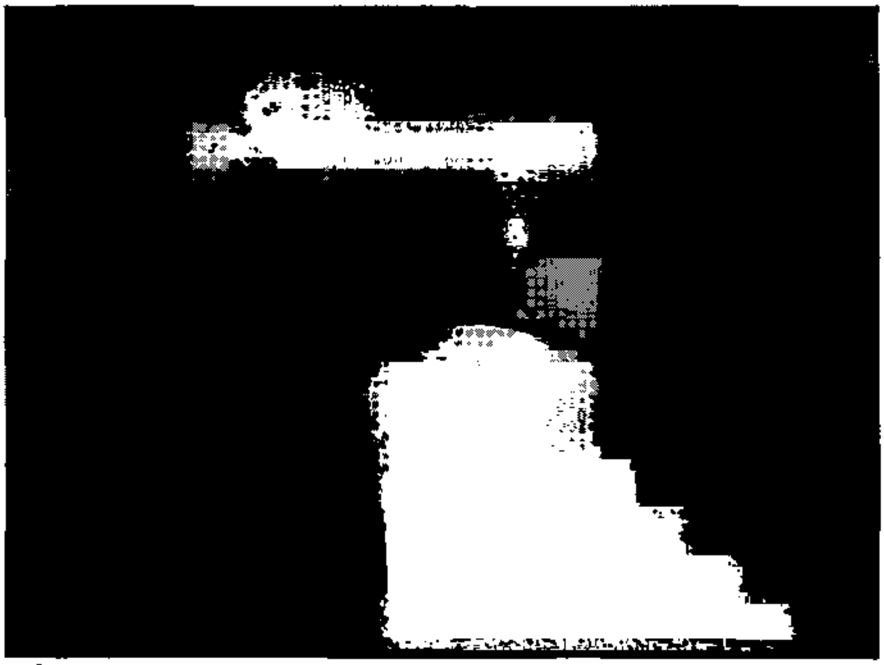


Photo 3.7 Serve bacterial infection of lenticels in a sample taken after the washing process

Because some damaged product is removed on the grading line, the level of injury recorded at various points along the line didn't necessarily increase, even though injuries were still occurring. For example, the reduced incidence of skin grazes, splits, and L-shaped punctures near the middle of the grading line (see 'Middle of grading line' category, **Fig. 3.14**) can be explained by the removal of injured product in the preceding section of the line.

3.2.2.2 Incidence of each type of injury for all farms visited

The range in the number of tubers found to have moderate to severe injury, for each of the major types of injury (skin grazes, splits, L-shaped puncture and bruise) at each stage of postharvest handling are shown in **Figs 3.15 – 3.19** respectively.

The range for skin grazes (**Fig. 3.15**) and splits (**Fig. 3.16**) was quite wide and both increased markedly in going from the harvester through grading. The highest incidence was around 55% for skin grazes and 40% for splits.

Fig 3.15 Range of skin graze injury in the moderate to severe category found in Australian potatoes

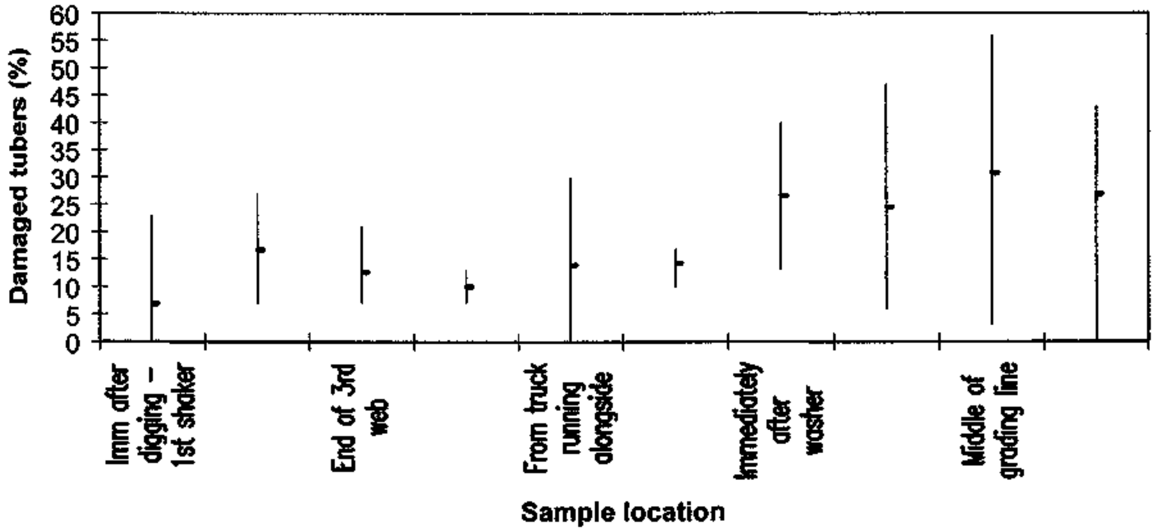
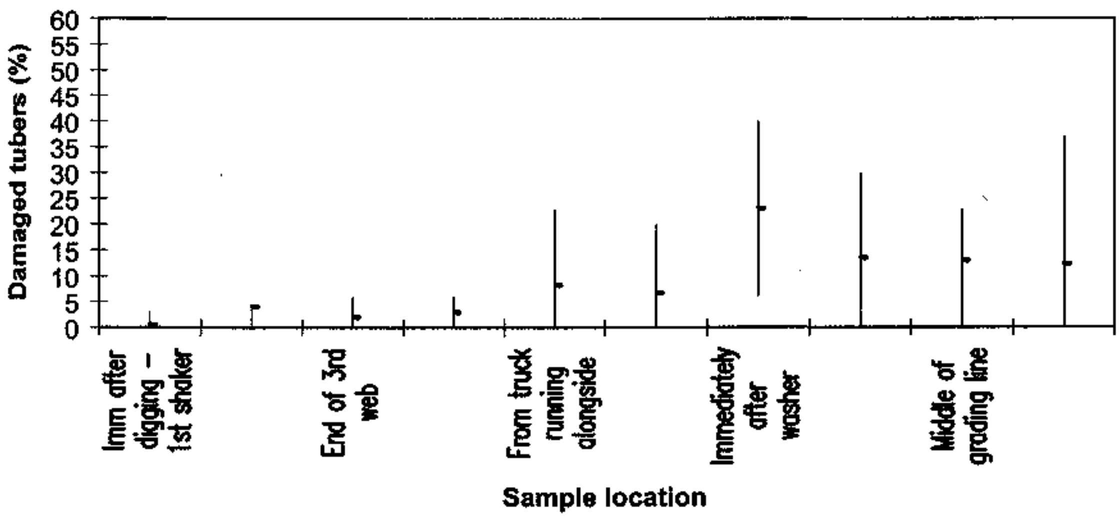


Fig 3.16 Range of split injury in the moderate to severe category found in Australian potatoes



The range for L-shaped punctures (**Fig. 3.17**) and bruises (**Fig. 3.18**) was smaller but also increased after the harvester, during grading. The maximum level of these injuries at any location was lower than for skin grazes and splits, around 25%, with an average of around 5% for L-shaped punctures and 10% for bruises.

Fig 3.17 Range of L puncture injury in the moderate to severe category found in Australian potatoes

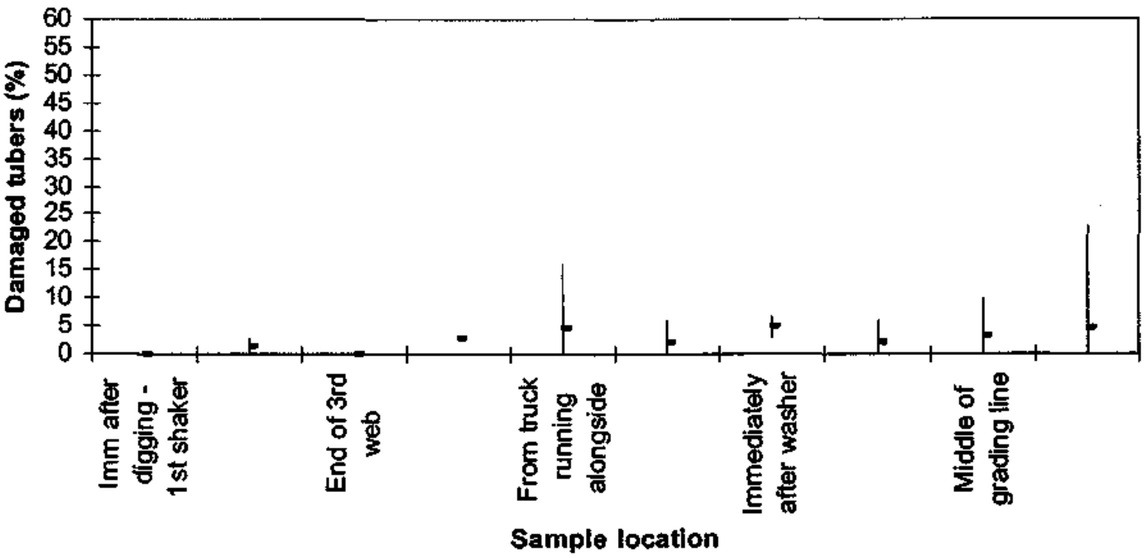
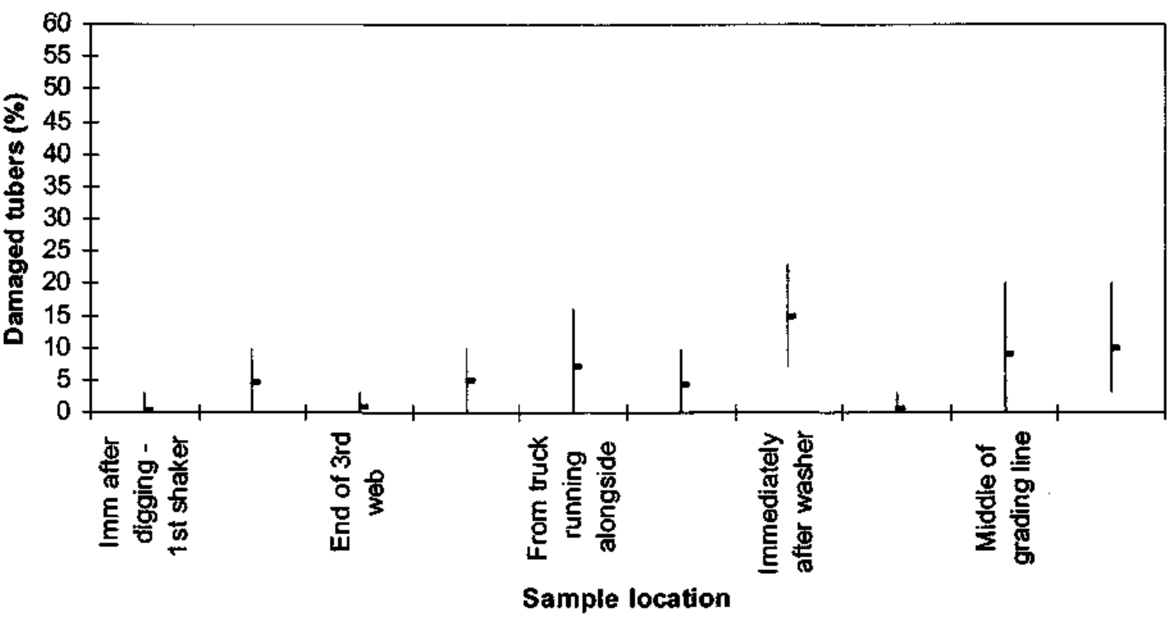
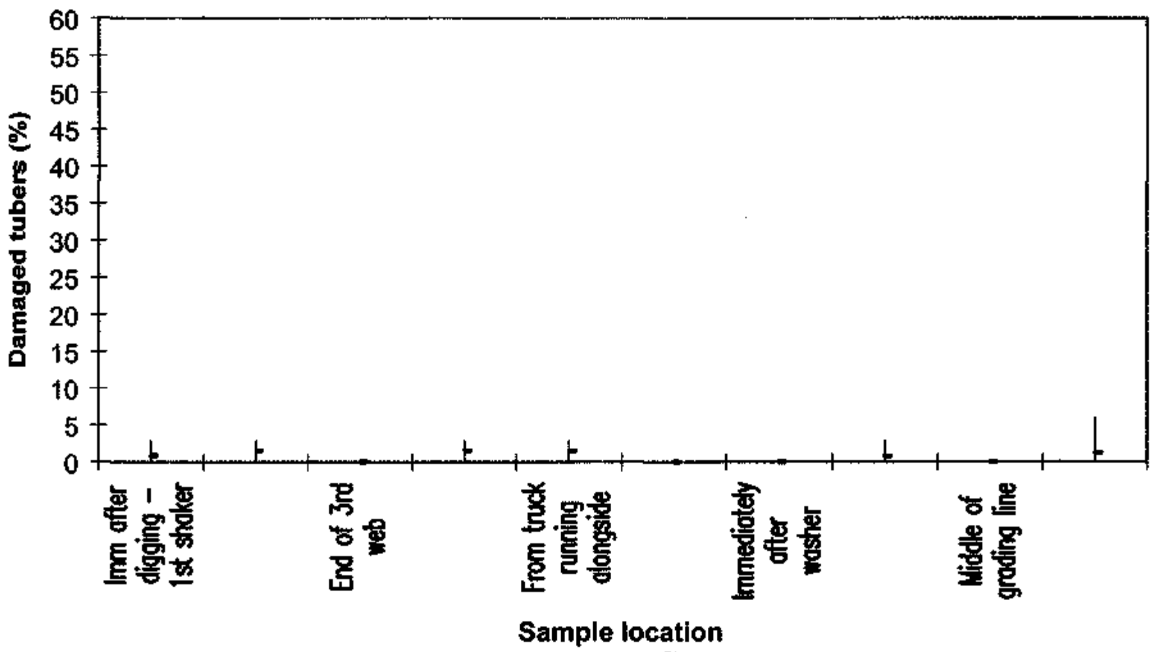


Fig 3.18 Range of bruise injury in the moderate to severe category found in Australian potatoes



The level of injury from embedded stone punctures (**Fig. 3.19**) had a very narrow range which did not increase during grading. This is consistent with these injuries occurring during harvest only, in contrast to the other types of injury that could occur during harvest or subsequently.

Fig 3.19 Range of embedded stone puncture injury in the moderate to severe category found in Australian potatoes



3.3 Simulated shipment: Hong Kong → Melbourne

3.3.1 Rot Severity

The rot severity of the *Fusarium* and *Erwinia* inoculated treatments from the Pot-Tainer are shown in **Fig 3.20** and **Fig 3.21** respectively. Each rot severity value represents an average of the values for the eighty wound sites in each treatment. From **Fig 3.20** it can be seen that treatment 1, the combination of curing followed by fungicide treatment was the most effective in prevention of fusarium dry rot. The rot severity score was zero indicating total prevention of rot.

Fig 3.20 Severity of fusarium dry rot development during a simulated summer export shipment from Melbourne to Hong Kong, in the Pot-Tainer

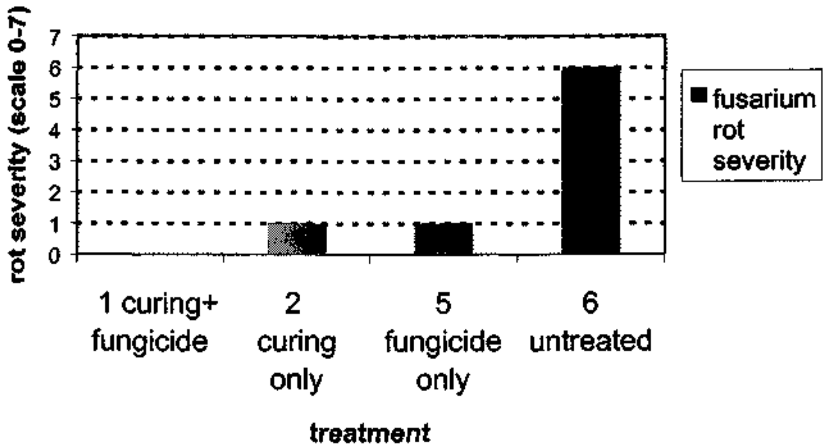
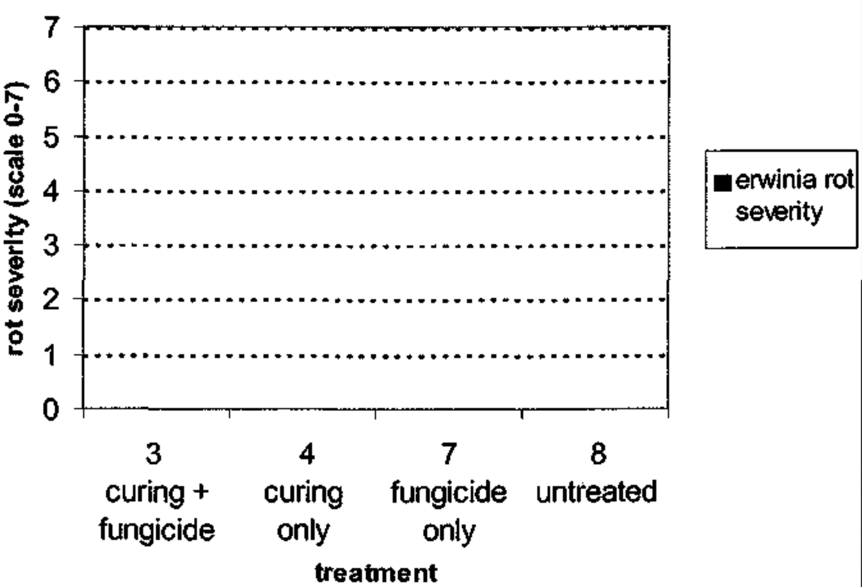


Fig 3.21 Severity of erwinia soft rot development during a simulated summer export shipment from Melbourne to Hong Kong, in the Pot-Tainer



Treatments 2 and 5, the cured only and TBZ fungicide treated only were also very effective preventers of dry rot. Both had a rot severity score of 1, indicating minimal rot development.
Treatment 6 had no *curing* or fungicide application, and failed to prevent the development of fusarium dry rot. The rot severity score was 6, indicating severe rot development. A comparison of the potatoes from the four treatments is shown in **Photo 3.8** (image 30 May 7). Treatment 6, the water dipped treatment is clearly more rotted than the others.

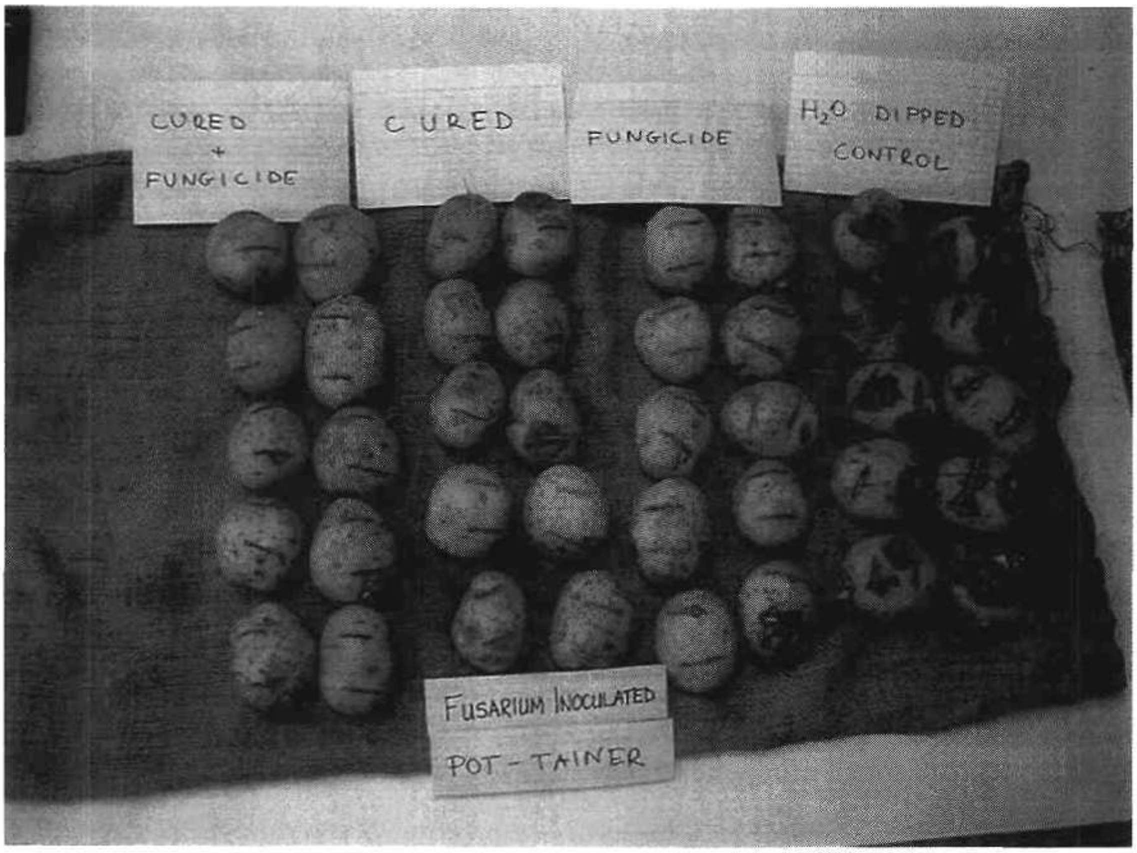
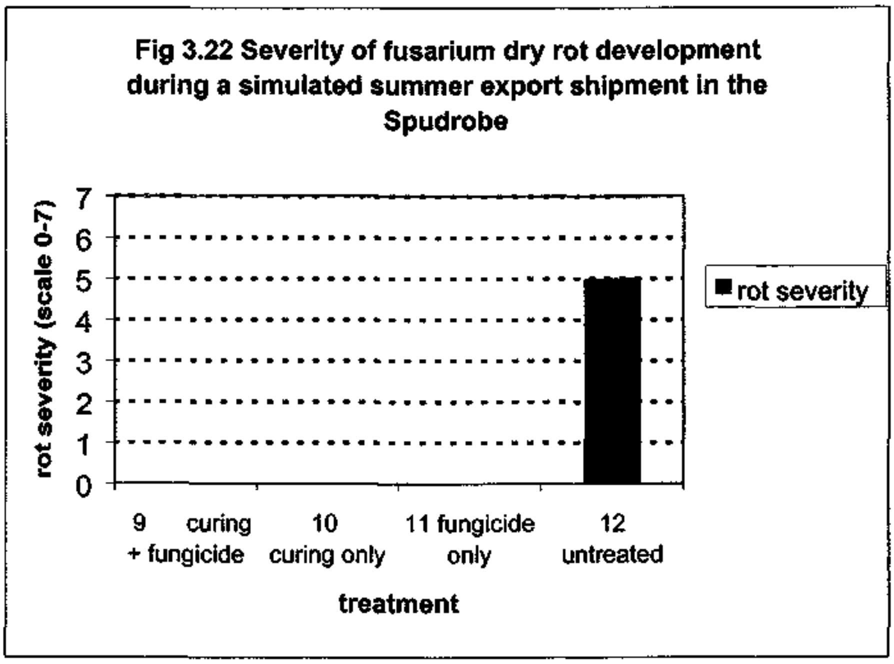
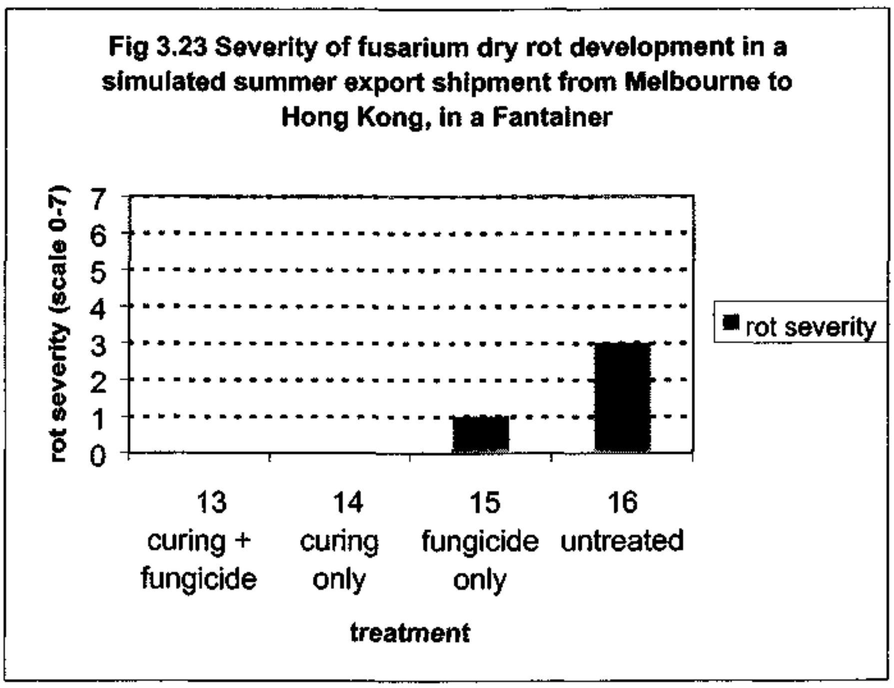


Photo 3.8 Comparison of the four treatments

Fig 3.21 shows that no rot developed in potatoes inoculated with *Erwinia* bacteria. This further supports earlier laboratory findings that suggest bacterial soft rot will rarely invade wounded potatoes in the absence of a primary fungal infection.

Patterns of infection similar to those in the Pot-Tainer were observed in the Spudrobe and Fantainer. **Fig 3.22** shows the rot severity scores of the four *Fusarium*-inoculated treatments in the Spudrobe and **Fig 3.23** those in the Fantainer. The combination of curing followed by fungicide application (treatment 9 in the Spudrobe and 13 in the Fantainer), the cured treatment alone (treatment 10 in the Spudrobe and 14 in the Fantainer), and the fungicide treatment alone (treatment 11 in the Spudrobe and treatment 15 in the Fantainer), were each effective in prevention of *Fusarium* dry rot. This mirrors the pattern seen in the Pot-Tainer.





The treatment that received no curing or fungicide (treatment 12 in the Spudrobe and 16 in the Fantainer) failed to prevent dry rot development, as was the case in the Pot-Tainer. This treatment in the Fantainer however did have a noticeably lower rot severity value than that in the Pot-Tainer or Spudrobe. This is an interesting result; it suggests potatoes may be transported at ambient temperature, in a fan ventilated container, without humidity control, provided they are properly handled and treated prior to shipment. It should be borne in mind however that damaged potatoes with no postharvest rot-prevention treatment still develop an unacceptable degree of dry rot in this system. It should also be realised that this was a single trial in a scaled down model of a Fantainer. More comparisons would need to be made before a definitive conclusion could be made about the reliability of a Fantainer system for ambient transport of potatoes.

The *Fusarium* inoculated pathogenic control was highly infected with *fusarium* dry rot. It had an average rot severity rating of 7, indicating extreme infection.

Soft rot did not develop in any of the eighty wound sites in the *Erwinia* inoculated control. Initial reasoning suggests that the *Erwinia* bacteria used as an inoculum had lost its pathogenicity to potatoes. However we believe, based on our previous experimental work, that a more likely explanation exists. Bacterial infection is initiated only by the most severe of incubation environments. Factors required include elevatred temperature, free water on potato surfaces and a deep injury containing crushed or bruised tissue. The wound type used in this experiment was a shallow scratch and no free water was present on the surface of the potatoes at the time of incubation. The wound surface probably dried out before the bacteria could become established.

3.3.2 Rot width and depth

The spread of rot outward from the wound site mirrored the pattern seen in the rot severity ratings for the various treatments, as would be expected. **Figs 3.24, 3.25** and **3.26** show the spread of *fusarium* dry rot in the treatments from the Pot-Tainer, Spudrobe and Fantainer respectively. Comparison with **Fig 3.20, 3.22** and **3.23** show the trends to be similar: treatments with the highest severity rating also have the greatest spread of rot beyond the wound site.

Fig 3.24 Spread of fusarium dry rot (width) beyond wound site during a simulated summer export shipment from Melbourne to Hong Kong, in the Pot-Tainer

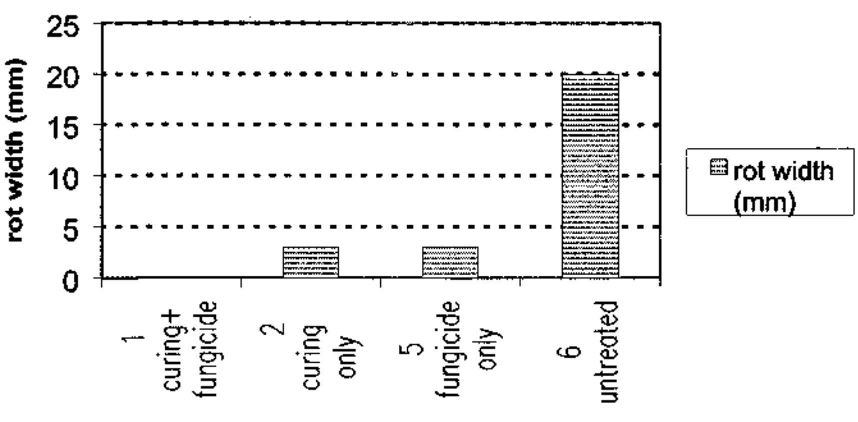


Fig 3.25 Spread of fusarium dry rot (width) beyond wound site during simulated summer export shipment from Melbourne to Hong Kong, in the Spudrobe

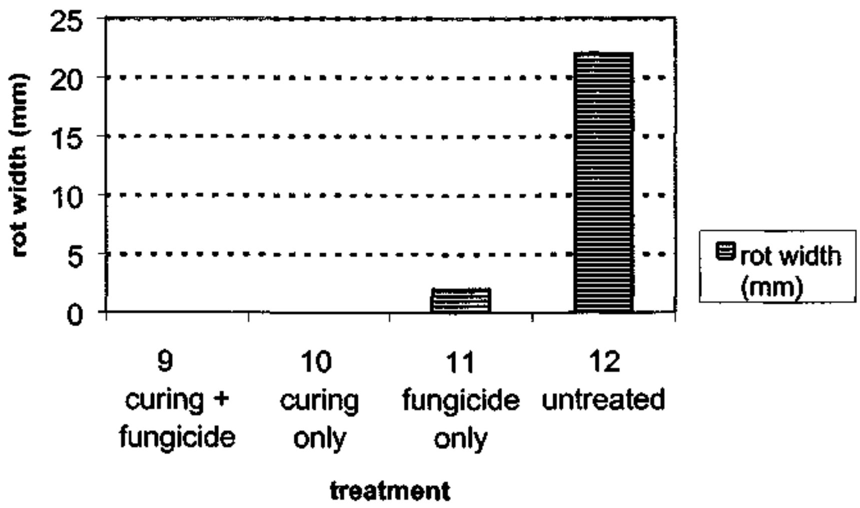
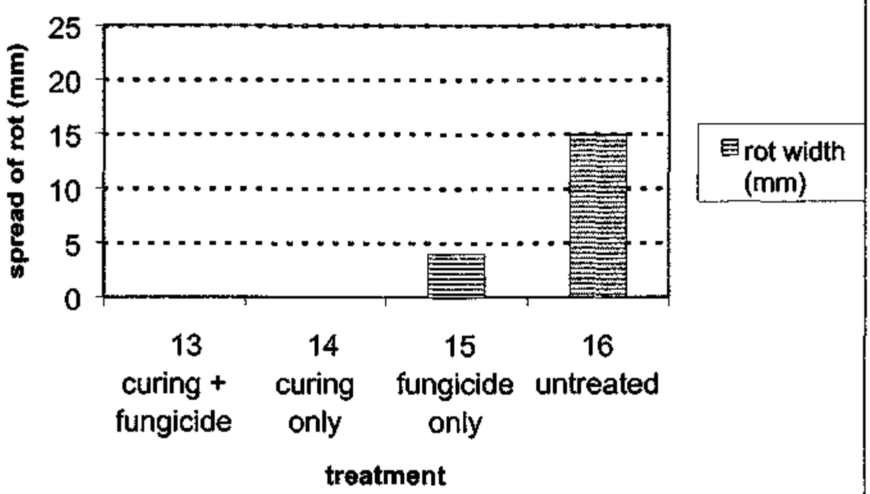


Fig 3.26 Spread of fusarium dry rot (width) beyond the wound site during a simulated summer export shipment from Melbourne to Hong Kong in the Fantainer



3.3.3 Secondary infection

The treatments given no curing and no fungicide application, and inoculated with *Fusarium*, developed the most severe fungal dry rot. Despite the fact that they had not been inoculated with bacteria, these treatments also developed some bacterial soft rot. The soft rot appeared to be a secondary infection invading tissue around the margins of the dry rot. Bacteria appear to enter the wound site as an opportunistic infection only after the fungus has begun maceration of the tissue. The soft rot infection around the margins of dry rot, in one of the water dipped control treatments is shown in **Photo 3.9. Photo 3.10** shows the extent to which the soft rot destroyed the potato tissue in the control treatments. The damage is quite extensive since the bacteria once established acts quickly to macerate potato flesh.

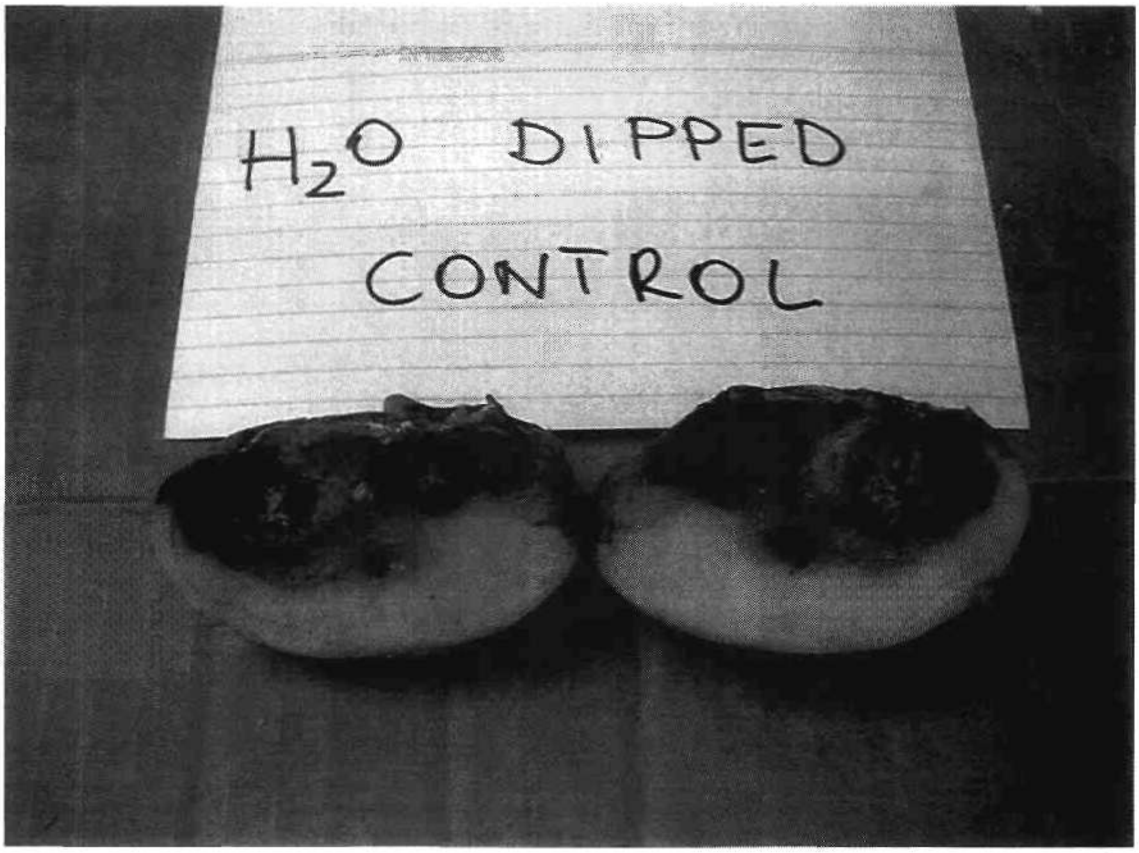


Photo 3.9 Soft rot around the margins of dry rot in a control treatment

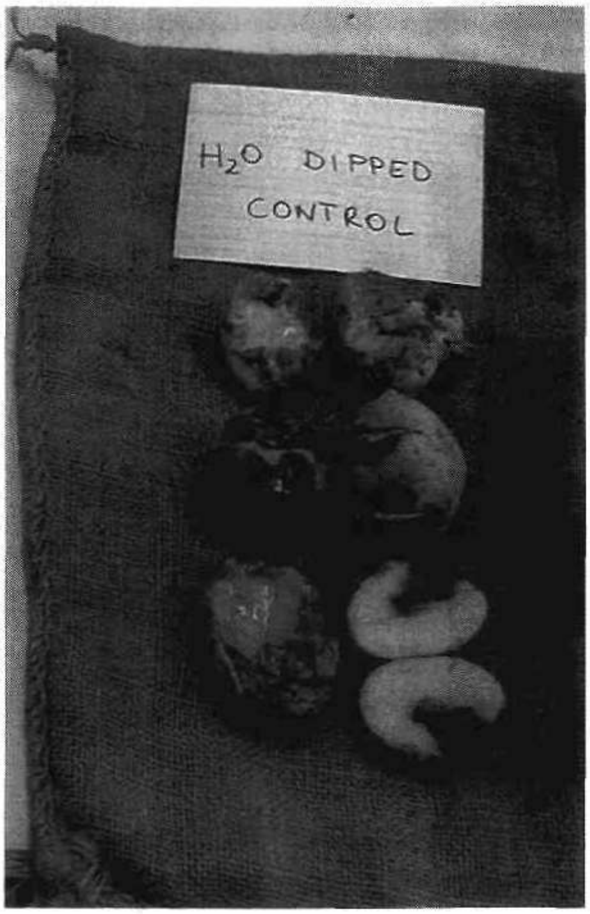


Photo 3.10 Extent of soft rot in the control treatments

Treatments that incorporated both curing and fungicide, or the two individually, were protected from *Fusarium* dry rot infection and consequently did not fall prey to secondary *Erwinia* bacterial invasion.

The greatest degree of secondary bacterial infection occurred in the *Fusarium* inoculated pathogenic control. This is not surprising since the incubation conditions were the most severe, being designed to encourage *Fusarium* growth. This led ultimately to secondary bacterial invasion of *Fusarium* infected wound sites.

3.3.4 Weight Change

The weight change in six bags of Sebago variety, stowed as a comparison to the bulk of the stow was, over the course of the simulated shipment, a loss varying from 1.4 to 2.3 percent of the total bag weight. The average weight loss was 1.9 percent. This compared favourably with the bulk of the stow (Desiree variety), where the weight loss was, on average, 5.0 percent. The considerable difference was due to the skin set and maturity differences between the two varieties. The Desiree varied greatly in maturity and skin set; the size gradient was large, despite the fact that all were supposed to be 'smalls' and many potatoes had a high degree of skin loss. This latter factor led to the higher moisture loss. The Sebago variety were all mature with good skin set. **Photo 3.11** shows the size variation and skin loss in the Desiree variety. This can be compared with the Sebago variety pictured in **Photo 3.12.**

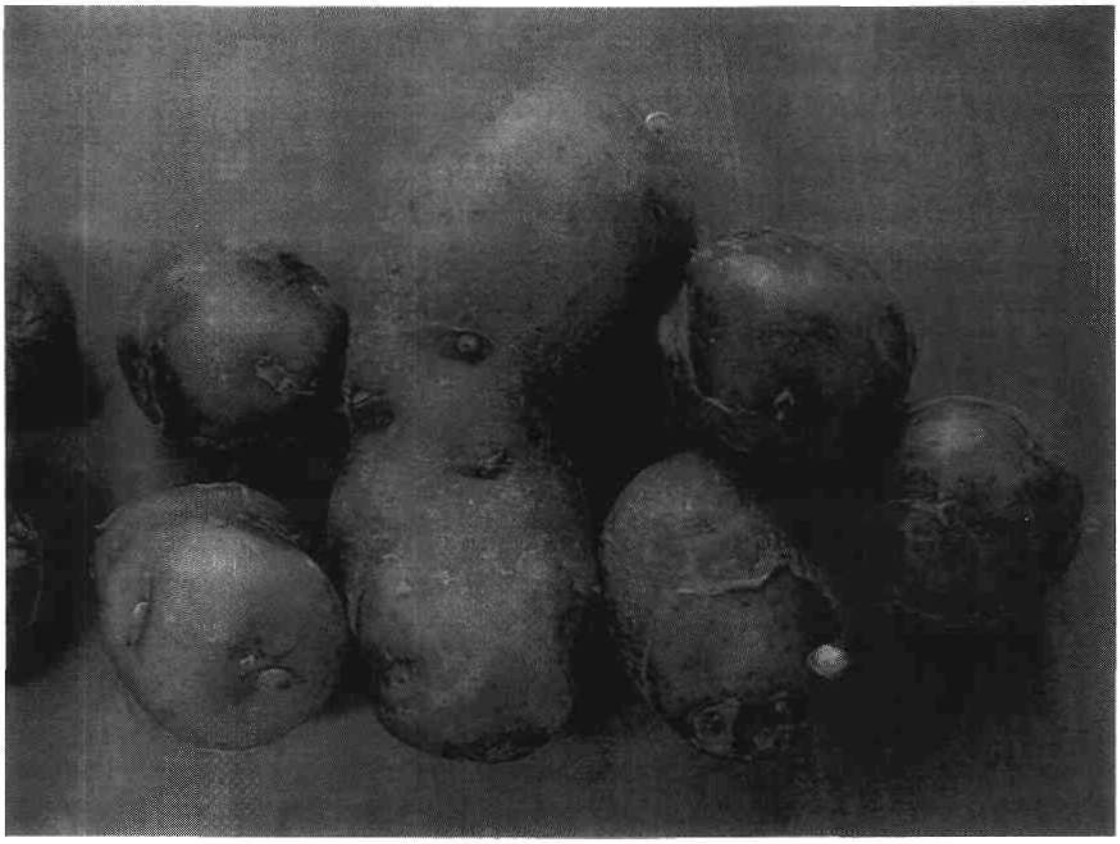


Photo 3.11 Size variation and degree of skin loss in Desiree potatoes

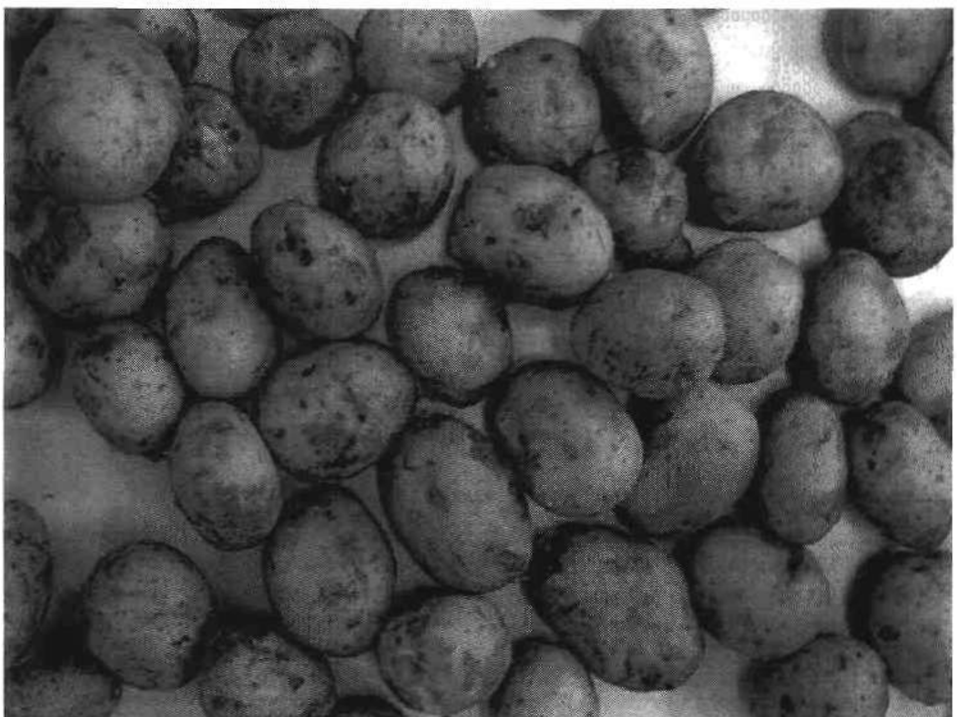


Photo 3.12 mature Sebago potatoes with good skin set

Bags of Sebago potatoes, held in a coolroom at 10°C, had an average weight loss of 1.5 percent. With only an additional 0.4 percent loss this compares favourably with the comparison bags of Sebago variety in the Pot-Tainer.

3.3.5 Visual Inspection At Outturn

3.3.5.1 Injury level

The overall injury level in the Sebago variety was low. Minor splits and scuffs totalled about 5 percent. The splits were shallow, typically only a few mm deep. Very little skin grazing was present, around 1 percent.

The Desiree variety had more damage than the Sebago variety. Severe skin grazing was the most obvious injury. In some bags examined as many as 60 percent of the potatoes had 50 percent or more of their skin removed. On average severe skin grazing affected about 25 percent of potatoes examined. The substantial skin loss resulted in excessive moisture loss. Potatoes with extensive skin grazing felt soft and turgid in the skinned areas, while areas with skin intact retained their firmness. The excessive skin loss also contributed to increased microbial decay.

Minor damage in the form of shallow splits and scuffs was widespread, affecting, on average, around 40 percent of potatoes. More severe scuffs were much less common, around 1 percent of potatoes being affected. However, many of these injuries were supporting *Fusarium* hyphal growth. Clean cuts were uncommon affecting around 1 percent of potatoes.

3.3.5.2 Sprouting

Most potatoes in the six comparison bags in the Pot-Tainer showed evidence of sprouting. The average number of sprouts on a random sample of thirty potatoes from each bag was 1. The average length of the longest sprout was 5mm, that of the shortest 2mm.
The average number of sprouts on a random sample of thirty potatoes from fifteen bags of Desiree, selected from various positions within the stow, was 3. The average length of the longest sprout was 9mm, that of the shortest 3mm. Comparison with the Sebago show that the Desiree were exhibiting more advanced sprouting. This is likely to be purely a varietal difference.

Results from both varieties indicate that a sprout inhibitor may be necessary for ambient temperature transport of potatoes in the Pot-Tainer system.

The refrigerated control potatoes showed no sign of sprouting after storage at 10°C.

3.3.5.3 Microbial infection

3.3.5.3.1 Fungal infection – *Fusarium*

Fusarium infection in the Sebago potatoes from the six comparison bags was low, appearing mainly as minor hyphal growth in some of the scuff and split injuries.

Many potatoes exhibited infection of the lenticels. This appeared as small, dark coloured, swollen lesion surrounding the lenticels. It was not possible to determine if this was a fungal or bacterial infection, though the latter seems more likely since the swollen areas felt soft to touch. The same infection was present in the lenticels of the refrigerated controls thus it appears that it was unrelated to conditions inside the Pot-Tainer. The lenticel infection in the refrigerated potatoes is shown in **Photo 3.13**. (image 21 May 7).

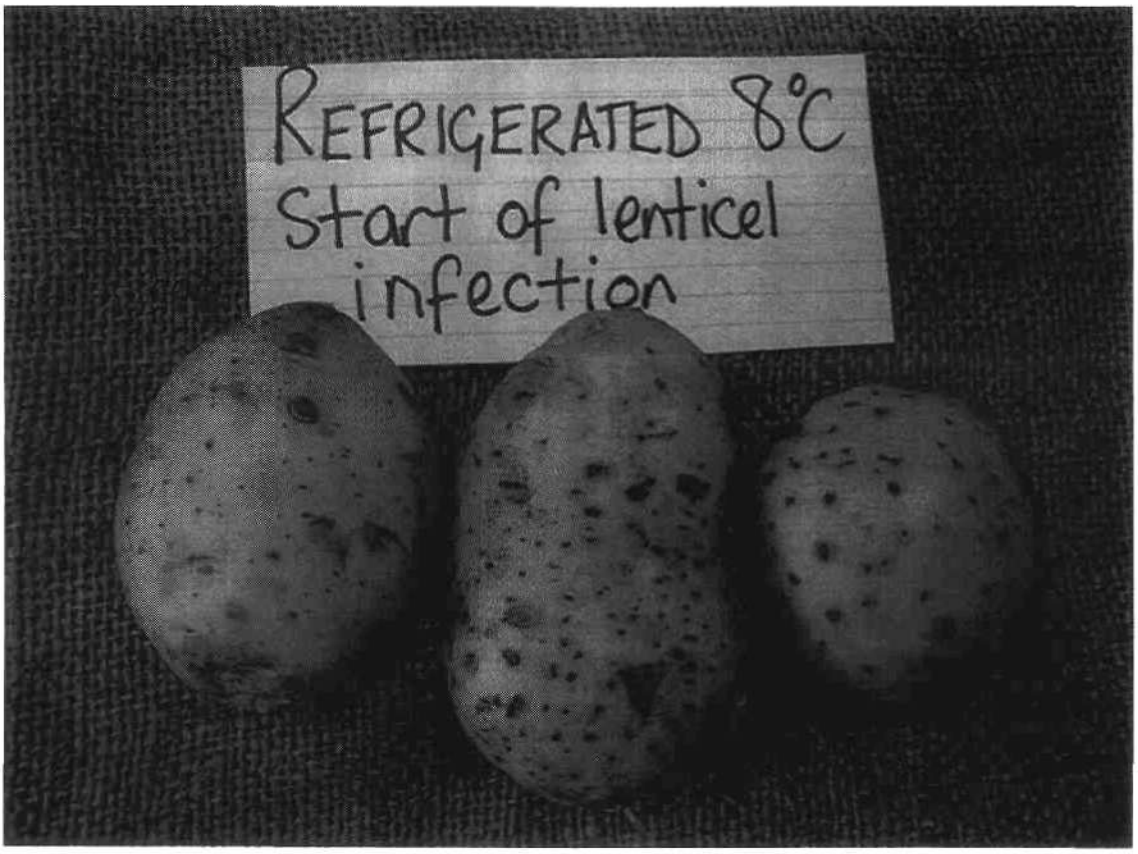


Photo 3.13 Lenticel infection in refrigerated potatoes

More severe *Fusarium* dry rot was present in the Desiree than the Sebago variety. In injury sites there was evidence of a low level of both inactive and active *Fusarium* growth. Some potatoes had *Fusarium* dry rot lesions and it was difficult to determine if these were developing at the site of original injury. Such lesions are shown on the exterior of the potato in **Photo 3.14** Rot was so severe in some lesions that the exterior of the lesion was supporting *Fusarium* hyphal growth. This can be seen in **Photo 3.15**.

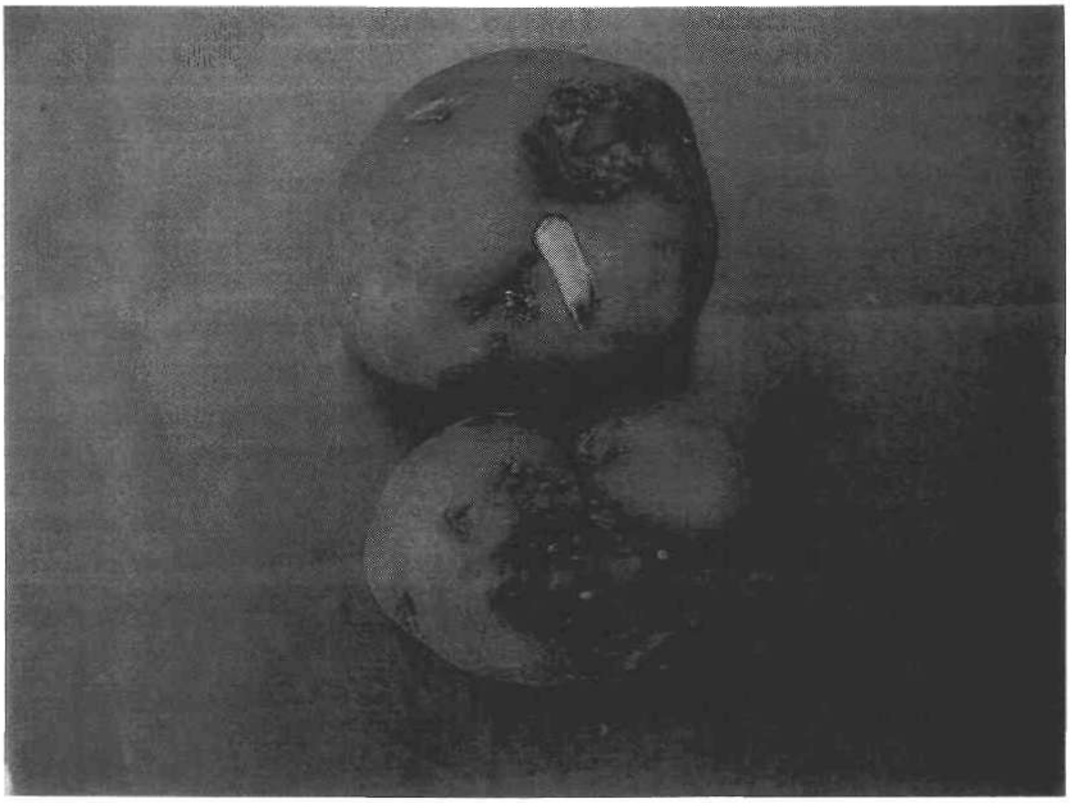


Photo 3.14 Dry rot lesions on the exterior of potatoes

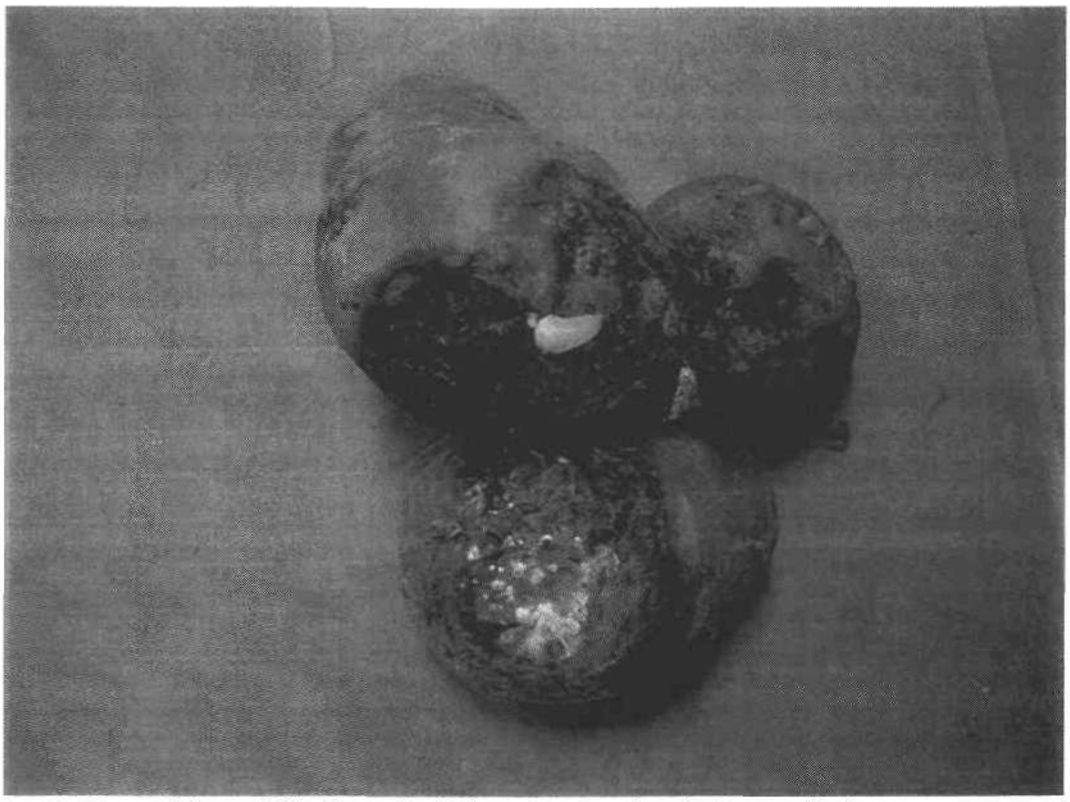


Photo 3.15 Growth of *Fusarium* hyphae in dry rot lesions

3.3.5.3.2 Bacterial infection – *Erwinia*

In each of the six bags of Sebago variety potatoes there was a low occurrence of soft rot. The average percentage of potatoes affected in each of the six bags was around 2 percent. This equates to around six potatoes from each bag. In the main these potatoes were so badly rotted that it was not possible to determine whether the rot originated at a site of injury; the potatoes were completely rotted and the flesh smeared across others.

Bacterial soft rot was present in the Desiree variety that formed the main stow. The rot was most pronounced on the large areas of skin grazing where its growth was active. The rot had formed beneath the area of grazing so that the thin flesh above the rotted region was at least in part intact, with soft bacterial macerated tissue beneath. This is shown in **Photo 3.16**. Where skin remained intact on the potato it was less prone to soft rot development. The loss of such large portions of skin clearly led to increased susceptibility to soft rot development.

Photo 3.16 Bacterial soft rot beneath areas of severe skin grazing

In some potatoes bacterial infection was associated with *Fusarium* infection and creamy-white hyphae of the fungus were seen growing in the soft rot lesion. In this instance it is likely that the bacterial rot was a secondary opportunistic infection, feeding on the already decaying tissue of the *Fusarium* infection.

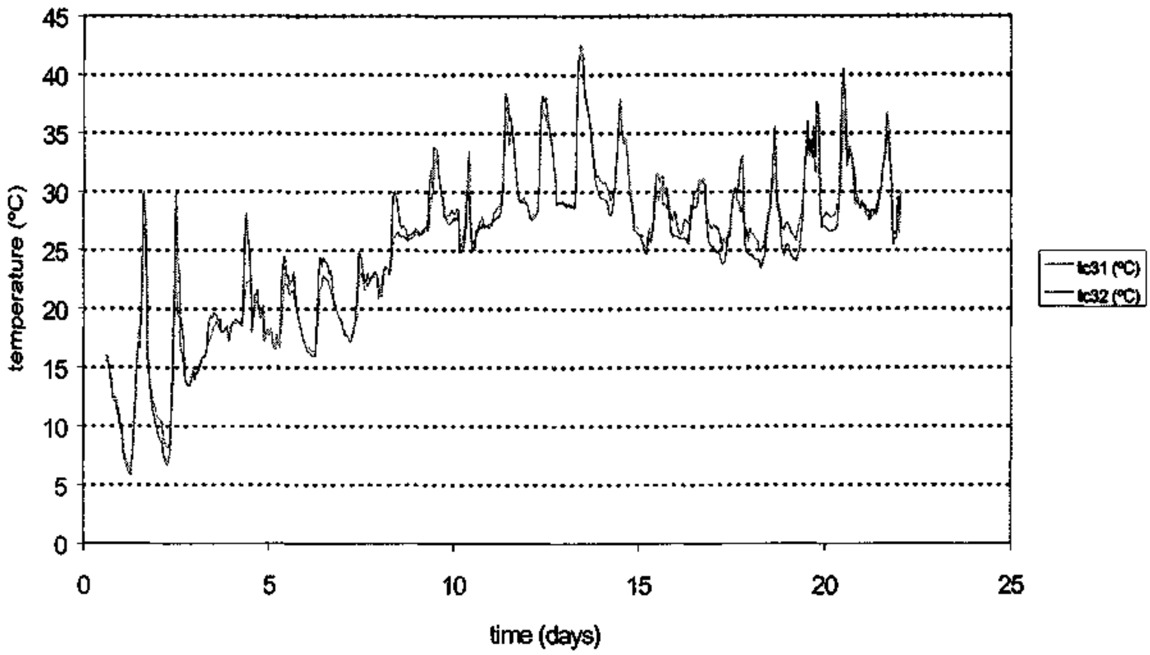
3.4 Trial shipment: Melbourne → Hong Kong

3.4.1. Temperatures

3.4.1.1 Ambient air temperatures

Ambient air temperatures are shown in **Fig. 3.27**.

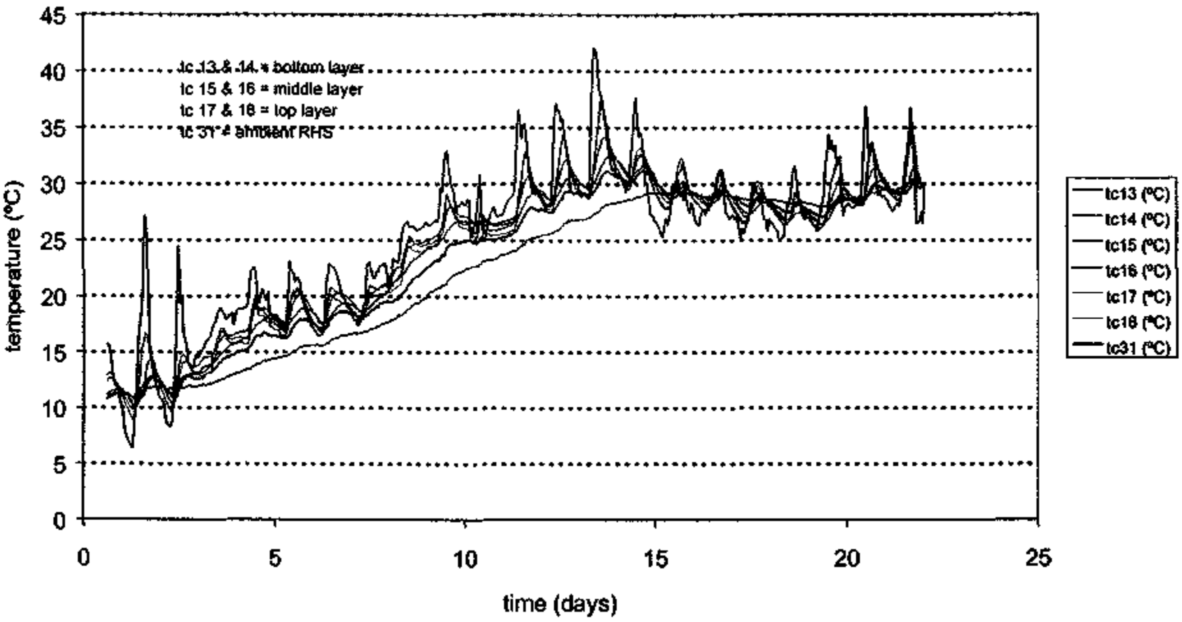
Fig. 3.27 Hong Kong Trial Shipment - April / May 99. Measured ambient air temperatures



These indicate large diurnal fluctuations while the container was on land in Melbourne. For example on day 2 there was a 24°C swing. This is an unusually large diurnal variation for April. The high daytime temperature suggests that the ambient air temperature sensors were subjected to some radiant heat load, leading to a higher diurnal fluctuation than the air would experience.

There are also unusually large diurnal fluctuations while the vessel was at sea. For example on day 13 there was a 13°C swing. This suggests again that the ambient temperature sensors experienced a radiant heat load. Ambient temperatures appeared at first glance to be high for a spring voyage to Hong Kong. However the *Ships Weather Predictor* software developed by CSIRO for predicting ambient air temperatures surrounding containers during shipment, indicated that the predicted mean temperatures lie within the standard deviation bands of the predicted data. The software predictions however, did not match the diurnal fluctuations shown in the trial shipment. (see **Fig. 3.28.**)

Fig. 3.28 Hong Kong Trial Shipment - April / May 99. Potato temperatures in Slice C

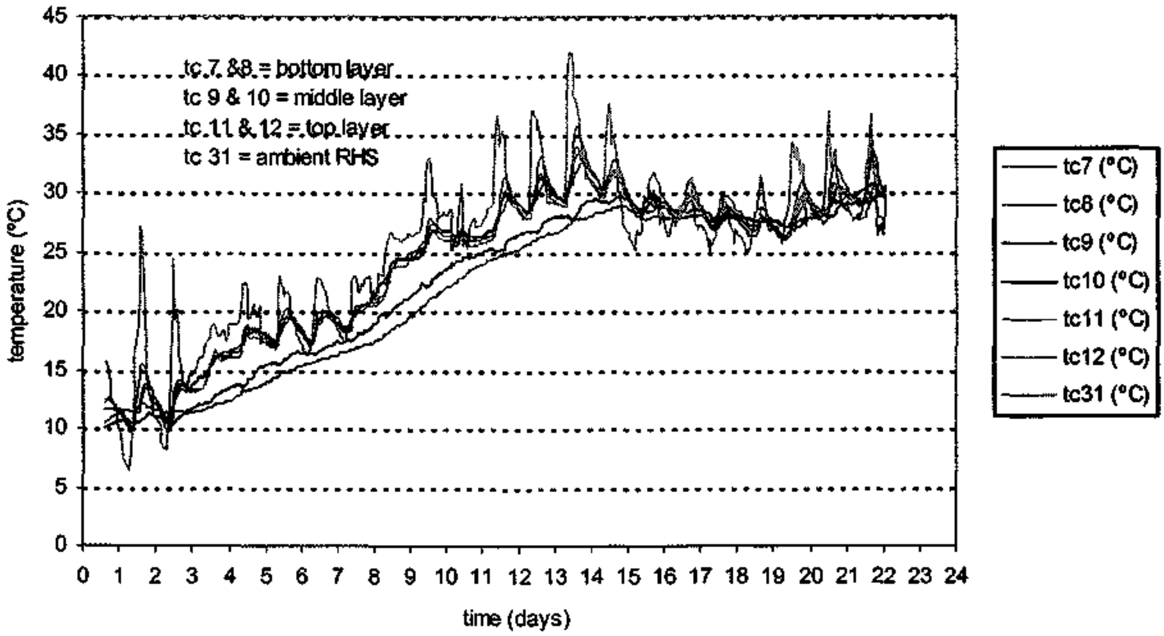


Temperatures rose as the vessel sailed to Sydney and continued to rise as it approached the tropics.

3.4.1.2 Product temperatures

Product temperatures followed ambient temperatures with a time lag due to the thermal capacity of the potatoes. Product temperatures close to the exterior surfaces of the container (near the top and sides of the stow) showed the fastest response to changes in ambient temperatures and showed some diurnal fluctuations. This is shown in **Fig. 3.29**

Fig 3.29 Rapid reponse of product temperatures in the top and bottom layers and slower response of those in the middle layers



3.4.2 Condition of product at outturn: The refrigerated container

3.4.2.1 General appearance

At outturn it was obvious that the load had settled during transport. The headspace that was around 100mm at the time of loading was around 300mm at unloading.

Externally the bags looked to be in good condition with no damp areas in the load. There were no rots in any part of the stow. The importer was however disappointed with the high level of mechanical damage (which we had noted was present at loading).

3.4.2.2 Preliminary product inspection

A few randomly chosen bags were opened in a preliminary inspection as the container was being unloaded. Two features were most apparent:

1. A high level of mechanical damage in the white skin Nardin variety. **Photo 3.17** shows one of the bags opened for inspection. The mechanical damage seen was indicative of the load as a whole.

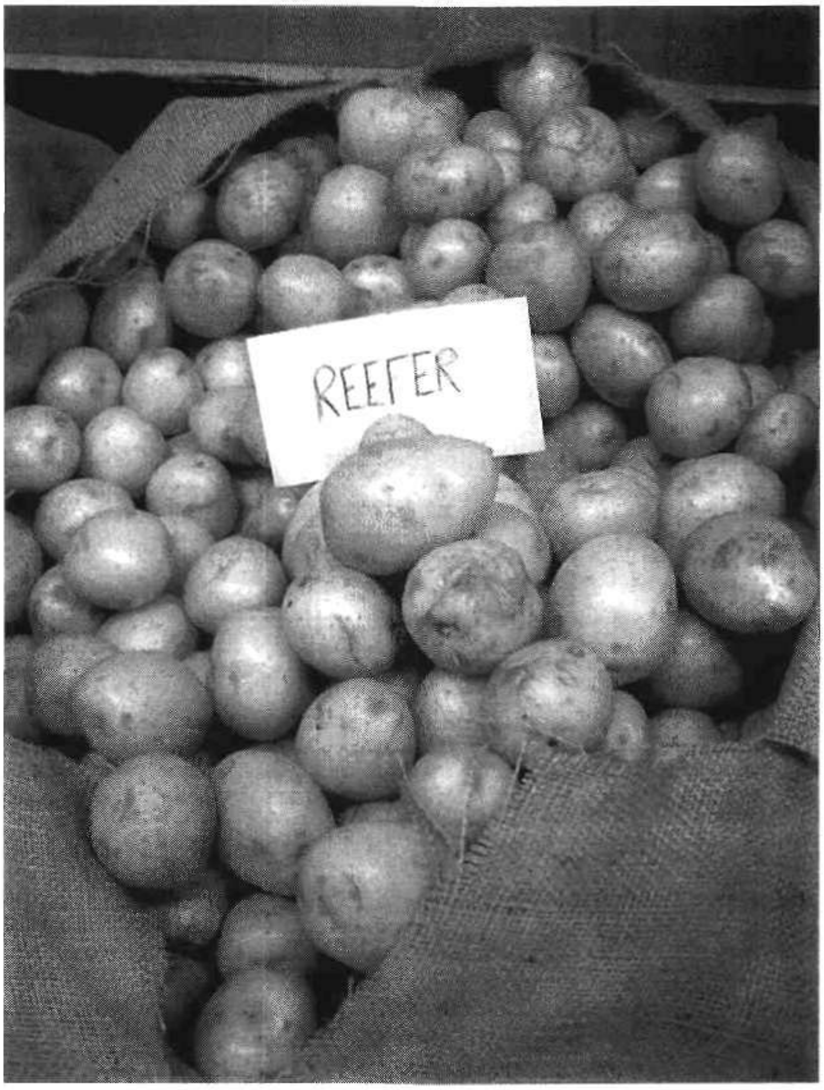


Photo 3.17 Mechanical damage in one of the bags of white skin potatoes opened for inspection

2. A white film covered the red skin Pontiac variety, suggesting that the fungicide treatment applied by the exporter was too high in concentration. This is shown in **Photo 3.18.** In our experience in the laboratory, potatoes treated with the same fungicide, at the recommended concentration have no visible residue.

Photo 3.18 White residue on the surface of fungicide treated potatoes

3.4.2.3 Weight loss
Five bags from the reefer were weighed at the time of loading in Melbourne. The same five bags were re-weighed, using the same balance, at outturn in Hong Kong. Weight loss, as expected, was low. The average weight loss from the five 20 kg bags was 0.20 kg or 1%.

3.4.2.4 Detailed examination of product
The five tagged bags that were placed throughout the stow at loading were opened and examined. No bag examined contained rotten potatoes. There was no evidence of sprouting. The mechanical damage that was present at the time of loading was very obvious, particularly the high level of shatter bruising, giving the load an unattractive appearance.

A number of bags of red skin Pontiac variety from the reefer were also opened as a comparison to the Nardin variety. No rotten potatoes were found and there was no evidence of sprouting. There was less mechanical damage than in the Nardin variety, as had been the case at loading. **Photos 3.19** and **3.20** show the Nardin and Pontiac bags from the reefer.

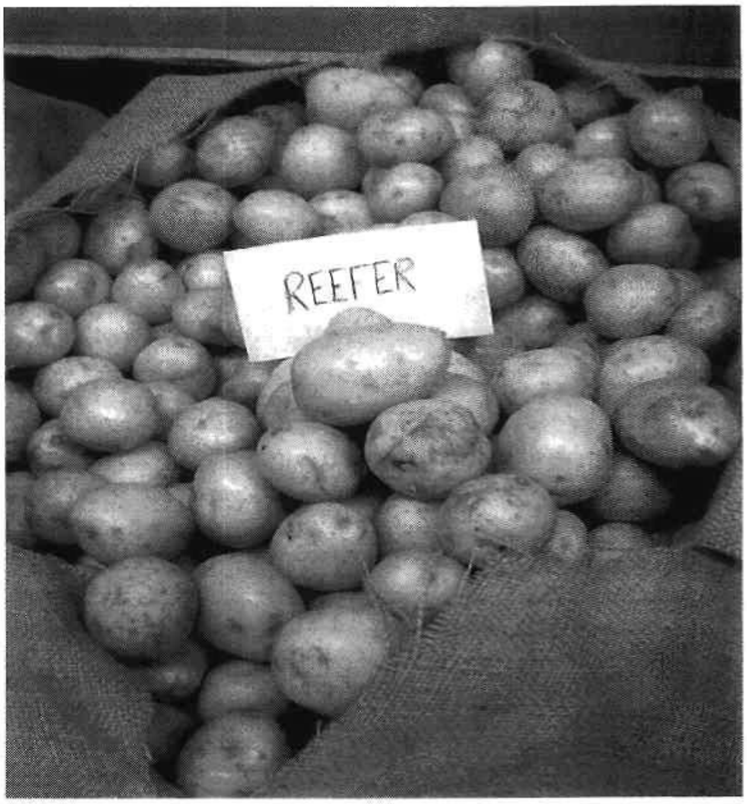


Photo 3.19 Nardin variety potatoes from the reefer

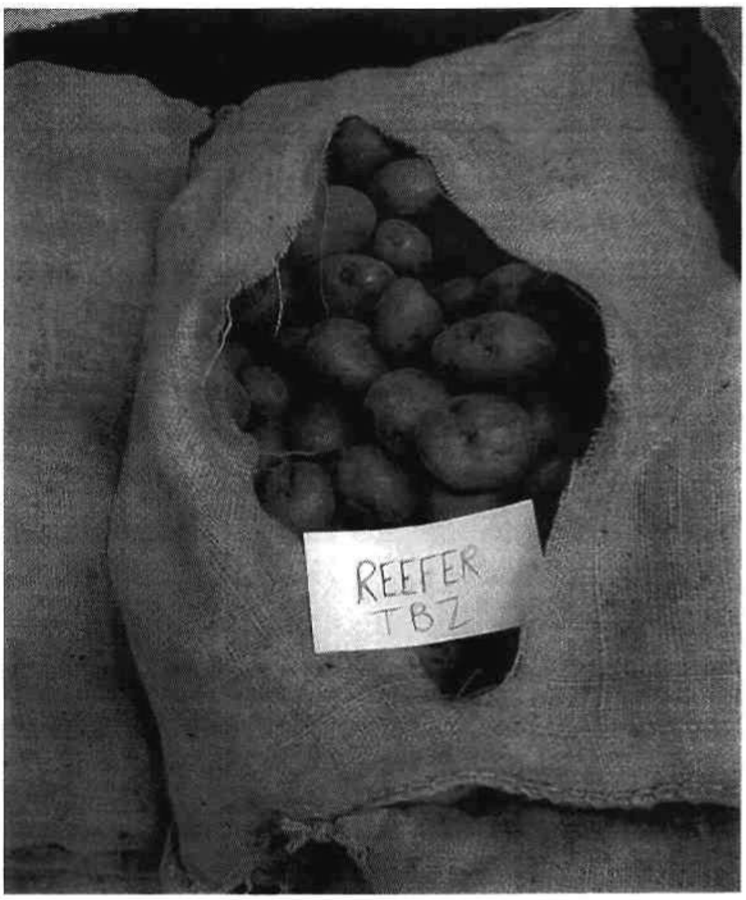


Photo 3.20 Pontiac variety potatoes from the reefer

3.4.3 Condition of product at outturn: The Pot-Tainer

The gap between the first row of pallets and the bulkhead caused a problem as the bulkhead was being removed. Bags of potatoes had fallen forward in the area behind the fan. This made removal of the bulkhead and recovery of the data loggers from the top of the load difficult.

The bags appeared to have settled considerably during transport; the headspace at the time of unloading was around 400mm. This compares to around 100mm at loading.

3.4.3.1 General appearance

The overall appearance of the load suggested the presence of bacterial soft rot, which could also be smelt as the container was opened. Some bags had visibly wet patches indicative of wet rot inside.

One of the most noticeable observations as the container was being unloaded was the difference in the appearance of bags from the left and right hand sides. The left side had more bags that appeared to contain bacterial soft rot than the right (bags with visible wet patches), and was consistently higher in temperature. One location was an exception, the back of the container, where both sides appeared to have equally as many bags containing rots and temperatures were similar. The bags that contained rots were concentrated in the upper layers (layers 5-10), with the lower layers noticeably absent of wet bags. This was indicative of poor air flow at the back of the container, which might be expected due to the reduced pallet gap (75mm instead of 100mm).

3.4.3.2 Product temperature

Temperature measurements using a hand held digital thermometer indicated that at the door end and in the centre, the potato temperatures on the left hand side of the container were 2°C warmer than those on the right. The thermometer probe was inserted between bags to take the measurements. High temperatures were recorded on both sides of the container. At the door, on the left side, the temperature was 31°C on the right 29°C. At the centre left hand side of the container, on pallet 5, 34°C was recorded, on the right 32.5°C. The difference between sides suggests that during the voyage the left side of the container was exposed to some radiant heat. Attempts to confirm the container's stowage position on the vessel failed since ship's log information was withheld as a result of an insurance claim lodged by the exporter.

3.4.3.3 Condensation

The ventilated plastic wrap enclosing the pallets resulted in condensation on the inside of the plastic. This was particularly advanced on pallet 5, in the centre of the container on the left hand side. Bags from this pallet are shown in **Photo 3.21**. The photo shows that these bags were saturated, and when brought into the refrigerated loading bay they began to steam. The majority of the bag wetness was caused by condensation not by rot. When opened for examination the bags were found to contain only a few potatoes infected with soft rot. When the pallet was removed from the container it could be seen that condensed water had dripped onto the floor beneath.

Photo 3.21 Condensation affected bags from pallet 5

3.4.3.4 Preliminary product inspection

As for the reefer, a few randomly selected bags were opened and inspected while the Pot-Tainer was being unloaded. Three features were most noticeable:

1. Although some bags of white skin Nardin appeared very damp, most contained only a few rotting potatoes. This can be seen in **Photo 3.22**
2. Sprouting had commenced in both potato varieties but was more prolific and more advanced in the white skin.
3. The fungicide treated Pontiac potatoes had greatly fewer potatoes affected by soft rot than the white skin variety. **Photo 3.23** is indicative of the fungicide treated part of the load.

Photo 3.22 A few rotted potatoes in a typical sample of Nardin variety from the Pot-Tainer

Photo 3.23 A representative sample of the fungicide treated part of the load

3.4.4 Detailed examination of product

A number of bags from both the reefer and Pot-Tainer had been designated for examination and weight measurement. These were held in cool storage after unloading and assessed in detail the following day.

3.4.4.1 Weight loss

Eleven bags from the Pot-Tainer were weighed at the time of loading in Melbourne. The same eleven bags were re-weighed, using the same balance. The average weight loss from these bags was 0.60 kg or 3 %. However this figure included three bags which had moderate levels of soft bacterial rot; clearly these bags would be expected to have higher than expected weight loss. When these bags were removed from the sample the average weight loss was 0.41 kg or 2%. This compares more favourably with the refrigerated reefer and is similar to the weight loss measured in a simulated Pot-Tainer test shipment at the North Ryde test facility.

3.4.4.2 Examination of product

The five labelled, fungicide treated bags plus the five tagged, Nardin variety bags recovered from throughout the stow were opened and examined. The fungicide treated bags contained less soft rot than the untreated white skin potatoes. The only exception to this observation was in the bags of fungicide treated potatoes located on pallet 1, at the back left side of the Pot-Tainer. These two bags had a high proportion of soft rot compared with fungicide treated potatoes from other locations. This is consistent with the overall observation made during unloading that the back two pallets of the container contained the highest proportion of rot.

Where rot was present in the fungicide treated bags only around 1/3 of each affected potato was rotten. This contrasted with the untreated potatoes, which were completely macerated by rot. **Photos 3.24** and **3.25** show the rots in the fungicide and non-fungicide treated potatoes respectively.

Photo 3.24 Rots in the fungicide treated potatoes

Photo 3.25 Rots in the non-fungicide treated potatoes

Some bags appeared quite wet when viewed from outside, suggesting considerable wet rot within. However when these bags were opened many were found to contain few or no rots. The wetness was probably due to either condensation or contamination from contact with rot affected bags. **Photos 3.26** and **3.27** are an example showing the very wet appearance of a bag from the outside but no sign of rot inside.

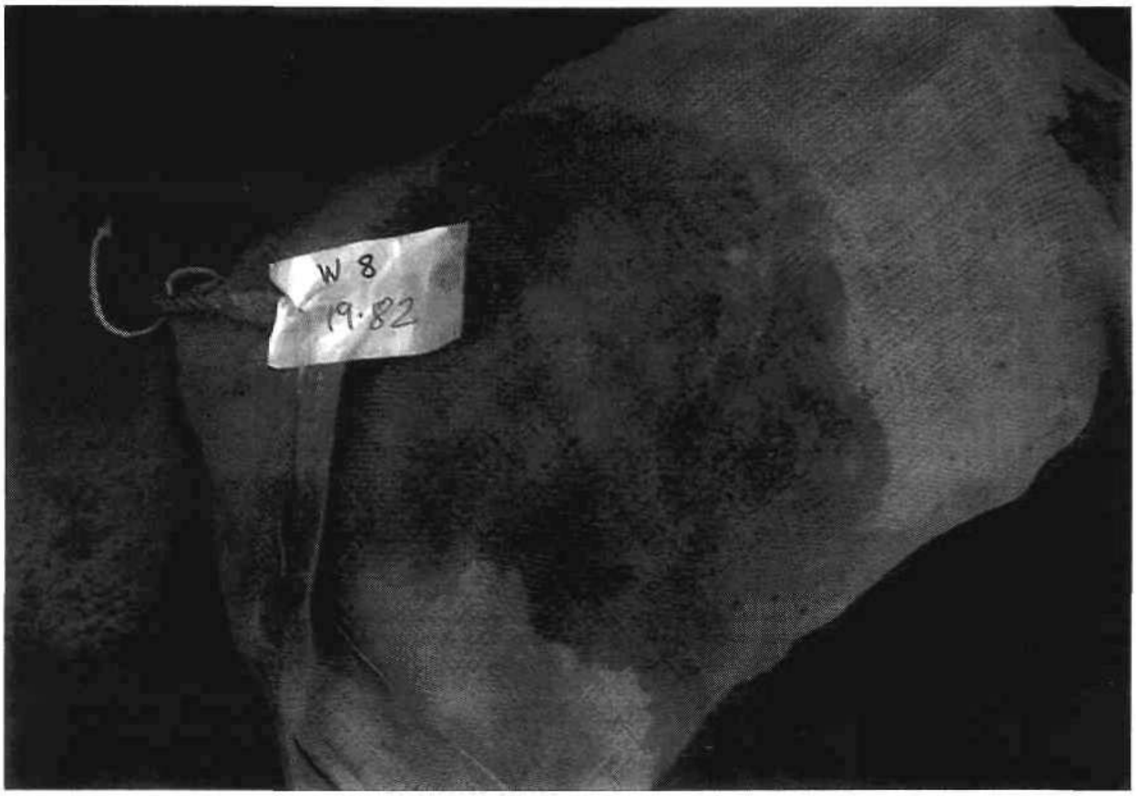


Photo 3.26 A bag showing external dampness

Photo 3.27 The damp bag from Photo 3.26 containing no rotted potatoes

The high level of mechanical damage documented at loading was still evident at outturn, and was more visually unattractive due to drying of the wounds, giving them a grey-white powdery appearance. The shatter bruises, in particular, also showed traces of *Fusarium* growth. This is shown in **Photo 3.28**. Previous laboratory experiments indicated *Fusarium* growth does not occur, even under favourable conditions, provided potatoes contain no mechanical damage. The mechanical damage assessment at outturn is shown in **Table 4**. Each result is an average of five bags. As expected the level of damage is similar to that recorded at the time of loading.

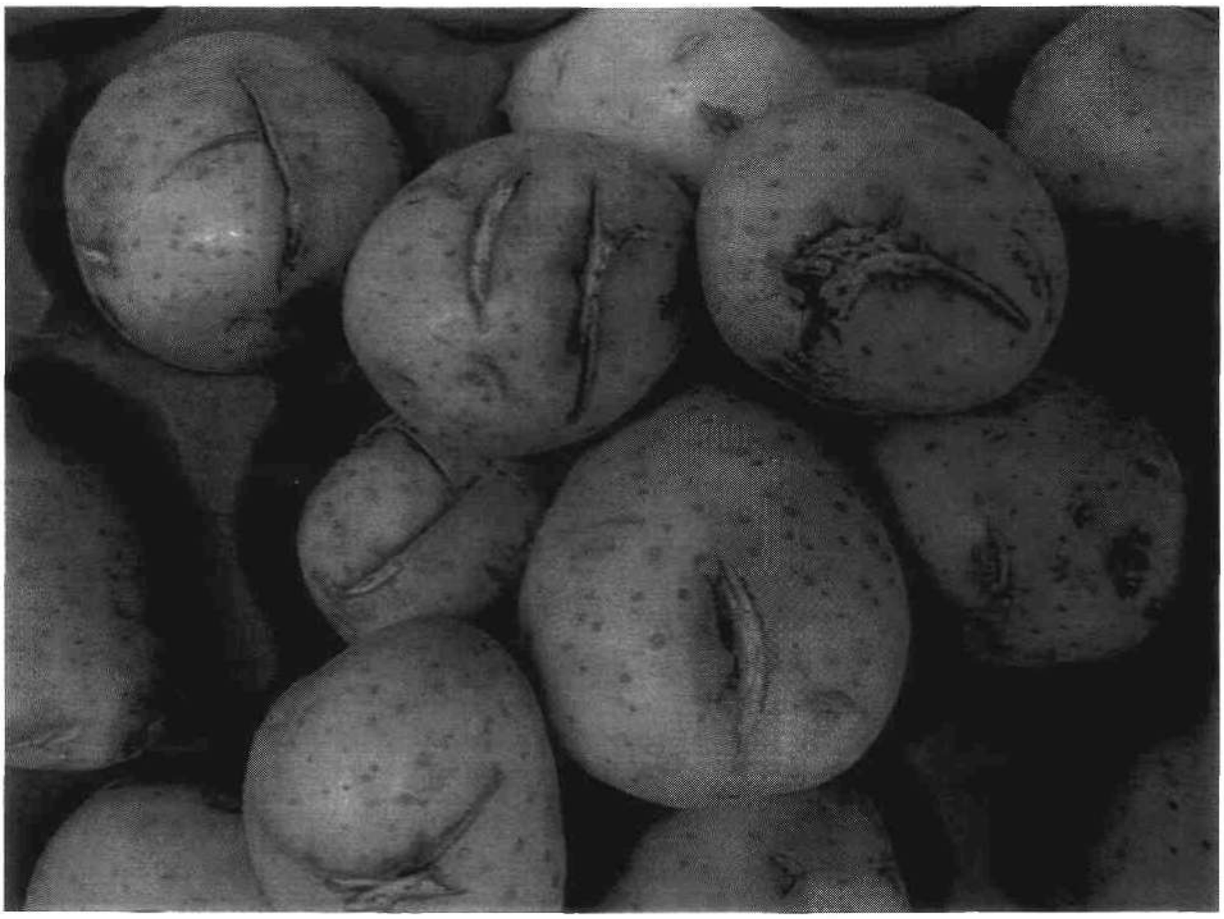


Photo 3.28 Shatter bruises showing traces of *Fusarium* growth

Table 4: Level of mechanical damage observed at outturn in potatoes from Pot-Tainer

Container	Potato variety	Damage level % none	skin graze	cuts/splits	shatter bruise	other
Pot-Tainer	Pontiac	31.5	28.9	16.2	21.4	4.7
	Nardin	36.1	0.7	13.0	47.9	2.3
Refrigerated container	Nardin	45.1	0.8	15.3	36.4	2.2
	Pontiac	30.2	29.3	17.0	21.9	5.1

4. DISCUSSION

4.1 Laboratory studies

4.1.1 The Spudrobe as a simulation of the Pot-Tainer

The Spudrobe operated successfully as a Pot-Tainer. The module's humidity control system was able to maintain the desired high relative humidity within the loadspace, thus closely mimicking conditions expected in a Pot-Tainer. We were able to effectively cure wounded potatoes within the Spudrobe, providing an indication that in-container curing may be feasible in a Pot-Tainer.

4.1.2 Rot prevention

A combination of wound curing followed by fungicide treatment with one of the thiobendazole group of fungicides appeared to entirely prevent *fusarium* dry rot development. Wound sites in the experiment were inoculated with a much higher high level of *fusarium* than would normally be encountered in the paddock or grading shed. Under this rigorous challenge the treatment was still able to entirely prevent rot development.

Wound curing alone or the use of carbendazim fungicide alone were both shown to provide almost complete protection against *fusarium* dry rot. Timing of curing appeared a critical factor. The process needs to be carried out as soon as possible after harvest because once a *fusarium* infection has taken hold in a wound, curing appears unable to halt further spread of the rot.

Fusarium infection appeared to be the most significant postharvest decay problem in laboratory and simulated shipment experiments. The fungus invaded even shallow wounds aggressively over a period of two weeks, a time frame equivalent to an export shipment. *Erwinia* does not appear to infect wounds when present on its own except under the most aggressive incubation conditions. It will however readily enter tissue already degraded by a primary *fusarium* infection. This strongly suggests that prevention of primary *fusarium* infection leads to elimination of *erwinia* infection.

4.1.3 Need for postharvest treatment

While the Pot-Tainer system is designed to maintain an ideal storage environment for potatoes, the high humidity conditions also favour the growth of disease-causing microorganisms. This was graphically illustrated by the fact that wounded potatoes that were neither cured nor fungicide treated developed severe *fusarium* infection, coupled with severe secondary *erwinia* infection.

This result indicates that the Pot-Tainer system per se is not the answer to a good quality outturn; the quality and treatment of the potatoes before they are loaded is crucial. Wounded potatoes should be eliminated, since wound sites provide easy entry points for disease forming organisms that once established have ideal growing conditions. Where eradication of injury is deemed impossible wounded potatoes should be cured or fungicide treated prior to being sent for export.

4.1.4 Need for a sprout inhibitor

We observed sprouting at a moderate level in the Testroom Simulation and the trial shipment. The high humidity and moderate temperature environment within the Pot-Tainer is known to be conducive to sprouting. We did not specifically investigate sprouting or the effectiveness of sprout inhibitors, and at this stage can only recommend that potatoes be treated with a sprout inhibitor prior to shipment in Pot-Tainers.

4.2 Field survey

4.2.1 On the harvester

Skin grazing on the harvester webs is likely to result from bouncing on the shaker web, collision with edges of the belt, insufficiently padded rollers, and coarse vines or stones. Harvester speed and soil condition can affect this and bruising; a slower harvester speed results in less vibration on the machines' webs and belts. In our survey, one grower reported that 20% of tubers suffered injury during dry conditions, but only 10% were injured after recent rain.

4.2.2 Unloading At the shed

When potatoes were unloaded at the grading shed several factors were observed to produce injuries. These included the nature of surfaces with which tubers impact while in transit from the paddock and while being unloaded, plus the height of drops involved. While growers were generally careful to protect tubers from injury during loading in the paddock, there were still some considerable drops onto unpadded surfaces.

Typically the sides and rear corners of the truck were metal and unpadded. The central conveyor belt in the base was padded with thin rubber sheeting, and sometimes covered with wooden boards. On unloading the boards could be removed a few at a time ensuring that potatoes were released onto the conveyor in sections from the back to front of the truck. This prevents potatoes being dragged from all parts of the truck onto the conveyor at once and thus reduces the risk of grazing and scuffing.

Measured drops into the truck from the harvester were from 5cm to 100cm depending on the fullness of the truck. When empty this resulted in tubers dropping a long distance onto hard surfaces on the floor and sides of the truck. When partially full, tubers rolled down the sides of the accumulating pile and again impacted with the unpadded walls of the truck. On arrival at the grading shed unloading typically involved drops of around 100cm from the back of the tipper truck onto the first conveyor. Often this conveyor was steeply angled, resulting in tubers rolling back down when the belt was full. Long drops also occurred as tubers rolled down the floor of the angled tipper trucks towards the exit chute.

Drops from conveyors into holding bins were sometimes high. When conveyors were overloaded tubers fell distances of up to 300cm, resulting in splits and bruising.

4.2.3 During Washing

The washing process can be a major cause of injury. Water-filled flume channels in the concrete floor were not always padded, causing tubers to roll several meters along concrete, with no cushioning other than the water. The washers themselves were sometimes unpadded or poorly padded, allowing tubers to tumble vigorously against hard surfaces, causing skin grazes, splits, punctures and bruises.

If wash water is not renewed regularly organic material accumulates, rendering chlorine treatments ineffective, and leading to potential bacterial infection. This is of particular importance in varieties such as Coliban which appear susceptible to such infection.

4.2.4 On the Grading Lines

Numerous drops were observed along the grading lines, where surfaces were generally padded only with thin rubber sheeting. Drops ranged from around 10cm to 70cm, with an average of around 20cm to 40cm. In parts of some grading lines carrying lower quality tubers, severe, almost vertical drops of up to 60cm onto hard surfaces were noted. Some rollers were not padded, particularly if wooden.

4.2.5 Packing

During bagging, potatoes were observed to drop distances of between 20cm to 90cm into the bag, depending on how full the bag was. In most instances the operator took measures to prevent the tubers from dropping directly onto the concrete floor (the operator folded the lower half of the bag up off the floor until the bag was around 1/3 full then lowered it so that tubers never fell more than around 60cm. In other cases tubers were observed to drop 90cm into the base of bags resting on concrete.

It was observed that potatoes were often packed damp. For red skin varieties this is said to improve the colour. Any residual water left on the surface at the time of packaging, however, can help create anaerobic conditions, in which bacteria can thrive. This problem is compounded if potatoes are packed in plastic bags. Even if perforated, these maintain a high humidity environment around the potatoes, further encouraging both fungal and bacterial growth.

At each stage in the harvest, grading and packaging operations our observations led us to believe that injury could be minimised by implementation of some simple low cost solutions.

Firstly operators need to recognise that potatoes, like any other horticultural produce, will be damaged by rough handling, and that this damage is the initiating step in the further deterioration of product quality. Secondly better cushioning and regular maintenance of the surfaces with which potatoes impact would reduce many forms of injury observed.

If potato quality is diminished by rough handling or poor grading, no technology, no matter how good, can reverse the deterioration, it can, at best maintain it. Therefore to achieve good export quality of Australian potatoes it is imperative to have a good quality product leaving Australia's shores, and this requires vigilance at all stages of the handling chain.

4.3 Testroom voyage simulation

Results from the disease control experiment in the three container systems, those from the comparison bags of Sebago variety and from the bulk of the stow, suggest that any container system alone is unlikely to guarantee a good quality outturn.

Our results showed that the quality and treatment of the potatoes prior to loading into the container system is crucial. Potatoes given no postharvest rot prevention treatment (curing or fungicide application) were highly susceptible to disease development, regardless of the container system used for transport. While the Pot-Tainer system creates and maintains a high humidity environment that is ideal for limiting weight loss, the same environment is also ideal for the growth of microorganisms, particularly at elevated ambient temperatures. It is therefore not surprising that injured potatoes, where entry of disease organisms is easy, have a high likelihood of rot development if no preventative treatment is applied.

Results from the disease control experiment indicate that a combination of postharvest wound curing, followed by a thiobendazole fungicide treatment provides excellent protection from disease development in injured potatoes. Challenge conditions were rigorous; wound sites in the experiment were artificially treated with a high level of *fusarium* fungi and still the combination treatment was able to inhibit dry rot formation. Potatoes in the paddock and grading shed would normally be exposed to a lower level of fungus than that used in our experiment. It is predicted therefore that in a commercial situation this treatment would perform as well if not better than in the experiment.

Curing for a period of at least five days soon after harvest or fungicide application appear to be very effective inhibitors of rot development in damaged potatoes. Both provide almost complete prevention and both are equally effective.

As in laboratory experiments, *Fusarium* dry rot infection was the most significant postharvest decay problem in the disease control experiment. Untreated potatoes with shallow scratch wounds became highly infected during the course of the simulated shipment. *Erwinia* bacteria did not infect wound sites when present on its own; the *erwinia* inoculated pathogenic control did not develop any soft rot. Secondary soft rot was however common in sites of primary *fusarium* infection. Once again this suggests that prevention of primary *fusarium* infection would eliminate bacterial infection.

Previous experimental work indicated that minor skin grazing was not a precursor to disease development. At loading a high proportion of the Desiree potatoes in the main stow had large areas of skin missing. This appeared to lead to a high incidence of bacterial soft rot in the skinned regions. The skinning may have been a result of the maturity of the potatoes. Fully mature potatoes were requested from the supplier but the load that arrived appeared to be of both mixed size and maturity. Less mature potatoes do not have a good skin set and are less resistant to skin loss during harvest, washing and grading.

Need for a sprout inhibitor
The high humidity environment maintained in the Pot-Tainer system coupled with the high ambient temperatures in the latter part of the shipment encouraged the emergence of sprouting. This indicates that a sprout inhibitor may be required for ambient temperature shipment of potatoes in a Pot-Tainer system.

4.4 Trial shipment

The trial shipment consisted of a commercial consignment of two containers of washed potatoes which would probably both have been shipped in refrigerated containers had they not been used for this trial. Instead, one was carried in a Pot-Tainer.

The postharvest handling and shipment protocol developed at CSIRO during the course of this project was supplied to the exporter well in advance of the proposed shipment date. The full protocol is shown in Appendix I of this report. The laboratory experiments showed that mechanical injury predisposes potatoes to the development of postharvest rots if they remain moist or are given no rot prevention treatment. Our field survey showed that potatoes are likely to suffer mechanical damage during harvest/grading/packaging operations. While eradication of this damage is the foolproof method of avoiding postharvest rot it is probably impractical to hope to eliminate all injury during postharvest handling. We showed that low levels of moderate injury can be tolerated if potatoes are given appropriate postharvest treatments:

- **chemical**: postharvest treatment with the thiobendazole group of fungicides (such as TBZ and carbendazim)
- **non-chemical**: postharvest 'curing' to 'heal' wounds by exposure to moderate temperature and high humidity for several days.

The Pot-Tainer system itself operated in the manner in which it was intended. The hardware of the operational and control parts of the Pot-Tainer system functioned without problems.

Dataloggers carried inside the containers during the shipment to Hong Kong, showed both containers remained connected to mains power (except for short periods while the containers were being repositioned). These records also showed that all aspects of the Pot-Tainer control system (comprising the fan, humidity sensor, humidity controller, power supply, controller, damper motor, actuating mechanism and damper) functioned normally throughout the entire journey. Thus continuous air circulation and accurate humidity control were delivered throughout the journey. The refrigerated container also functioned normally. The shipping company agreed to monitor both containers twice daily, to help ensure both operated normally in the terminal and throughout the voyage. Presumably they did so, but we were unable to recover any records, as a result of an insurance claim lodged by the exporter after outturn.

Although the containers functioned normally, at outturn the quality of produce from both containers was found to be unacceptable. We believe the reason for this was failure to follow the export protocol we had provided, and in particular:

- high levels of mechanical injury,

- failure to either cure the potatoes or treat them with fungicide, and
- the choice of an East Coast route rather than the less-challenging West Coast route.

4.4.1 Initial quality of potatoes: (especially the level of mechanical damage)
The handling and export protocol developed at CSIRO for ambient temperature shipment of potatoes (see Appendix I) sets strict limits on the type and level of mechanical damage that are acceptable for export in the Pot-Tainer system. The protocol specifies that all injury other than minor skin grazes **must** be excluded, since more severe levels of injury predispose potatoes to microbial breakdown, particularly at elevated temperatures. It specifies that for transport at ambient temperature, potatoes must be either cured or treated with a postharvest fungicide (or both).

Mechanical damage in both the red and white skin varieties provided by the exporter for this shipment was far in excess of the protocol limits (see Table 3). After conducting an initial damage assessment, and taking into account that the load had received neither curing nor fungicide application, we informed the exporter that these two factors together would potentially threaten the success of the Pot-Tainer outturn. The exporter ordered an independent inspection and decided to continue with the shipment.

Product from neither the Pot-Tainer nor the refrigerated container presented an acceptable appearance at outturn. Potatoes from the Pot-Tainer contained a high proportion of microbial breakdown, and those from the refrigerated container, while not apparently diseased, were unsightly due to drying out of the mechanical injury sites that were present at loading.

4.4.2 Palletisation of the stow
The method requested for loading the Pot-Tainer was hand-stowing onto an airflow floor. This can be formed by a layer of pallets, provided they provide a clear space of at least 100mm beneath the stow. Previous CSIRO studies found this configuration gives uniform air circulation through the stow. The packing shed operator however palletised the stow using a palletisation rig normally used for palletisation of onions for Fantainer shipment. Palletisation led to two main problems:

- Gaps left between the two rows of pallets could only be partially filled by fitting in single bags where the gap was wide enough. Such gaps allow part of the circulating air stream to bypass the stow. Potentially this leads to sweating, either on the product or on the roof and walls of the container.

- A gap remained between the bulkhead and the first last two pallets after loading. The gap was partially filled with loose bags, but the remaining spaces would also allow part of the air stream to bypass the stow.

4.4.3. Bypass of the circulating air stream
The height of the floor space (the clear depth of the airflow floor) is known to control how uniformly the circulating air stream is distributed beneath the stow. Extensive tests carried out in 20' containers at the CSIRO, North Ryde laboratory have indicated

that with the air circulation rate used in the Pot-Tainer, the far end of the stow is 'starved' of air if the clear space beneath the stow is less than 100mm (i.e. the runners of the pallets must be at least 100mm high). Such pallets are specified in our export protocol. Pallets supplied for the trial shipment had runners of only 75mm depth. With 75mm runners the far end of the stow receives insufficient ventilation to warm the potatoes faster than the rise in dew point, and moisture condenses on that part of the stow as the container warms during its transit through the tropics. Damaged potatoes, coupled with free moisture and elevated temperatures predispose the load to microbial breakdown.

4.4.4 Inspection of the Pot-Tainer control system

When the control system was inspected after outturn, there was no evidence of salt infiltration (from seawater or salt-laden air) and hence no sign of rusting or seizure of any of the metal components. There was also no evidence of any friction between the disc containing the vent and its backing board, thus suggesting smooth operation of the air freshening vent throughout the journey.

We belief that failure of the exporter to follow our handling and export protocol meant that this trial shipment was unable to demonstrate the capability of the Pot-Tainer system for delivery of good quality potatoes. For this reason we believe that the shipment should be repeated, with strict adherence to the protocol. Even had the trial had a satisfactory outturn, further trials would be necessary to investigate the many variables of commercial shipment, including:

- Variety of potato
- Location and production processes
- Postharvest handling
- Season
- Destination
- Route
- Weather en-route

5. RECOMMENDATIONS

This study has shown that it is possible to ship Australian potatoes to distant markets without the use of refrigeration. This is possible by a combination of a rigorous postharvest handling protocol with a fan-ventilated, humidity-controlled container (the 'Pot-Tainer'). Like refrigerated containers, Pot-Tainers need to be kept connected to electrical power throughout the journey (except for short periods while they are transferred between terminal and ship).

5.1 Scientific Recommendations

- The Spudrobe (which holds 7 bags of potatoes) has been shown to be a useful piece of experimental apparatus in which to study potatoes shipped in Pot-Tainers, and is recommended for use in further studies.

- Curing is shown to be an effective, non-chemical treatment to help prevent the development of *fusarium*, but injuries must be cured without delay. We have shown that in principle it is possible to cure potatoes in the Pot-Tainer after loading for export ('in-container curing'), and possible even during the initial stages of the journey ('in-transit curing'), although the container may require supplementary heating during cool weather. We recommend investigation of whether potatoes can be cured effectively in the container, and if so determine appropriate curing procedures.

- The conditions within a Pot-Tainer are conducive to sprouting. Investigate whether sprouting will always be expected, and investigate suitable techniques to suppress sprouting, taking into account any restrictions of the importing country on the use of chemical sprout suppressants.

5.2 Industry Recommendations

- Further carefully designed, controlled trial shipments are required to show that potatoes can always be shipped without refrigeration, to investigate any influence of factors such as:

    - ⊗ Variety of potato
    - ⊗ Season
    - ⊗ Location potatoes are grown, and local production processes
    - ⊗ Variation to postharvest handling techniques
    - ⊗ Destination
    - ⊗ Route

- Damaged potatoes are attacked aggressively by *fusarium* (responsible for dry rot) during shipment in Pot-Tainers unless they are cured and/or treated with a fungicide. Curing (or treatment with fungicide) prevents *fusarium* growth in shallow wounds, which not only prevents the development of dry rots, but also prevents *erwinia* (responsible for wet bacterial rot) establishing itself as a secondary infection. It is, therefore, essential to exclude any potatoes showing any mechanical injury more severe than minor grazes, and to cure and/or treat with fungicide. Other aspects of postharvest handling, as listed in the Appendices (Appendix I: Export Protocol and Appendix II: Guidelines) are also essential for successful shipment at ambient temperature in fan-ventilated containers.

- It is possible to minimise the temperature stress to potatoes exported from S.E.Australia to the Northern Hemisphere by choosing a shipping route that minimises the time spent at high temperatures. Measures under the exporter's control when shipping from, say, Victoria, include choosing a vessel that travels via Fremantle rather than via the East Coast, and choosing a vessel that sails direct to the destination, rather than one that stops at intermediate ports. Especially avoid transhipment, because of possible extended delays at the intermediate port.

- Potatoes with injuries more severe than minor skin grazing should not be used for export in the ambient temperature Pot-Tainer transport system, as they are susceptible to disease development.

- Wounded potatoes require postharvest treatment with either curing &/or a thiabendazole fungicide to prevent rot development during ambient temperature shipment regardless of the transport system being used.

- Complete prevention of fungal and bacterial rot is achievable if potatoes are cured for at least five days soon after harvest and treated afterward with a thiobendazole fungicide.

- The two treatments used in isolation are almost as effective in rot prevention as the combination, provided that curing is commenced soon after wounding occurs.

- Prevention of *fusarium* infection largely eliminates bacterial infection, since the latter is often a secondary, opportunistic invader rather than the primary cause of rot.

- Potatoes should be treated with an appropriate sprout inhibitor before shipment in the Pot-Tainer system.

6. TECHNOLOGY TRANSFER

6.1 Field Days attended

- Robertson Potato Field Day and Seminar: Place: Hill's Property, Belmore Falls Rd, Robertson. Attended by: B.E. Stephens and S.C. Morris

- National Potato Field Day, 18 Feb 1999: Place: Toolangi, VIC. Attended by B.E. Stephens and S.C. Morris

6.2 Patents

'A cargo container' (Pot-Tainer patent): Australian patent application No. PP9468: filed 26-3-99.

6.3 Technical and scientific papers presented and/or published

- **Innovative transport and disease control systems.** B.E. Stephens[1], S.C. Morris[2], and A.I. Bokshi[1] Sustainable Production in Highland Potato Growing areas of NSW, Discussion Evening, Mar 26 1998, Burrawang, NSW

- **Australian potatoes: taking the hard knocks and healing the wounds.** B.E.Stephens[1], S.C.Morris[2], A.K.Sharp[1] and A.K.Bokshi[1]. 1999 Australasian Postharvest Horticulture Conference, Oct 3-8 1999,Waitangi, New Zealand.

- **Potatoes for export need a soft touch.** S.C. Morris[2], B.E. Stephens[1] and A.K.Sharp[1]. Potato Australia, 10, 51 – 53 (1999).

- **Pot-Tainers – a non-refrigerated export system for potatoes.** S.C. Morris[2], B.E. Stephens[1], A.K. Sharp[1]. Eyes On Potatoes, (1999)

- **Damage and disease survey of potatoes for three districts in Australia.** S.C. Morris[2]; B.E. Stephens[1] and A.I. Bokshi[1] Refrigeration, Storage & Transport Report No. 57 (99/07): report to growers who took part in the survey.

- Abstracts submitted to Potatoes 2000 Conference
  1) **The Pot-Tainer potato export system,** Alister Sharp[1], Stephen Morris[2], Barbara Stephens[1] and Anowarul Bokshi[1]
  2) **Induction of systemic resistance in potatoes,** Anowarul Bokshi[1], Stephen Morris[2], Brian Deverall[3] and Barry Stephens[1]
  3) **Control of postharvest disease: a comparison of curing and treatment with fungicides.** B.E.Stephens[1], S.C.Morris[2], A.K.Sharp[1] and A.K.Bokshi[1]

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APPENDIX 1

PROTOCOL FOR POSTHARVEST HANDLING and SHIPPING POTATOES TRANSPORTED WITHOUT REFRIGERATION

Harvesting

- Ensure potatoes are fully developed/mature at the time of harvest,
- Ensure potatoes are harvested with minimal physical damage,
- Ensure potatoes are transported and unloaded at the packing shed with minimal physical damage.

Washwater (if potatoes are washed before packing)

- Change the washwater at least daily, and certainly often enough to keep it clean,
- Chlorinate the washwater using sodium hypochlorite or calcium hypochlorite at a level of 50-100ppm, and maintain the pH between 7.0 – 7.5,
- After washing, dip the tubers in, or mist them with, an appropriate fungicidal solution. The only satisfactory treatment found in our laboratory studies so far is TBZ (also known as carbendazim or 'Tecto'), at a level of 500 ppm (i.e. 1ml of Tecto' per litre).

Grading

- Configure the grading line so that there are no drops capable of causing physical damage,
- Discard all tubers with any damage other than minor skin damage (any damage more severe than 'minor skin grazes'),
- Ensure the tubers are completely dried before packing into bags

Sprout inhibitor

If acceptable to the importer, treat potatoes to be shipped at ambient temperature with an approved sprout inhibitor.

Packaging

Pack the tubers in jute bags, not plastic film, woven polypropylene, net bags or fibreboard cartons (plastic allows sweating, fibreboard becomes weak at high humidity and may obstruct air circulation, and net bags permit greening, and tend to cut the surface of the tubers).

Curing

Cure the packed tubers by holding for at least 5 days at 15 - 20°C, 90 - 95%RH (this can be done in a Thermfresh room, or, if ambient temperatures are appropriate, in the container used for export).

Dryness when loading into the freight container

If cool-stored before shipment, warm the tubers slowly to ambient temperature before loading into the container to ensure they are not wetted by condensation of atmospheric moisture.

Shipment in an appropriate container
Many types of container, 20' and sometimes 40' long, are used currently to ship potatoes at ambient temperature, including:

- ❖ Fan ventilated containers:
  - 'Door-ajar' onion Fantainers
  - P&O onion Fantainers
  - The CSIRO experimental *'Pot-Tainer'*

- ❖ Naturally ventilated containers:
  - 'Door-ajar' general-purpose containers
  - 'Flat racks', covered fully or partially with a tarpaulin

  (needs to be opaque to UV to prevent greening).

The choice of the most appropriate type of container to use will depend on many factors, including the route, time of year, type of product (ware potatoes, seed potatoes or processing potatoes) and a risk/cost assessment.

Suitable stowage in the container
To help distribute air uniformly, stow the bags of potatoes on pallets to provide an 'air-flow' floor with a clear sub-floor height of at least 100mm (i.e. pallets with 100mm runners). *Pallets with smaller runners are unsuitable!* It is better to hand-stow onto the airflow floor than to pre-palletise, to avoid gaps between pallets through which air may bypass the stow.

For fan-ventilated containers, maintain the container on-power
Make every effort to maintain the container on-power continuously before, during, and after the voyage. The only exception is that the container may be off-power for up to 2 hours (but preferably only 1 hour), during transfer to and from the wharf, during transfer to and from the vessel, or during intermediate stops during the voyage. Ensure each body responsible for the container (terminal/ship/terminal) maintains a log-sheet to report on the status of the container (whether plugged in and operating) at least twice daily from the time the container is stuffed until it is unstuffed.

Route
High temperatures are less damaging later in the voyage than earlier, so choose a route that spends as little time as possible in the tropics, and if possible avoid transhipment at intermediate ports, especially at intermediate ports in the tropics.

Prompt removal of load from container
The container is not suitable for storage of potatoes after arrival; unstuff the container without delay after arrival, certainly within 5 days of the vessel's arrival in port.

APPENDIX II

GUIDELINES FOR POSTHARVEST HANDLING OF POTATOES DESTINED FOR SHIPMENT WITHOUT REFRIGERATION

1. Harvesting

- Dig potatoes deep enough to avoid cutting them.
- Ensure sufficient soil is lifted onto 1st shaker web to protect potatoes until they reach the top of the web and maintain low harvester speed sufficiently low to avoid damage.
- Keep chains tight and minimise use of shaker webs when soil conditions are good.
- Avoid harvesting when the soil is very dry.
- Avoid harvesting from stone laden areas of the paddock, especially small, sharp rocks that can become embedded in tubers.
- Rotate crop sufficiently often to prevent the accumulation of rot organisms, particularly bacterial soft rot.
- Do not return rotted potatoes to the paddock: remove all potatoes from the paddock and dispose of rejects elsewhere.
- Keep drops into trucks below 25cm and pad or rubberise floor and walls of truck.
- Unload truck in sections along a rubberised conveyor to avoid dragging tubers through whole pile onto the conveyor.
- Harvest only tubers with a mature skin set.
- Do not harvest tubers when cold.

2. Grading Shed

- Regulate unloading from truck onto steep incline or vertical belts to eliminate potential for potatoes to fall large distances – if possible eliminate this type of handling and restrict operations on one level.
- Keep all drops below 25cm.
- Rubberise or pad all potato handling surfaces on every piece of equipment used for handling .potatoes through the grading and packing shed, taking care to design for ease of cleaning.
- Avoid sharp corners on handling surfaces – these create L-shaped punctures.
- Eliminate stones before the washer – use a sink tank.
- Pad or rubberise floor flume channels.
- Monitor microbial levels and renew wash water regularly to avoid microbial build up.
- Avoid aggressive washing or samples being held up in the washer and avoid sharp or rough surfaces in the washer.
- Chlorinate rinse water after washer with 100ppm Cl (sodium hypochlorite). Use automated dosing system and monitor Cl level twice per shift. Do not rely entirely on Cl to remove bacteria; wash water must also be renewed regularly.
- Use water-eliminating sponge rollers after washing to remove residual free water films from the surface of the potato.
- Between water eliminating rollers and grader use a registered disease control chemical. Apply this within 6 – 8 hours of harvest. Chemicals being investigated for suitably include fungicides (e.g. Carbendazim or Prochloraz) and food preservatives (e.g. sodium benzoate or citric acid).

3. Grading Table

- To avoid missing defects present on only part of the surface, turn or rotate potatoes during visual or optical inspection.
- Grade out all defects (e.g. mechanical injury as well as all rots from export lines).
- Pad or rubberise all belts and drops.
- Avoid long drops into packaging.
- Dry thoroughly before packing; moist anaerobic conditions encourage bacterial growth.

4. Transport

- Pack export lines in jute bags rather than polypropylene bags or fibreboard cartons.
- If exporting at ambient temperatures do not refrigerate prior to loading - condensation on potato surfaces must be avoided.
- Ensure good airflow through potatoes during transport.
- Cure potatoes prior to export - provide conditions of around 20°C, 90% RH rather than refrigeration.

APPENDIX III

1 *Introduction*

1.1. Induction of Systemic Resistance to disease

Control of potato postharvest diseases currently depends on refrigerated storage and the application of fungicides, but there is increasing consumer concern regarding toxic pesticide residues. An alternative control method is to supply the potato with compounds that increase its natural resistance to diseases. Several chemicals have been reported to induce or increase resistance to disease organisms when applied to plants [Ozeretskovskaya 1995]. The possibility of applying this technique, to reduce the incidence of postharvest disease in potatoes during export shipment at ambient temperature, was investigated during this project.

One of the major postharvest losses of potatoes in storage and marketing channels is storage rots caused by *Fusarium* spp (Hide and Lapwood, 1992; Venette and Harrison, 1973). *Alternaria solani* is another important caused fungal disease in potato field crops, causing significant losses in yield and rots in storage (Turkensteen *et al*, 1991 and Venette *et al*, 1973). Control measures mostly depend on fungicide use, which is not always economically feasible and environmentally safe (Melinda *et al*, 1991). Cultivation of resistant varieties, is the only safe disease control method, but is apparently not possible in a variety with all other desirable attributes.

Research of recent years indicates the effectiveness of systemic induced resistance in laboratory and in field situations by biological means or chemical spray (Kessmann *et al*, 1994; Cohen *et al*, 1991; Ozeretskovskaya, 1995). Systemic induced resistance (SIR) is taken to mean an enhanced resistance in a plant towards disease organisms. This can be the result of a previous treatment with a disease organism, an attenuated disease organism or a chemical that is not itself a pesticide (Deverall and Dann, 1995). Reports from several workers have demonstrated that salicylic acid and its functional analogues like 2,6-dichloroisonicotinic acid (INA) and benzothiadiazole (BTH) protect many crops against their disease organisms (Vernooij *et al*, 1995; Kessmann *et al* 1994; Gorlach *et al* 1996; Lawton *et al* 1996; Colson, 1998).

In this study we attempted to minimise the use of fungicides and/or bacteriocides in control of leaf and tuber diseases throughout the export and marketing channels. To achieve this we used induction of systemic resistance. A number of chemicals were studied for their effectiveness in inducing systemic resistance on potato tubers as well as on plants. Efforts were made to determine the optimum stage of plant growth at which chemical induction should be triggered to develop resistance on tubers. Persistence of the resistance in plants was also investigated.

2. *MATERIALS AND METHODS*

2.1 Induction of systemic resistance

2.1.1 Potato tubers and plants

Red Pontiac and Sebago variety tubers were used in initial laboratory experiments for trialing systemic inducing chemicals for disease control. Plants of Sebago, Coliban and Atlantic varieties were used in field and glasshouse trials. Plants were treated with systemic resistance inducing chemicals 2,6, dichloroisonicotinic acid (INA), acetylsalicylic acid (ASA) and benzothiadiazole (BTH) in the following situations:

- 60 day old Sebago plants from a field crop at Robertson, NSW sprayed with differing concentrations of ASA and BTH to induce resistance in harvested tubers
- Coliban plants grown in a glasshouse at CSIRO, Sydney, treated with 100ppm BTH, observed for leaf and tuber diseases and enzyme activity
- 60 day old Atlantic plants, in a commercial glasshouse at Bowral, NSW sprayed with 50ppm BTH to induce resistance against powdery mildew

2.1.2 Pathogens

Resistance to dry rot, leaf spot diseases and powdery mildew were tested with inoculation of *Fusarium semitectum, Alternaria solani* and *Erysiphe cichoracearum* respectively.

2.1.3 Chemcials tested for systemic induced resistance (SIR)

Three chemicals reported to be inducers of resistance in various crops were used in this study. These are shown in **Table 2.2**

Table 2.2: Test regime for various chemicals evaluated for induction of systemic resistance

Concentration	Chemical		
	ASA	INA	BTH
a)	167 ppm	200 ppm	8.5 ppm
b)	500 ppm	600 ppm	25 ppm
c)	1500 ppm	1800 ppm	75 ppm

Whole tubers with either intact or partially peeled skin were dipped in chemical solutions for either 5, 30 or 60 minutes. Tuber discs were either dipped for 5 minutes or dipped and vacuum infiltrated for 3 minutes. Samples were then incubated for 6 days to allow systemic induction and challenged with dry rot fungus, *Fusarium semitectum.* Following a further two weeks incubation for the whole tubers and four days for the discs disease development was assessed according to the scales shown in **Tables 2.3** and **2.4** Tuber discs were also analysed for increase in β-1-3-glucanase enzyme, reported to be responsible for induction of systemic resistance.

Table 2.3: Scheme used to evaluated severity of rot on wounded, whole tubers, based on size of rot and whether or not the rot is active at the time it was evaluated

Score	Proportion of wound site infected	Current rot activity
1	no sign of infection	No rot evident
2	<25% wound site infected	Rot not active
3	>25% wound site infected	Rot not active
4	<25% area infected	Rot is active
5	26 - 50% area of wound infected	Rot is active
6	51 - 75% of wound area infected	Rot is active
7	75 – 100% of wound area infected	Rot very active
8	>100% area infected, extensive hyphal growth and severe degradation of the potato tissue	

Table 2.4: Scheme used to evaluated severity of rot on tuber discs (after 4 days of incubation)

Score	Appearance of rot
1	No sign of infection
2	Rot within inoculation hole
3	Rot spread up to 2 mm surrounding the hole
4	Rot spread >2 - 4 mm surrounding the hole
5	Rot spread >4 mm to whole disc

2.1.4. Treatment of field crops for SIR

Following laboratory observations on tuber discs, the field crop at Robertson was treated with 25, 50 and 100ppm BTH and 400ppm ASA. 60 day old plants were sprayed twice, at a one week interval and harvested six weeks after the first spray. Tubers were transported to CSIRO, Sydney to be tested for disease resistance and enzyme activity. Tubers were wounded with either a scratch or skin graze, then inoculated with two concentrations of *Fusarium semitectum* and incubated at 20°C for two weeks, to allow disease development. Disease development was assessed according to previously reported scales. Samples for enzyme analysis were frozen and later tested.

2.1.5. Treatment of glasshouse plants for SIR in plants and tubers

Plants grown in the CSIRO glasshouse were treated with BTH according to three regimes:

1. Treatment 30 days after sprouting for observation of resistance to *Alternaria* leaf spot
2. Treatment of 30 day old plants for observation of accumulation and persistence of disease resistance enzymes in various plant parts
3. Treatment of plants at differing growth stages for observation of postharvest resistance to dry rot in tubers

2.1.5.1 Challenge inoculation of leaves and tubers

To study the development of leaf spot disease, plants were grown outside the glasshouse and inoculated with *Alternaria solani*; a fungal suspension was sprayed onto the upper surface of the leaves. Plants were then covered with a perforated plastic bag and held in the dark for 24 hours before being kept in shade for a further 24 hours and finally being allowed to grow under sun in the glasshouse. Leaves were assessed for disease development 7 days after inoculation by counting the number of visible infection sites on each leaf. Harvested tubers were assessed for resistance to dry rot according to previously described methods.

Plants in the commercial glasshouse at Bowral were treated with BTH 60 days after sprouting and observed for four weeks thereafter to determine the development of powdery mildew. Determination was made by counting the number of colonies that had developed on the middle five leaves of each plant. Leaf and tuber samples were also analysed for β-glucanase enzymes.

3. Results

3.1 Induction of systemic resistance in potato tubers

Treatment of whole tubers with intact and partially peeled skin at different concentration of chemicals for different times did not yield significant reduction of rots over the control treatments. The above results it is yet to confirm for the effectiveness of the chemicals to induce resistance in potato tissues.

Potato tuber when cut into disc and treated with BTH by pressure through vacuum infiltration for 3 min showed an significant control of *Fusarium* rot at a concentration of 8.5 ppm while with higher concentrations of BTH did not gave significant results over the control treatment. Dipping the tuber disc for 5 min in a range of concentrations significantly reduced rot at 8.5 and 25 ppm. The disc treatment with INA in different methods and at different concentrations did not show any variation in rot development over the control. ASA at 400 ppm effectively reduced rot severity in both vacuum infiltration and in dipping in solution.

From the results of the above experiments it was found that BTH at 25 ppm and ASA at 400 ppm were effective for induction of systemic resistance against *Fusarium* dry rot of tuber disc when applied by dipping. These two chemicals were then tested for their relative effectiveness in developing resistance in tuber disc against dry rot fungus. Treated tuber discs were also assessed for enzyme activities.

Tuber discs dipped in BTH at 25 ppm had significantly increased resistance against *F. semitectum* compared to ASA at 400 ppm and control treatments **(Figure 1)**. ASA at 400 ppm caused a significant reduction in dry rot over the control treatment but was less active than BTH at 25 ppm. The results of this experiment clearly indicate that the chemical BTH at 25 ppm as a dip is more effective than ASA at 400 ppm for induction of resistance against dry rot in potato tuber discs. Similar results were found by the analysis of β-glucanase enzyme activities in tuber discs treated with BTH and ASA. **Figure 2** showed a significant increase in enzyme activities in the BTH treated discs over ASA and control treatments. The increase of enzymes in ASA treated discs was significantly higher than the control but was lower than the BTH treatment. These results reveal that the increase in resistance after treatment is correlated with increased enzyme activities in tuber discs.

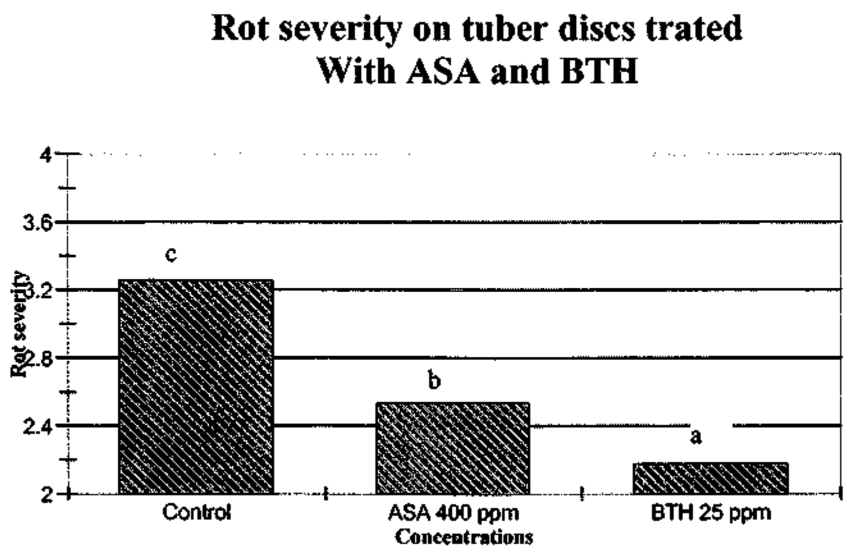

Figure 1 Dry rot disease developed on tuber discs treated with BTH and ASA

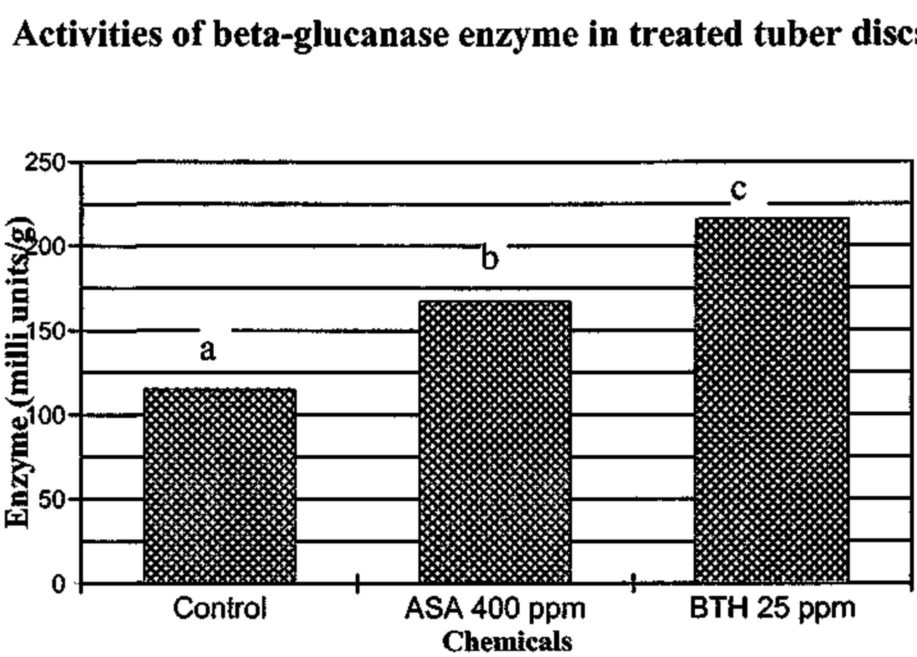

Figure 2 Enzyme activities in tuber disc treated with BTH and ASA

3.1.1 Induction of systemic resistance in potato tubers by treating plants in the field
BTH and ASA found to be effective in induction of resistance in potato tuber disc in laboratory conditions were sprayed on potato plants in the field, to induce resistance in harvested tubers. On harvest tubers were inoculated with *F. semitectum* for the development of dry rot disease. Results show tuber rots after challenge inoculation were not significantly affected by the BTH and ASA treatments. However, **Figure 3** shows a clear trend of reduction in rot severity from scratch wound inoculation at both 0.6 and 0.2 OD in the treatment with BTH at 50 and 100 ppm. On the other hand ASA 400 ppm increased rot severity at both inoculum concentrations from scratch wounds. Whereas, with a skin graze wound and at 0.6 OD of inoculum it gave maximum control of dry rot over all other treatments. Potato tubers from the BTH treatment at 25 ppm showed inconsistent rot development.

From the above results, it was suspected that development of disease resistance in potato tubers varied in different layers of tissues with different treatments. In skin grazes, where only superficial layers were exposed to inoculum, highest resistance developed in the treatment of ASA at 400 ppm followed by the BTH at 100 ppm. The reduction in dry rot from scratch wounds after BTH treatments mainly at 50 and 100 ppm indicates increased resistance in the sub-surface tissues of tubers.

The enzyme activities in the leaf extracts are shown in **Figure 4** (7 days after spray) and **Figure 5** (at harvest). From the activities of leaf enzyme 7 days after treatment it was found that BTH at all levels of concentrations significantly increased β-glucanase over control and ASA at 400 ppm. The induction of β-1,3-glucanase enzymes was more or less in equal amount in all BTH treatments after 7 days but declined after a longer period from treatment (**Figure 5**). The results from leaves at the time of harvest indicated that the plants treated with BTH at low concentrations (25 and 50 ppm) had lesser activities compared with BTH at high concentration (100 ppm) which maintained a high activity of β-1,3-glucanase enzyme.

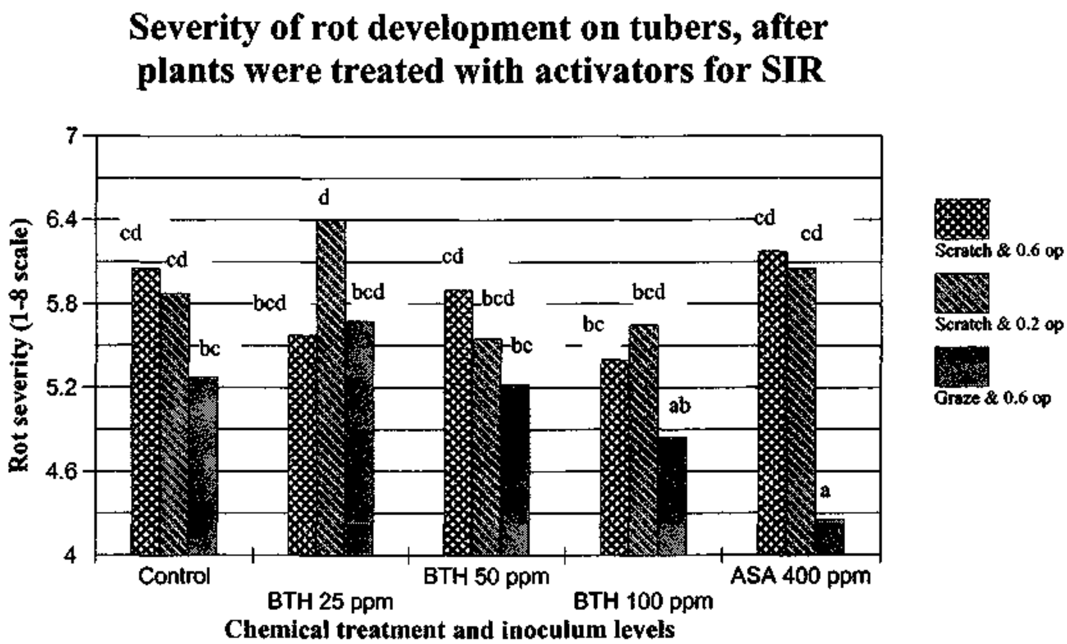

Figure 3 Disease developed on potato tubers harvested from plants treated BTH and ASA in the field

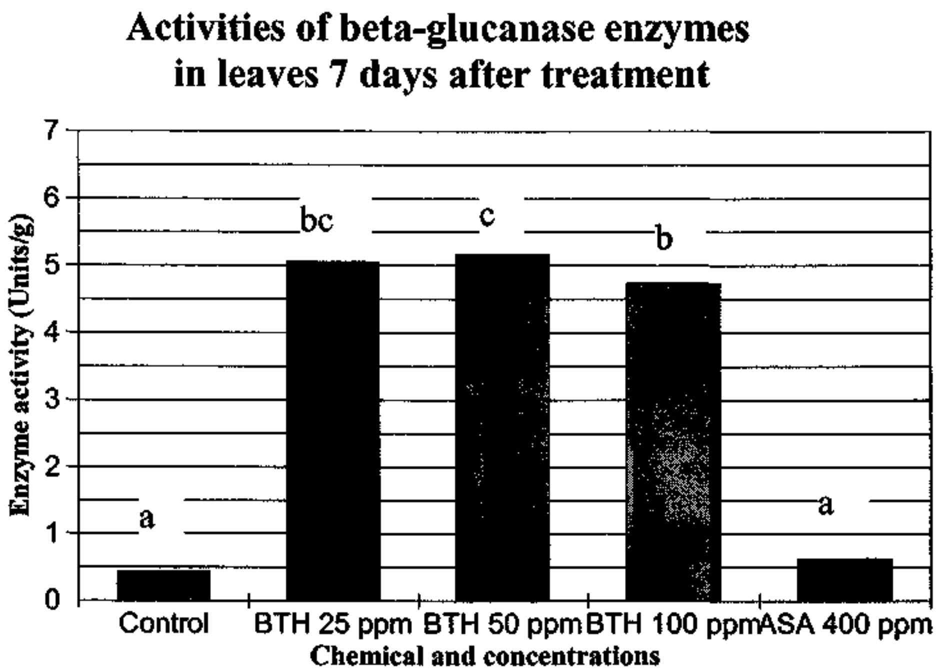

Figure 4 Enzyme activities in potato leaves 7 days after spray with BTH and ASA in the field

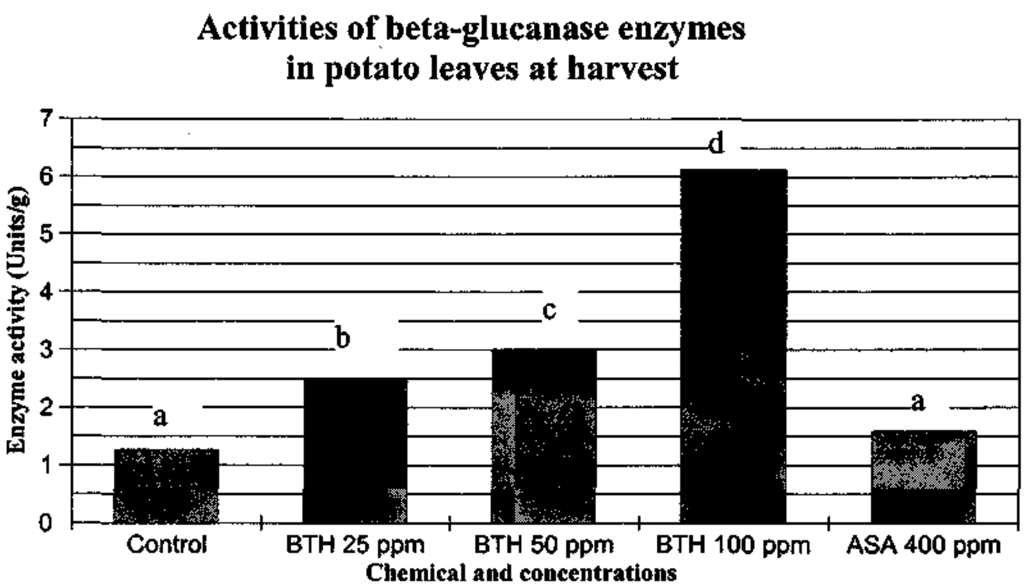

Figure 5 Enzyme activities in potato leaves 5 weeks after spray with BTH and ASA in the field

The analysis of potato tubers after harvest for the activities of β-1,3-glucanase enzymes showed significant variations among the treatments. BTH treatment at 100 ppm caused maximum activities of β-1,3-glucanase enzymes, insignificantly followed by BTH at 25 ppm and BTH 50 ppm The enzyme activities of harvested potato tubers show a similar pattern to enzyme activities in potato leaves found 7 days after second spray of the chemical activators. BTH treatments increased enzymes activities in leaves and tubers over control and ASA treatments.

3.1.2 Induction of systemic resistance in potato plants in glasshouse

BTH treatment on potato plants in the glasshouse showed a significant control of leaf spot disease when inoculated with *A. solani* (**Figure 6**). There was very little disease development in BTH treated plants inoculated with *A. solani* which varied little from non-inoculated control or BTH treated plants. It was also observed that on BTH treated plants, inoculation caused a few leaves to develop small spots of infection which did not spread afterwards. On the other hand most of the infection sites in control plants continued to grow and developed larger spots on leaves.

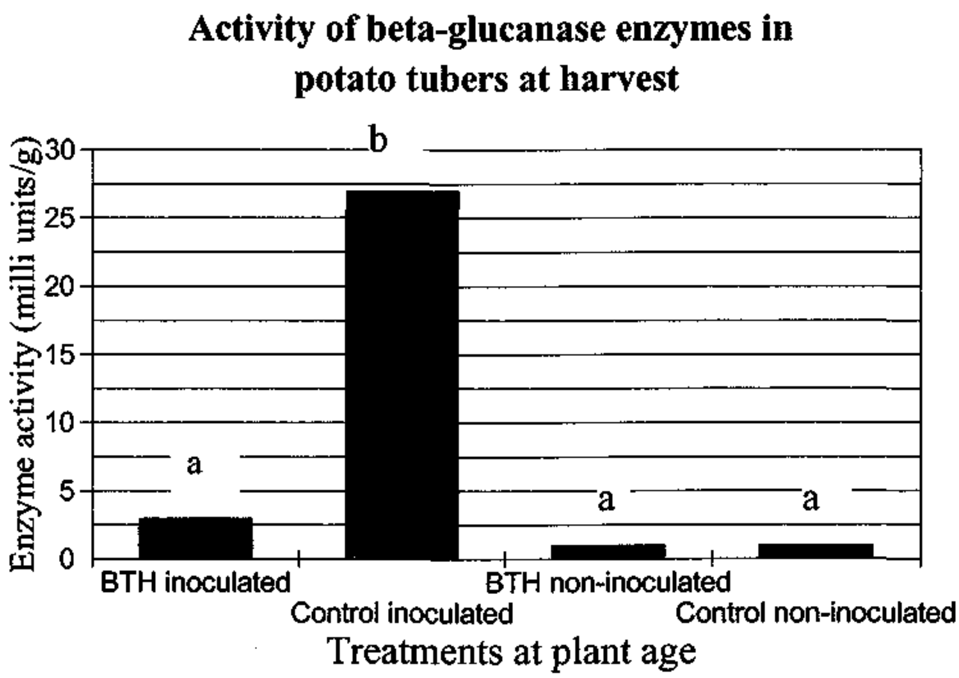

Figure 6 Development of leaf spot disease on potato leaves treated with BTH in glasshouse

Assessment of leaf enzymes from the BTH treated plants showed a significant increase at the 7th day after treatment and was continued to maintain higher amount up to 45 days of treatment. The leaf enzymes analysed from treated old leaves and newly grown leaves showed significant variations in activities 30 days and 45 days after treatment. Results showed that plants increased the activity of enzymes on treated as well as new growth compared to their controls.

BTH treatment on potato leaf at different stages of plant growth affect the development of dry rot disease on challenge inoculation with *F. semitectum*. The results in the **Figure 7** indicate a significant variation in rot severity after different treatments. Maximum control of dry rot disease was found on tubers from plants treated with BTH at both 30 and 60 days of growth, followed by the BTH treatments at 30 days or 60 days. There was no significant variations in rot development among the control treatments.

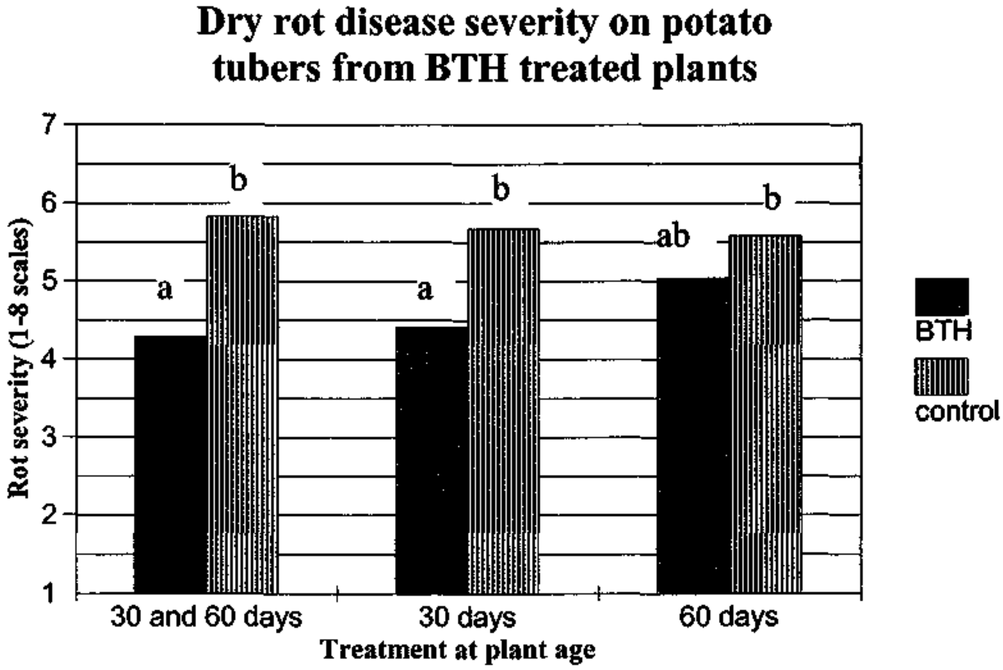

Figure 7 Dry rot disease developed on potato tubers treated with BTH in glasshouse

Activities of β-1,3-glucanase enzyme was analysed from the harvested tubers treated with BTH at different stages of plant growth. Increase of 1,3-glucanase enzyme due to treatment with BTH varied significantly after treatment at different stages of growth of plants. The highest increase in enzyme activity occurred in tubers from the plants treated at 30 days of growth, insignificantly followed by treatment at both 30 and 60 days (**Figure 8**). Plants treated only at 60 days of growth did not have significantly increased activities compared to controls. Results also showed that BTH treatments at 60 days or both 30 and 60 days had statistically similar effects. The activities of β-glucanase enzymes in all the control plants gave insignificant variations. The results further indicate that the resistance in tubers correlated with the accumulation of 1,3-glucanase enzymes after treatment.

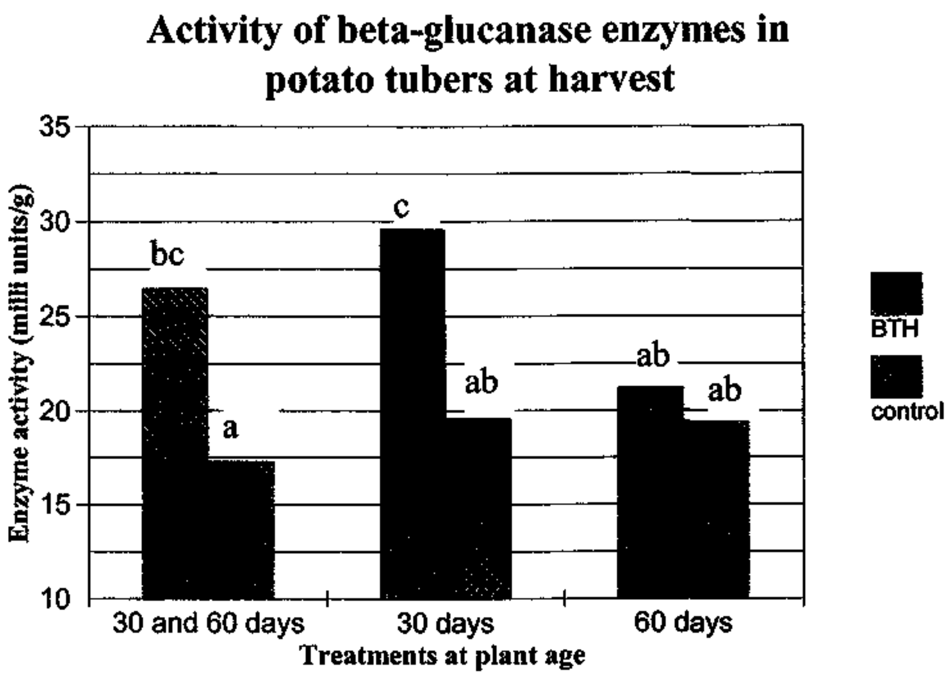

Figure 8 Enzyme activities in potato tubers harvested from the plants treated with BTH in glasshouse

In principle, with systemic induction resistance, the whole plant including its root systems should show induced resistance. BTH treatment increased enzyme activities in different plant parts but it did not increases enzymes in potato roots. There may be limitations on transmission of systemic signal from leaves to roots through the stem.

Treatment of BTH to potato plants at different stages of growth greatly affected the further development of the plants. Plants treated with BTH at both 30 and 60 days of growth were severely affected in growth, insignificantly followed by the treatment of BTH at 60 days. BTH spray at 30 days had no significant effect on plant growth compared to control treatments. The results indicate that BTH spray at early stages (within 30 days of growth) of potato plants did not hamper further growth. On the other hand, treatment with BTH more than once or at later stages (60 days) of growth affected the development of potato plants. Similar trends on the yield of potato were found with the treatment of BTH at different stages of crop growth.

Results showed that BTH spray at 30 days of growth did not affect significantly the yield of potato tubers over the control treatments. BTH treatment at both 30 and 60 days of growth of the plant effectively reduced the tuber yield compared to control as well as other treatments. From the results it was found that BTH treatment at the later stages of tuber development greatly affected the plant growth as well as tuber yield of potato.

Treatment of BTH on potato plants in the commercial glasshouse showed an excellent resistance against powdery mildew compared to control plants **(Figure 9)**. Development of powdery mildew also influenced by the light conditions and it was higher on plants grown under shade compared to plants grown under sun. Assessment of leaf enzymes was also found that the BTH treatment increased significant amount of ß-glucanase activity in leaf compared to control treatment. Enzyme activities was found to vary on the different light conditions of the plants Plants under shade were shown to have more green leaves at the time of harvest and with higher enzyme activities compared to those grown under sun or partially shade. Activities of ß-glucanase enzymes in tuber did not show any significant variation.

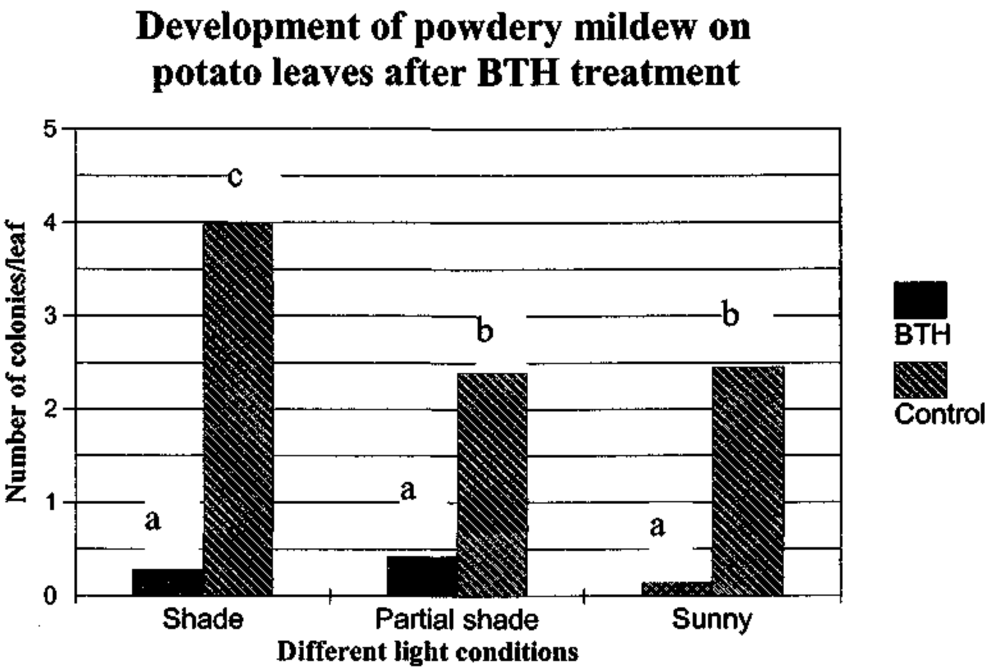

Figure 9 Powdery mildew disease developed on potato leaves treated with BTH in a commercial glasshouse

4. *Discussion*

4.1 Induction of systemic resistance

In this study systemic induced resistance was not achieved for whole potato tubers may be due to the maturity status of the harvested tubers or because the nature of resistance mechanisms in tubers is not responsive to chemical induction.

Since there was a problem with whole tubers to induce resistance, tuber discs with a large peeled surface area were used as a test system. Dipping of tuber discs in BTH and ASA was shown to increase resistance against dry rot incited by *F. semitectum* and also increase in activities of β-glucanase enzymes. Treatment of BTH at 25 ppm on tuber disc by dipping caused higher levels of resistance compared to ASA at 400 ppm which shown a correlation with the activities of β-glucanase enzymes in tuber discs. The increase in resistance and resistance inducing enzymes such as β-glucanase is one of the classical features of SIR as reported by Mauch *et al.* (1988), Kombrink *et al.* (1988) and Schröder *et al.* (1992). It may need further search to define the efficacy of INA for induction of resistance in tuber tissues.

Previous research has found that these chemicals are readily carried around the plant in the vascular system, therefore, further studies were carried out by applying the induction chemicals to growing plants so that they can enter the tubers via the vascular systems. The aim of the field spraying was to induce resistance in tubers by enabling movement of the induction chemicals ASA and BTH into the tubers via vascular system. The application of chemical inducers in the field during later stages of tuber development did not prove to be effective in inducing resistance in tubers against dry rot fungus after harvest. A lack of disease resistance might be due to the more severe disease challenge with a virulent strain of *Fusarium* sp. for potato dry rot in a most favourable incubation conditions. It might be that the natural infections with the common pathogens could be controlled.

However, increase in activities of β-glucanase enzymes in harvested tubers provides evidence of systemic effects in potato tubers in response to chemical spray on foliage. In spite of higher activities of β-glucanase enzymes, tuber disease was not reduced significantly which might be because the increased activities of β-glucanase enzymes was not enough to fight against the dry rot fungus (Kuć, 1995). Application of activators at the later stages of crop growth when tuber formation was over might be another reason for non-activation of resistance in tubers (Guedes *et al.*, 1980).

Higher activities of β-glucanase enzymes in leaves after BTH treatment are a further indication of development of systemic effects in potato leaves. Higher concentration of BTH sprayed on field plants helped to sustain increased activities of enzymes in potato leaves.

Activities of β-glucanase enzymes from harvested tubers followed the pattern of activities of leaf enzymes seven days after chemical treatment. Declines in activities of leaf enzymes at harvest in plants treated with lower concentrations of BTH was not mirrored by changes in activities of tuber enzymes.

The above results led us to investigate the effect of BTH on induction of systemic resistance against leaf diseases and also the age of the plant for induction of resistance in tubers against storage diseases. Foliar application of BTH at 100 ppm (a.i) on glasshouse potato plants at CSIRO, North Ryde, was observed to greatly control leaf and tuber diseases in association with an increased activities of β-glucanase enzymes throughout the plants except roots.

Development of leaf spot disease after infection by the fungus demonstrated a great effect on the BTH treated plants. *A. solani* caused very minor levels of infection on the BTH treated plants and disease development on the infection sites was very slow or fully stopped, whereas, in the control plants, the spread of disease lesion continued successively. It seems that the resistance developed on potato leaves from BTH treatment start prevention of entry in every process of fungal growth from the early infection to the later stages of disease development.

BTH treatment at early stages of plant growth (30 days) resulted in induction of greater resistance against tuber disease infection than treatment at later stages of plant growth (60 days). Application of the compound twice in the growing period of the potato plants, both before and after tuber formation, resulted in maximum protection against the dry rot fungus and in the accumulation of higher activities of β-glucanase enzymes, but at a cost to tuber yield due to a phytotoxic effect on the foliage and plant growth.

In a further trial with potatao plants in a commercial glasshouse almost complete control of powdery mildew caused by *E. Cichoracearum* was found. This means that excellent control is achievable for two potato leaf diseases. Similar effects for controling powdery mildew disease development on wheat due to BTH spray has been reported by Görlach *et al.* (1996) who suggested the low infection was because the fungal growth was inhibited in every steps after spore germination to disease development by the structural and molecular changes in the treated plants.

In this second glasshouse trial β-glucanase was also greatly increased in leaves. There was a range of light conditions over the experimental area. The plants grown under sunnier conditions had lower activities of β-glucanase enzymes compared to those grown under shade. This may be due to the earlier leaf senescence for plants with sunnier condition. Higher activities of β-glucanase enzymes in leaves under shade was correlated with greater resistance against powdery mildew compared to leaves under sun.

Application of BTH at 100 ppm concentration in the glasshouse caused some leaf curling in potato plants and restricted height and tuber yield. BTH spray at later stages (60 days) of growth halted further growth of plants, and more than one spray (30 and 60 days) severely stunted plant growth and resulted in early death of plants. Adverse effects on plant growth due to spraying BTH at 100 ppm in the glasshouse might be because the concentration of chemical was higher than the tolerable dose for the potato plants, which already had high levels of enzyme activities. Similar results have been reported by Cohen and Kuć (1981), where they found dwarfing, premature senescence and symptoms resembling nitrogen deficiency in tobacco plants.

Tolerance levels to chemical concentrations that adversely affect plant growth vary depending on the growing conditions of plants. In the field, BTH at 100 ppm did not cause any leaf curling or symptoms other than a little early senescence compared to

ASA or control plants. Similarly in the commercial glasshouse where BTH was sprayed at 50 ppm, no leaf curling or any other growth retarding symptoms were observed. It is speculated that the stress conditions due to low air movement and control atmosphere in the glasshouse potato plants might cause higher initial levels of leaf enzymes which increased further on treatment with BTH at higher concentration resulting in leaf curling from phytotoxic effect of excessive enzymes in leaves.

Analysis of enzymes from treated old leaves and leaves that developed after BTH application confirmed the ability of BTH to stimulate the new growth of a plant to increase enzyme activities. High initial activities of β-glucanase enzymes in old leaves of potato plants compared to newly grown young leaves is in compliance with the results of Beerhues and Kombrink (1994) and Métraux *et al.* (1991), who found increased activities of both chitinase and β-glucanase in old leaves.

Induction of systemic resistance and increased activities of enzymes due to BTH treatment on potato foliage seemed to occur simultaneously in all plant parts. Seven days after BTH treatment the activities of β-glucanase enzymes in stems of potato plants increased slightly. However, unlike leaves, enzyme activities in the stem continued to increase at 30 days after BTH treatment.

There was a significant increase in the activities of β-glucanase enzymes in potato stolons and tubers as a result of BTH treatment on leaves. Activities of β-glucanase enzymes in stolons and tubers at the early stage of tuber formation demonstrated a strong correlation between the increase of stolon enzymes and tuber resistance found at harvest. Seven days after BTH treatment the activities of β-glucanase enzymes increased both in stolons and newly formed tubers to about equal strength. Activities of stolon enzymes increased with aging of plants showing similarity with the results of Beerhues and Kombrink (1994) but the activities of β-glucanase enzymes in tubers were found to decrease. Like stem enzyme activities in stolon and tubers were very low compared to leaves.

The initial amount of enzymes in tubers from stolons at the time of its formation are thought to be dispersed in developing tubers which decrease in concentration with the increase in volume of tubers. However, higher activities of enzymes in tubers from plants treated with BTH were noticed over controls during the development of tubers and they persisted up to harvest. It is evident from these results that the low activities of enzymes in potato stolons during the formation of tubers contributes to the low levels of enzymes in tubers. The results of this study in contrast to the findings of Guedes *et al.* (1980) and Beerhues and Kombrink (1994) stating the early treatment for induction of systemic resistance suggest that for induction of systemic resistance in potato tubers, plants should be treated before stolon formation.

Assessment of activities of β-glucanase enzymes in leaves of potato plants revealed that BTH treatment required more than three days to initiate events associated with and seems within seven days to complete them. The results agree with Platonova *et al.* (1982) where they speculated that for complete induction of systemic resistance a period of 72-96 hours is required for necessary rearrangement of cell ultrastructure and cellular changes to occur. Mauch-Mani and Slusarenko (1994) reported that development of complete resistance required about 7 days and partial resistance 4 days after inoculation with *Fusarium oxysporum* as inducer on *Arabidopsis*. These results support evidence suggesting that induction of systemic resistance in potato plants with foliar application of BTH required more than 3 days and 7 days for complete induction.

4.3.1 Conclusions

The compounds included in the study (INA, ASA and BTH) have been reported to be active for induction of resistance in a diverse group of plants, including plants of potato family (Mills and Wood, 1984; Walters *et al.*, 1993; Nielsen *et al.*, 1994; Vernooij *et al.*, 1995; Görlach *et al.*, 1996; Benhamou and Belanger, 1998). BTH was found to be the most active for inducting resistance but other compounds still need more investigation for their potentials as inducer of systemic resistance.

Studies of diseases on potato leaf and tubers for their resistance in response to chemical activators are economically important for the potato industry. Dry rot caused by several fungi including *Fusarium* spp. is the most important storage disease (Nielsen, 1981). Early blight caused by *Alternaria solani* is another major disease on potato field crop can frequently result in storage problems which may later either limit market quality or seed performance and ultimate yielding ability (Hooker, 1981; Melinda and Stevenson, 1991). Powdery mildew disease occurred in potato is mainly caused by the fungus *Erysiphe cichoracearum* (Lawrence, 1978) which in early infection could cause significant loss in tuber yield (Easton and Nagle, 1990).

In this study BTH have demonstrated systemic induction of resistance against multiple pathogens of potatoes (leaf and tuber diseases) in different cultivars at various growing conditions. Economic feasibility of using BTH has been demonstrated in wheat by Görlach *et al.* (1996) which is comparable with potatoes as it has similar growing period in the field. In this regards the potential of BTH as chemical inducer for disease management would play an excellent role for exploring the plant's existing defense mechanisms.

There is, however, a need for more research in different areas of production and postharvest storage of potatoes. This study provides baseline information on the systemic induced resistance in potatoes and a direction on future works with chemical activators as a practical approach on field and storage diseases. The study has obviously been helpful for developing and generalization of systemic induced resistance in potatoes as well as other member plants of this family.

These studies assist in meeting the social demand for using environmentally safe disease control mechanisms in the field for crop production. Foliar diseases control of potatoes in the field will reduce the risk of yield loss as well as help to reduce inoculum carried to harvested tubers. This could minimize storage decay and infection of successive crops in the field. Many aspects of application of the compound BTH will have to defined for the field crops such as the ideal age of the plants, seasonal or varietal effects on induction of resistance against a range of pathogens and nutritional supplement to overcome early senescence caused by BTH. In addition a number of storage pathogens of soft rots and dry rots should be brought into future studies to yield a package of recommendations for postharvest potatoes.

5. Recommendations

- It is too early to recommend use of chemical inducers of systemic resistance based on this study. However, results showed excellent control of two potato leaf diseases in glasshouse conditions, indicating the possibility of using BTH as an inducer of systemic resistance in potato plants. **(but see Note)**

- Use of BTH as an inducer of systemic resistance in potato plants could be part of disease a control regime in the field and in stored potatoes, preventing infections through natural resistance mechanisms. **(but see Note)**

- **Note:** Regarding the induction of systemic resistance we must emphasise that the chemicals investigated for systemic induction of resistance are not currently registered in Australia for use in this way. However, it seems these chemicals have the potential to convey systemic resistance, and we suggest that a range of concentrations of BTH be tested in field conditions:

- The chemical should be tested by treating from very early stages of crop growth to the tuber development stages.

- Crops grown in different seasons such as early, medium and late should be tested against the respective seasonal pathogens in field conditions.

- Prevention of a range of leaf and postharvest storage diseases should be tested on chemical treated plants and tubers.

- Persistence of resistance in tubers from chemical treated plants should be tested in storage conditions.