PT105
Control of black leg, black scurf and other postharvest storage rots of seed potatoes

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HAL

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1.1 Industry Summary

Storage rots of seed potatoes cause significant losses for growers in Victoria. Mercuric dips were used effectively for many years to control fungal and bacterial rots but have been withdrawn from use. There are few suitable alternatives for disease control. Potential replacement treatments for the control of blackleg (*Erwinia carotovora* subsp. *atroseptica* (Eca)) gangrene (*Phoma exigua* var. *foveata*) and black scurf (*Rhizoctonia solani*) were evaluated in glasshouse and laboratory trials.

The effects of hot water dips of seed tubers infected with Eca, of various temperature and time combinations, were evaluated in glasshouse and field trials for their effects on blackleg and the emergence and yield of progeny. In one trial, pre-dormant infected seed treated at 48°C for 30 minutes produced as many healthy plants as uninfected untreated controls, whereas the emergence of healthy plants from infected, untreated seed was reduced by 30%. However, the results of these treatments could not be duplicated in a second trial. A treatment of 55°C for 5 minutes caused significant reductions in emergence of plants from uninfected seed. A hot water treatment of 48°C, 30 minutes reduced the incidence of progeny with black scurf by 50%. Although experiments showed the potential of hot water treatments to control blackleg of seed potatoes, immersion of potatoes in hot water baths for long periods of time are not practical for growers. A more practical bulk, continuous flow dipping system (55°C for 5 minutes) has shown promise in controlling blackleg in trials in the United Kingdom and a similar system is used to control diseases of mangoes in Australia.

Losses of up to 60% of tubers (cv. Sebago) to gangrene rot were recorded in experiments in growers sheds where naturally infected tubers were graded and stored at 5°C for 4 months without curing. Tubers dips and ultra low volume sprays of thiabendazole or imazalil, applied after grading, resulted in major reductions in the proportion of tubers with gangrene rots after cool storage. Imazalil was as effective as the standard registered treatment thiabendazol (Tecto Flowable Fungicide®). Ultra low volume spray treatments, which were applied over roller tables, were not as effective as dips, but provided a practical method of applying fungicides post-harvest.

Several fungicide treatments applied either to the seed tubers (cv. Russet Burbank) before planting, or sprayed onto the seed and into the furrow at planting, were evaluated for the control of rhizoctonia stem canker and black scurf. In one trial, stem canker did not develop in the crop but the fungicides tolclofos-methyl, pencycuron, iprodione and procymidone caused a slight reduction in the level of black scurf on progeny tubers. In a second trial, which included the registered fungicides tolclofos-methyl (Rizolex 100D®) and iprodione (Rovral Aquaflo Fungicide®), stem canker reduced emergence and stunted plants. Although most fungicide treatments reduced the numbers of stunted plants somewhat, only tolclofos-methyl sprayed onto seed and into the furrow caused a significant reduction. Fungicide treatments did not improve total or marketable yields, or change the size distribution of tubers. Treatments did not reduce black scurf in this instance. Conclusive recommendations could not be made from these trials.

These trials have highlighted the need for more research on effective methods of controlling fungal and bacterial diseases of seed potatoes.

1.2 Technical Summary

There are few suitable alternatives to mercuric dip treatments for the control of fungal and bacterial rots of seed potatoes. Potential replacement treatments for the control of blackleg (*Erwinia carotovora* subsp. *atroseptica* (Eca)) gangrene (*Phoma exigua* var. *foveata*) and black scurf (*Rhizoctonia solani*) were evaluated in glasshouse and laboratory trials.

The effectiveness of various hot water dip treatments of seed tubers infected with Eca in controlling blackleg in progeny was investigated. Potato seed (cv. Sebago)(50 kg) was loaded into a 100 L pre-heated hot water bath, brought to temperature, heat treated at various times and temperatures and emergence and yield in progeny assessed. In one trial, pre-dormant infected seed treated at 48°C for 30 minutes produced as many healthy plants as uninfected untreated controls, whereas the emergence of healthy plants from infected, untreated seed was reduced by 30%. This provided circumstantial evidence that the heat treatment controlled blackleg. However, these results could not be duplicated in second extensive field trial. Higher temperatures of 52°C for shorter periods of immersion caused significant reductions in the germination of tubers. A hot water treatment of 48°C, 30 minutes reduced the incidence of progeny with black scurf by 50%. Although experiments showed the potential of hot water treatments to control blackleg of seed potatoes by immersion of potatoes in hot water baths for long periods of time, such treatments are not practical for growers. A more practical bulk, continuous flow dipping system (55°C for 5 minutes) has shown promise in controlling blackleg in trials in the United Kingdom and a similar system is used to control diseases of mango fruits in Australia.

Losses of up to 60% of tubers (cv. Sebago) to gangrene rot were recorded in 5 experiments in growers sheds where naturally infected tubers were graded and stored at 5°C for 4 months without curing. Wounding during sorting, especially under cold conditions makes tubers susceptible to gangrene. Tubers dips and ultra low volume sprays (spinning disk nozzle) of either thiabendazole or imazalil at recommended rates, resulted in 50% to 400% reduction in the proportion of tubers with gangrene after cool storage. Imazalil was as effective as the standard registered treatment thiabendazol (Tecto Flowable Fungicide®). Ultra low volume spray treatments, which were applied over roller tables, were not as effective as dips (2 times as many sprayed tubers than dipped tubers rotted), but provided a practical and simple method of applying fungicides to tubers.

Several fungicide treatments applied at recommended rates either to seed tubers (cv. Russet Burbank) before planting, either as dusts, dips or sprays, or sprayed onto the seed and into the furrow at planting, were evaluated for the control of rhizoctonia stem canker and black scurf. In one trial, stem canker did not develop in the crop but seed and seed/furrow treatments of the fungicides tolclofos-methyl, pencycuron, iprodione and procymidone, caused a slight reduction in the level of black scurf on progeny tubers. In a second trial, stem canker reduced emergence and stunted plants. Although most fungicide treatments including the registered fungicides tolclofos-methyl (Rizolex 100D®) and iprodione (Rovral Aquaflo Fungicide®) reduced the number of stunted plants somewhat, only the tolclofos-methyl seed/furrow treatment and experimental fungicide caused a significant reduction of 30% of the untreated control. Fungicide treatments did not improve total or marketable yields, or change the size distribution of tubers. Treatments did not reduce black scurf in this instance. Conclusions on the effectiveness of pencycuron, which is registered for use in Europe and not in Australia, could not be made from these trials.

Although these studies have provided some useful data on the effectiveness of imazalil for the control of gangrene, Australia still lags behind Europe in availability of effective treatments for the control of fungal diseases of seed potatoes.

1.3 Publication Schedule

de Boer, R.F. (1993). Post-harvest diseases and their control. *In* 'Proceedings of the Improved Potato Seed Handling Workshop, Lenswood Horticultural Centre, Lenswood, South Australia, September 1993'. (Ed C. Williams). (Lenswood Horticultural Centre, Lenswood, SA).

Minchinton, E. (1993). Hot water for blackleg in potato seed. *Peelings Newsletter, No. 39.* (Ed T. Myers). (Department of Agriculture, Victoria).

Minchinton, E. (1993). Get into hot water over blackleg. *Seed Potato Quarterly, No. 15.* (Ed T. Biggs) (Victorian Certified Seed Potato Growers Association).

de Boer, R.F. (1995). Effects of seed and seed/furrow fungicide treatments on the control of stem canker, black scurf and yield of cv. Russet Burbank potatoes. *Fungicide and Nematicide Tests*

Proposed

de Boer, R.F. (1994). Controlling gangrene of potato in storage. *Potato Australia.*

de Boer, R.F. (1995). Gangrene of potatoes. Agnote. Department of Agriculture.

de Boer. R.F. (1995). Effect of fungicides and method of application on gangrene of potatoes in Australia. *Tests of Agrochemicals and Cultivars* (Supplement to Annals of Applied Biology).

2. Technical Report

2.1 Introduction

Victoria is the premier seed producing state in Australia. Storage rots caused by fungi and bacteria have been estimated to cause losses in excess of 30%. Mercuric dips, which were once the mainstay of post-harvest disease control, have been withdrawn from use. As a consequence there are no satisfactory control methods for bacterial rots. Furthermore, at the start of the this project in 1991, fungicide treatments registered for the control of post-harvest fungal diseases were restricted to thiabendazole for the storage rots, gangrene (*Phoma exigua* var. *foveata*) and dry rot (*Fusarium* spp.), and tolclofos-methyl for the control of black scurf (*Rhizoctonia solani*).

2.1.2 Blackleg

Blackleg is a complex bacterial disease caused by a group of bacteria known as the soft erwinias (*Erwinia carotovora* subsp. *atroseptica* (Eca), *E.c.* subsp. *carotovora* and *E. chrysanthemi*). The disease causes serious economic losses to potato growers, especially seed potato growers, both in the field and in storage. Blackleg has been increasingly affecting seed crops in Victoria since 1982, and seed crops grown under the Victorian Seed Potato Certification Scheme have sometimes been rejected because of the disease. Furthermore, interstate and overseas grower organisations which import Victorian seed have complained of blackleg infection in the seed. At present there is no satisfactory method for controlling seed infection.

Blackleg causes rotting and breakdown of tubers in storage accompanied by a distinctive smell, pre-emergence death (ie failure to emerge) and a post-emergence wilt and a brown soft rotting of plant stems from the soil level up to the shoot (Perombelon and Kleman, 1987). Mother tubers are considered to be the main source of infection for daughter tubers (Harris and Lapwood, 1978). The incidence of blackleg increases rapidly when the *Erwinia* concentration exceeds 10^3 cell/tuber (Wale *et al.*, 1986). However, the bacterium is also known to be water borne (McCarter-Zorner *et al.*, 1984), present as atmospheric aerosols (*Quinn et al.*, 1980), spread by insects from infected plant debris (Harrison *et al.*, 1977), spread during grading of tubers (Elphinstone and Perombelon, 1986) and carried-over in soils on diseased plant material and on alternative hosts (Gudmestad and Secor, 1983).

Hot water dips of seed tubers infected with Eca were shown to have potential to control blackleg. MacKay and Shipton (1983) found 55°C for 10 minutes eliminated *Erwinia* from naturally contaminated potato tubers. Since then others have reported success with 45°C for 30 minutes (Robinson and Foster 1987a), 44.5°C for 10 minutes (Wale and Robinson 1986) and 55°C for 5 minutes (Burnett *et al.* 1988; Dashwood *et al.* 1991).

Chemical treatments have been shown to have potential in controlling *Erwinia*. Harris (1979) reduced soft rotting on tubers by 54% with the general sterilant 8-hydroxyquinoline. Copper oxychloride was found to control contamination of progeny by airborne erwinias (Elphinstone and Perombelon 1987).

2.2.2 Fungal diseases

Fungal diseases are a major problem in the production of seed potatoes in Victoria. Fusarium dry rot affects tubers in storage and when planted. Whole tubers become infected through lenticels and wounds during storage, whilst seed pieces are contaminated during cutting and planting. Rotted tubers shrivel and become mummified in storage. Dry rot alone, or in conjunction with soft-rot erwinias, can partially or completely destroy the seed piece resulting in reduced plant size and reduced emergence.

Gangrene is an important storage disease. Severe losses can occur in stored potatoes, particularly when the crop is harvested in cold weather. Gangrene rots are usually extensive and affected tubers are unsuitable for planting.

Rhizoctonia solani can attack potato plants at all stages of growth. Heavy infection of seed potatoes can result in stem canker and subsequent poor emergence, also seed covered with high levels of sclerotes is unsaleable. The disease also reduces numbers of tubers, increases misshapen tubers and produces shifts in the size distribution of potatoes.

2.2.3 Objectives of the project

The main objectives of the project were to evaluate hot water dips and chemical treatments for the control of blackleg and evaluate fungicides not registered in Australia for their efficacy against storage rots and black scurf. Maughan *et al.* (1991) had shown the effectiveness of thiabendazole and imazalil in controlling gangrene and dry rot. Pencycuron and iprodione were shown be effective against black scurf in Europe and elsewhere but had not been tested under Australian conditions.

2.2 Materials and Methods

2.2.1 Evaluation of hot water dip treatments and chemical treatments for the control of blackleg

2.2.1.1 *Preliminary experiments*

Artificial inoculation of tubers was by vacuum filtration at -80 kPa for 10 min with a suspension of a 2-day-old culture of 10^7 cfu/mL of Eca grown on Medium B of King *et al.* (1954) (Kings Medium B). Tubers of cv. Sebago were used in all experiments except where stated otherwise.

Tubers were hot water treated in a bench-top circulating water bath (Julabo SW-200). Treatment times were measured when hot water reached the desired temperature after immersion of tubers.

Unless otherwise stated, treated tubers were planted in pine-bark/sand potting medium, amended with fertilisers, in plastic pots, and grown in a glasshouse maintained at 15-25°C.

Thermal death point of *Erwinia carotovora* subsp. *atroseptica* in suspension culture

Kings medium B broth cultures of Eca in McCartney bottles (10 mL/bottle), which were prepared from a 24 h-old stock culture in the same medium, were incubated for 24 h after inoculation, on a mechanical shaker, and then immersed in shaking water baths at temperatures of 48°C, 50°C, 53°C or 55°C for 0-80 min. Cultures were sampled at 0 min (not heat treated) and thereafter at 5 min intervals by lawn plating 0.1 mL onto plates of Kings medium B agar. After 48 h incubation the presence or absence of growth was recorded.

In a second experiment 1-day old broth cultures of Eca, prepared as described above, were heat treated at 48°C for 10, 15, 20, 30 and 45 min; at 50°C for 15, 25 and 30 min; at 53°C for 5, 10, 15, 20 and 30 min; at 54°C for 3, 5, 10 15 and 20 min; at 55°C for 3, 5, 10, 15 and 20 min; and at 56°C for 3, 5 and 10 min. Uninoculated McCartney bottles were used as controls. Cultures were sampled and inoculated onto Kings medium B agar as described above. Viability of inoculum was also checked by spot inoculation onto Crystal Violet Pectate medium (Cupples and Kelman 1974).

Effects of hot water treatments of different sized seed potatoes on plant emergence and yield of progeny

Tubers of cv. Kennebec were graded into various size categories; mini (4 cm^3 surface area), small (9 cm^3 surface area), commercial (30 cm^3 surface area), large (140 cm^3 surface area) and half large (50 cm^3 surface area). Ten tubers per size category were heat treated in the hot water bath at 52°C or 55°C for 2, 3.5 or 5 min and planted in the field at the Institute of Plant Sciences, Burnley in a randomised block design with 6 treatments replicated 10 times (1 tuber/replicate). Tubers were planted in early February and harvested in early June. The number of plants emerged was monitored and the yield of daughter tubers recorded at harvest.

Effects of hot water treatments of pre and post-dormant seed potatoes on plant emergence and yield of progeny

Healthy tubers were treated either at the pre- or post-dormant stage at either temperatures of 50°C for 20 or 25 min, at 53°C for 10 or 12 min, at 55°C for 4 or 7 min or at 57°C for 4 min. There were 4 replicate tubers for each treatment. Treated tubers were planted in 30 cm diameter pots and arranged in a randomised block design on glasshouse benches. Plants were grown to maturity and weight and number of daughter tubers recorded after harvest.

Effects of hot water treatments of healthy and inoculated pre-dormant seed potatoes on plant emergence and yield of progeny

Two experiments examined the effects of hot water treatments on blackleg and the effects of fan drying of treated tubers to enhance effects of the hot water treatments.

In one experiment with 7 treatments, replicated 10 times (1 tuber per replicate), treatments were uninoculated and untreated; infiltrated with Eca and left untreated or either hot water treated at 52°C for 5 min or hot water treated and hot air dried; infiltrated with sterile distilled water (i.e. not inoculated) and left untreated or either hot water treated at 52°C for 5 min or hot water treated and fan dried. Tubers were each planted in 15 cm diameter plastic pots (1 per pot) and arranged in complete randomised blocks on glasshouse benches. Emergence was recorded 8 wks after planting and yield recorded after harvest of mature daughter tubers.

Treatments in a second experiment were essentially the same except that tubers were hot water treated at 50°C for 15 min and hot air drying treatments were omitted. Tubers were each planted in 30 cm diameter pots. Emergence and tuber yields were recorded as described for the previous experiment.

2.2.1.2 *Field experiments*

A cylindrical 100 L hot water treatment bath was designed and manufactured to specifications by Corke Engineering (Aust.) Pty Ltd (15 Export Drive Brooklyn VIC 3025). This bath allowed temperature control to ±0.1°C. Hot water treatments involved immersing tubers in the hot water bath for various lengths of time. Immersion of tubers initially caused a drop in water temperature; treatment times were measured from the time the water bath reached the desired temperature after immersion.

Field trials to evaluate the effect of hot water treatments on blackleg were conducted in 1992/93 and 1993/94. In trail 1 (1992/93) potatoes tubers of the cv. Sebago were obtained from two sources; from a certified seed crop essentially free of blackleg (clean seed) and from a diseased crop (naturally infected seed). In trial 2 (1993/94) tubers certified seed potatoes cv. Sebago were used.

Artificial inoculation of tubers was by vacuum filtration for 10 min at -50 kPa. A 10^8 cfu/mL suspension of Eca was prepared from a 2 d-old culture of a virulent strain of the pathogen (E23), grown on King B medium. The suspension was topped up when necessary between infiltrations and completely replaced every 2 h. Tests showed that

viable bacteria were still recovered from the suspension after this time. After infiltration tubers were allowed to air dry.

Trial 1, IHD Knoxfield

This trial examined the effects of hot water treatments, of artificially inoculated or naturally infected potatoes at the pre-dormant stage and artificially inoculated seed potatoes at the post-dormant stage, on blackleg. For pre-dormant and post-dormant seed, batches of 50 tubers (experimental unit), were either uninoculated or artificially inoculated; left untreated, dipped at 48°C for 30 min or 45 min, or dipped at 55°C for 5 min or 10 min (Table 3). The same treatments were applied to naturally infected pre-dormant tubers. Naturally infected post dormant seed was not tested. There were therefore 3 x 5 (15) pre-dormant treatment combinations and 2 x 5 (10) post-dormant treatment combinations.

The order of the treatments, in time, in the laboratory, and the allocation of treatments to plots in the field were randomised in an incomplete block design. This was done to avoid the possible obscuring effects of time on the results since hot water treatments 10 working days to complete. For this reason treatments were randomly allocated a time for treatment in relation to other treatments. There were 3 replicates of the treatments in the laboratory, each of which was then split in two for planting in the field, in double row plots each of 25 tubers (50 tubers in total. Each plot was separated by a single guard row (cv. Pontiac) to avoid cross contamination with Eca between plots. The trial was planted in late November 1992. Plots were not harvested.

The number of healthy plants emerged, which was defined as the number of plants emerged minus the number of plants with blackleg, was recorded in March 1993.

Trial 2, Ellinbank

This trial was established to further evaluate the most effective treatments from trial 1 on pre-dormant seed potatoes. Post-dormant treatments were considered to have significantly affected potato yields. Tubers were artificially inoculated as described above and heat treated 14 days later. Replicated batches of 75 tubers per treatment were hot water treated at 48°C for 30 min, 55°C for 5 min or not treated at all. Uninoculated tubers were either treated at 48°C for 30 min or not heat treated. After heat treatment, tubers were stored for 3 mths at 5°C before planting. Tubers were planted in triple row plots at the Ellinbank Dairy Research Institute in Gippsland, Victoria. The experimental design was an incomplete block with 5 treatments, where inoculated treatments were replicated 4 times and uninoculated treatments were replicated 5 times. Each plot was separated by a single row of healthy cv. Pontiac potatoes. Plots were planted in mid November 1993 and harvested in mid June 1994.

The proportion of healthy plants was recorded in late January 1994 as described for trial 1. Differences in plant height between treatments were noted. Weight of tubers in each plot was recorded at harvest. The incidence of the blemishing diseases silver scurf (*Helminthosporium solani*), black scurf (*R. solani*) and common scab (*Streptomyces scabies*) on the tubers from the uninoculated untreated and the uninoculated 48°C 30 min treatment were assessed.

2.2.1.3 *Evaluation of chemical treatments for the control of blackleg*

The effects of a bactericide on blackleg was evaluated in a glasshouse experiment. Tubers were either inoculated with bacterium as described in Section 2.2.1.2, or uninoculated, and were either dipped (5 g L) for 30 min with copper oxychloride (Chemspray®; Chemspray Pty Ltd)) or left untreated. Experimental design was a 2 x 2 factorial with randomised complete block replicated 60 times. After treatment tubers were planted in 15 diameter plots (1 tuber/pot) and arranged on glasshouse benches in a randomised block design.

Plants were assessed for healthy plants (%), as described in Section 2.2.1.2, 2 months after planting.

2.2.1.4 *Statistical Analysis*

Preliminary experiments (Section 2.2.1.1), were not subject to formal statistical analysis. The results from trial 1, IHD Knoxfield (Section 2.2.1.2) were analysed using restricted maximum likelihood (REML), a statistical procedure suitable for unbalanced data such as that arising from incomplete block designs (its analogue for balanced data is analysis of variance). The data from trial 2, Ellinbank, (Section 2.2.1.2) were analysed using a variety of statistical techniques, including REML, regression, and generalised linear models with binomial or multinomial error distributions. The results of Section 2.2.1.3 were compared using a generalised linear model with a binomial error distribution.

2.2.2 Evaluation of post-harvest fungicide treatments for the control of gangrene

All experiments were conducted with naturally infected seed, from certified seed growers properties, using growers grading tables. Three trials were conducted in 1992 and two in 1993. The experimental unit for all trials was 100 tubers of an intermediate seed size range (100-250 g) in a nylon mesh "onion" bag.

Normal post-harvest grower practice was followed by grading tubers over growers grading tables prior to applying treatments. This ensured damage to tubers, which is a perquisite for the development of gangrene, and typically occurs during the post-harvest handling process. Tubers with rots, and over and undersized tubers, were discarded during grading and groups of 100 tubers were counted into each of one onion bag at the end of the grading line. Where sufficient numbers of tubers of the desired size were not available, both larger and smaller tubers were used. Lots of larger and smaller tubers were each assigned to individual replicate blocks of treatments. Bags of 100 tubers were assigned identifying labels in a pre-described but random arrangement so as to avoid bias in the assignment of tubers to treatments. Randomisation was done through a statistical program (Genstat 5, Release 3®; Rothhamsted Experimental Station).

2.2.2.1 *Effects of tuber dip treatments*

Trials were conducted in 1992 on individual certified seed growers properties at Beech Forest in the Otway Ranges (Trials 1 and 2, Growers 1 and 2, respectively) and at Kinglake (Trail 3, Grower 3). The fungicide dip treatments of thiabendazole (Tecto Flowable Fungicide®), imazalil (Fungaflor 750 WSP®) and prochloraz (Sportac®) were evaluated for their efficacy against *P. foveata* var. *exigua* (Table 7) (Appendix 1). Thiabendazole is the currently prescribed and registered fungicide for the control of post-harvest storage rots of potatoes in Victoria. Imazalil is used widely in Europe but is not registered in Australia. Prochloraz is not normally used for the control of post-harvest diseases of potato but was included because of its potential to control black dot (*Colletotrichum coccodes*) of potato. Although dip treatments are not practical for growers they were used experimentally to ensure good coverage of fungicide on the tubers surface. Also, suitable spraying equipment was not available at the time of these trials.

Experimental design was a complete randomised block replicated 5 times with three fungicide treatments and an untreated control. Tubers from trials 1, 2 and 3 were treated on the 20 August, 3 September and 9 October 1992. respectively. Tubers had been harvested by growers in mid winter and stored under ambient conditions in their sheds.

Each replicate bag of 100 tubers was dipped in a fungicide solution in 40 L plastic containers for 2 minutes and allowed to drain and dry. Each replicate fungicide treatment was dipped in a corresponding 40 L container. Tubers were stored at 5°C within 24 hours of treatment.

2.2.2.2 *Effects of fungicide treatments and method of application*

An Ultra Low Volume (ULV) spinning disk spray applicator (Mafex®; Mantis ULV-Sprühgeräte GmbH, Germany) was purchased for trials in 1993. Two fungicide treatments, thiabendazole and imazalil, and two methods of application, tuber dips and ULV sprays, were compared in trials (Trial 1 and 2, Growers 1 and 2) at Beech Forest.
The two methods of application represented the two possible extremes, i.e. maximum and minimum coverage of the tuber surface with fungicide. A buffered formulation of imazalil (Imazalil 100 SL®) (Appendix 1) was used in these experiments instead of the Fungaflor 750 WSP used in previous trials, because the pH of the latter in solution (pH 1.3) was corrosive to the brass components of the pump in the ULV sprayer.

Experimental design was a complete randomised block replicated 5 times with 5 treatments (Table 10).

The ULV Sprayer was located over a roller table near the outlet of a grading line where rotating rollers would ensure that the entire tuber surface would at one stage be exposed to the fungicide sprays. Potato tubers which had previously been graded, bagged (100 tubers/bag) and assigned identifying labels, were removed from their bags, passed under the ULV Sprayer for treatment and rebagged.

To ensure that all tubers received the same degree of mechanical damage tubers in bags assigned to dip treatments and the untreated controls were also run across the roller table and rebagged. Bags assigned to dip treatments were immersed in fungicide solutions in 40 L containers for 2 minutes and then allowed to drain and dry. In contrast to procedures in the 1992 trials, replicate bags were dipped in succession in the one 40 L container.

Bags of potatoes were transported to IHD Knoxfield and stored at 5°C within 24 h of treatment.

2.2.2.3 *Disease assessment*

Tubers from the 1992 trials were assessed for the incidence and severity of gangrene in early January 1993. Before disease assessments were done tubers were washed with a high pressure stream of water to remove adhering soil. The severity of gangrene on each potato was recorded as the proportion of tuber rotted. The numbers of tubers in severity categories on 0, <1, 2-5, 6-10, 10-20, 20-30, 30-40 etc. % of tuber rotted were recorded. The average severity was calculated as the sum of the number of tubers in each category multiplied by the midpoint of that category and divided by the sum of the total number of tubers assessed for each replicated treatment. The number of gangrene lesions were recorded and the incidence of disease was defined as the percentage of tubers with the disease.

Tubers from the 1993 trials were assessed in early January 1994 for the incidence of gangrene and for the common blemishing diseases silver scurf, black dot and black scurf. The severity of gangrene on each individual tuber was recorded on a scale of 0-3 where 0 = no disease, 1 = <5% of tuber rotted, 2 = 6-30% of tuber rotted, and 3 = >30% of tuber rotted. The severity of silver scurf (*H. solani*), black dot (*C.*

coccodes) on each individual tuber was also recorded on a scale of 0-3 where 0 = healthy, 1 = trace (<5% of tuber surface covered), 2 = moderate (5-30% of tuber surface covered) and 3 = severe (>30% of tuber surface covered). The severity of black scurf was recorded on a scale of 0-5 where 0 = no detectable sclerotes of *R. solani*, 1 = lenticels occasionally infected, 2 = frequent infection of lenticels, 3 = occasional raised sclerotes on tuber surface, 4 = moderate covering of small to large sclerotes on tuber surface and 5 = severe covering of large, raised sclerotes on tuber surface. Disease incidence was recorded as the percentage of tubers with a particular disease.

2.2.2.4 *Statistical Analysis*

Data was analysed by Analysis of Variance using the Genstat 5, Release 3® statistical program (Rothhamsted Experimental Station, United Kingdom). Data that was not homogeneous was subjected to an appropriate transformation before analysis. Trials 1 and 2 conducted in 1993 were analysed as a 2 by 2 factorial (fungicide and method of application) plus an untreated control.

2.2.3 Evaluation of fungicide treatments for the control of rhizoctonia stem canker and black scurf of potatoes

2.2.3.1 *Glasshouse trial 1991/92*

Several treatments were evaluated for their efficacy as seed tuber treatments against rhizoctonia stem canker and black scurf. Treatments and rates used are listed in Table 1. Treatments were applied to tubers as dusts, dips or tuber sprays. Experimental design was a randomised complete block with 8 treatments replicated 10 times. Potato tubers (cv. Patronas) of varying sizes, with a slight to moderate level of sclerotes were graded into the size categories of 50-60 g, 61-70 g and 71-80 g and these were assigned to replicates 1-4, 5-8 and 9 and 10, respectively. Dust treatments were applied by mixing 10 replicate tubers with each fungicide in a large plastic bag for 2 minutes. For dip treatments, 10 replicate tubers were placed in nylon mesh "onion" bag and immersed for 5 minutes in 2 L of dip solution, and then allowed to drain and dry. The fine spray treatment was applied with an atomiser whilst rotating tubers in a large plastic drum. The spray solution was diluted to allow a practical working volume for application.

Tubers, both treated and untreated, were planted in late November into plastic pots (10 cm diameter), one tuber/pot, containing a pasteurised soil mix (sand:peatmoss; 1:1 v;v) amended with fertilisers. Pots were arranged on glasshouse benches in a randomised complete block design replicated 10 times. Glasshouse temperatures varied from 15-25°C. Pots were watered daily.

The number of plants emerged and the number of stems/plant were monitored and recorded. Tops were cut from the plants in early April and tubers were harvested one month later. Tubers were washed and examined for the presence of hyphae and sclerotes of *R. solani*.

Table 1. Potato seed tuber treatments for the control of stem canker and black scurf caused by *Rhizoctonia solani* in a glasshouse trial

Treatment	Method of application	Rate of application
Untreated control	-	-
Rizolex 100 D® (100g/kg tolclofos-methyl)	Dust	2 g/kg
Rizolex 50 WP® (500g/kg tolclofos-methyl)	Dip	2 g/L
Monceren 12.5 DS® (125g/L pencycuron)	Dust	2 g/kg
Monceren FS 250® (250g/L pencycuron)	Dip	40 mL/L
Monceren FS 250® (250g/L pencycuron)	Tuber spray	0.6 mL
Rovral Liquid Fungicide® (250g/L iprodione)	Dip	10 mL/L
Conquer® (*Pseudomonas fluorescens*)	Dip	10^8 cfu's/mL

2.2.3.2 *Field trial 1992/93*

A field trial was established at Clarkes Hill in the Central Highlands of Victoria on a growers property to evaluate fungicide for the control of rhizoctonia stem canker and black scurf on cv. Russet Burbank. The trial site had been under a mixed clover/grass pasture for 5 years and was cultivated in the spring prior to sowing.

Experimental design was a randomised complete block with nine treatments, including an untreated control, replicated 5 times. Four different fungicide treatments were applied either to the seed before planting or to the seed and into the planting furrow whilst planting seed (Table 2). The fungicide Sumisclex (active ingredient procymidone) was also included because it is a similar compound to Rovral (iprodione). Plots were single rows each 10 m long and spaced 80 cm apart. Seed sets were planted 30 cm apart (8 tubers/set).

Certified seed tubers of cv. Russet Burbank were machine cut. Cut sets were dusted with Douglas Fir Bark to facilitate drying and curing before planting.

Seed/furrow treatments were applied with spray nozzles mounted on a two-row cup planter. A fan-jet nozzle was mounted just in front of the twin furrow-opening-disks and sprayed the soil surface ahead of the disks. A second fan-jet nozzle was positioned under the planter and sprayed the seed and furrow as the set was dropped into the bottom of the furrow, and a third nozzle, a cone-jet, was positioned to spray behind into the furrow just ahead of the pair of closing disks. This arrangement ensured maximum concentration of fungicide on and around the set as well as in the soil over the set where daughter tubers are formed. Fungicides were sprayed applied at 300 kPa pressure in 560 L/ha.

The concentrations of dip treatments were the same as the concentrations of fungicide solutions applied to seed/furrow (Table 2). Sets for each treatment were placed in nylon

mesh "onion" bags and dipped for 2 min in 4 L of fungicide solution drained and allowed to dry before planting with the cup planter.

Table 2. Fungicide treatments of seed or seed/furrow in a field trial in the Central Highlands, 1992/93

Treatment	Seed dip treatments		Seed and furrow spray[A]	
	Rate/ tonne of seed	Dip concentration/ 100L	Rate/ tonne of seed	Rate/ha
Untreated control	-	-	-	-
Rizolex 50 WP® (500g/kg tolclofos-methyl)	0.4 kg	138 g	0.4 kg	0.8 kg
Monceren FS 250® (250g/L pencycuron)	0.6 L	209 mL	0.6 L	1.2 L
Rovral Liquid Fungicide® (250g/L iprodione)	0.8 L	276 mL	0.8 L	1.5 L
Sumisclex® (275g/L procymidone)	0.72 L	253 mL	0.72 L	1.4 L

[A]Applied in 560 L water/ha.

All plots were sown on the 3 January 1993 at a rate of 2 t/ha of seed. Fertiliser was banded under the seed at the time of planting. Fertiliser rate, irrigation and crop management for foliar pests and diseases were as per normal grower practice. Plant emergence was assessed on the 16th February 1993 and malformed plants caused by *R. solani* monitored at senescence in mid April 1993. Plots were harvested on the 29 June 1993. Plot yields were determined by weighing tubers in the categories <35 g, 35-100 g, 100-250 g, 250-350 g, >350 g and misshapen tubers. Numbers of tubers/plot, the yield of tubers/plot and the average size of each tuber was recorded.

Tubers were stored at 5°C and assessed for the incidence and severity of black scurf and other tuber blemishing diseases 2 months later. Disease incidence and severity was recorded as described in Section 2.2.2.3.

2.2.3.3 *Field trial 1993/94*

A field trial was established in 1993 at Clarkes Hill on the same property as the trial of 1992 but on a larger scale. As in the previous year the site had been in pasture for 5 years and was cultivated in the spring prior to sowing potatoes.

Experimental design was a randomised block with 14 treatments, including an untreated control replicated 4 times. Thirteen different fungicide treatments were applied either to the seed alone or to both the seed and into the furrow at planting (Table 14). Plots were double row, 240 m long and spaced 80 cm apart. Seed sets were planted 35 cm apart. Long plots were used in an attempt to cover some of the variation in the distribution of disease caused by *R. solani*, which occurs in distinct patches in a paddock.

Seed/furrow treatments were applied as described in Section 2.3.3.1. Fungicides were applied in 125 L/ha at 300 kPa of pressure.
Dust treatments were dusted onto half a tonne of sets as they tumbled from a conveyer into half-tonne bins prior to planting. Tuber spray treatments were applied to a half-tonne of sets with 2 cone-jet nozzles placed at the end of the conveyer as tubers tumbled into a half-tonne bins.

Plots were sown on the 23 November 1993 at a rate of 2 t/ha of seed. Fertiliser was banded below the seed sets at planting. Crop management was as per normal grower practice for cv. Russet Burbank.

At 90-100% emergence in early January 1994 the number of stunted plants/plot, the number of plants emerged in 5 random 10 m lengths of row length/plot and the diameter of plants in 5, 10 m random lengths of row/plot was recorded. The number of malformed plants/plot at senescence was recorded in early May 1994. These plants remained green after the majority of the crop had senesced, had characteristically thickened stems, and many small tubers in many of the leaf/stem axils and had rhizoctonia stem canker lesions on the stems below the soil.

Plots were harvested in mid June 1994 by taking tubers from 14, 1 m lengths of row every 15 m down each plot. Each alternate row of the two-row plot was sampled every 15 m. Tubers were graded into the size categories of 35-100 g, 100-350 g, >450 g and misshapen tubers. A random sub-sample of 100 tubers was taken from each batch of harvested tubers for disease assessments. Tubers were assessed for the incidence and severity of black scurf and other tuber blemishing diseases 5 months after storage at 5°C as described in Section 2.2.2.4. The number and yield of tubers in each plot sample was recorded.

2.2.3.4 *Statistical analysis*

Results were analysed by Analysis of Variance as described in Section 2.2.2.4.

2.3 Results

2.3.1 Evaluation of hot water and chemical treatments for the control of blackleg

2.3.1.1 *Preliminary experiments*

Thermal death point of *Erwinia carotovora* subsp. *atroseptica* in suspension culture

The preliminary experiments indicated that the thermal death point, that is the time of exposure to temperature to achieve 100% inactivation of the Eca isolate in suspension, was not reproducible at specific temperatures and time combinations. The Eca isolate survived exposures of 48°C and 50°C for up to 80 min. Thermal death points at 53°C was 30 min, at 54°C and 55°C was 15 min and at 56°C was more than 10 min.

Effects of hot water treatments of different sized seed potatoes on plant emergence and yield of progeny

Preliminary experiments in the field at Burnley indicated that hot water treatment at 52°C for 2-5 min did not cause significant differences in emergence between seed tubers of different sizes. However, hot water treatment at 55°C for 2-5 min reduced the number of stems emerged from mini to small tubers by 55% and from commercial to large tubers by 23% compared with the 52°C treatment. The 55°C 2-5 min treatment severely reduced the yield of daughter tubers from all categories of mother tubers compared with the 52°C treatments. The yield of mini to small tubers was 5 fold lower and the yield of commercial to large tubers 3 fold lower that corresponding yields from the 52°C treatments.

Effects of hot water treatments of pre- and post-dormant seed potatoes on plant emergence and yield of progeny

On average, pre-dormant hot water treated tubers gave better yields than post-dormant hot water treated tubers. Numbers of tubers and yield produced by post-dormant hot water treated seed was 30 % and 43% less, respectively than numbers and yields from pre-dormant treated tubers.

Effects of hot water treatments of healthy and artificially inoculated pre-dormant seed potatoes on plant emergence and yield of progeny

When compared with the uninfected, untreated control hot water treatment of uninfected seed at 50°C for 15 min reduced emergence by 10%. Inoculation with Eca reduced emergence by 40%, whereas hot water treatment of seed infected with eca reduced emergence by 90%.

The hot water treatment at 50°C for 15 min reduced yield by 20% compared with the untreated control. Tubers infected with Eca produced 60% less yield of daughter tubers compared with the uninoculated control tubers. Inoculated mother tubers, hot water treated at 50°C for 15 min yielded even less (80%) daughter tubers compared with infected untreated mother tubers. The hot water treatments of infected tubers did not control Eca.

In the second experiment hot water treatment of uninfected seed at 52°C for 5 min reduced emergence by 50% compared with the uninfected untreated control. Emergence in inoculated, untreated potatoes was 70% less than the uninfected, untreated control. By comparison, hot water treatment of the uninfected seed, however, did not increase emergence. Hot air drying did not enhance the emergence of inoculated hot water treated potatoes.

Hot water treatment of uninfected tubers at 52°C for 5 min reduced the yield of daughter tubers by 60% compared with the uninfected, untreated control. Inoculation of seed with Eca resulted in a yield reduction of 95% compared with the uninoculated, untreated control. However, hot water treated, inoculated tubers produced no yield. Hot air drying of inoculated treated potatoes did not significantly improve yield when compared with the non-dried treatment.

2.3.1.2 *Field experiments*

Trial 1, IHD Knoxfield

The pre-dormant hot water treatment of 48°C for 30 min or 45 min adequately controlled blackleg development in tubers and as a consequence there was improved emergence of healthy plants (Table 3). Emergence in the infected treated seed was similar to that of the uninfected untreated seed. By comparison, only 50% of tubers produced healthy plants from seed infiltrated with the bacterium without heat treatment. Temperatures of 55°C for 5 or 10 min were detrimental to emergence of uninoculated tubers of the cultivar Sebago, although this controlled blackleg. Levels of infection in the naturally infected seed were to low to show any effect of the heat treatments to control blackleg. The post-dormant heat treatments were ineffective because of the adverse effects of heat on germination.

Trial 2, Ellinbank

A pre-dormant hot water dip of 48°C for 30 min did not adequately control blackleg on artificially inoculated tubers (Table 4). Plants from artificially infected tubers, treated at 48°C for 30 min were slow to emerge, more uneven in growth and flowered one week later than the uninoculated and non heat treated control. By the end of the trial, however, plants arising from the heat treated tubers had caught up in growth to the non heat treated tubers. The failure of the tubers from the 55°C for 5 min treatment to emerge was attributable to heat damage to the tuber rather than blackleg, as tubers did not rot in the ground during the course of the trial. Suggesting that levels of the bacterium had been controlled but at the expense of germination.

Heat treatment of healthy seed slightly reduced the productivity of plants (Table 5), however, the weight of daughter tubers was not significantly less than that of daughter tubers produced from the untreated mother tubers.

Heat treatment of mother tubers did not reduce silver scurf on daughter tubers (Table, 6). In fact, the dipped mother tubers produced a significantly higher proportion of daughter tubers with ratings in the higher category (> 30% of the surface covered with symptoms). Hot water treatment of mother tubers significantly reduced the levels of

black scurf on daughter tubers by 50%. Hot water treatment of mother tubers did not affect levels of common scab in progeny.

2.3.1.3 *Evaluation of a copper oxychloride seed treatment for the control of blackleg*

On average, significantly ($P<0.05$) more plants emerged from inoculated than from infected treatments (Table 7). However, copper oxychloride did not significantly control Eca since emergence was no less ($P>0.05$) after treatment than in the infected untreated control.

Table 3. Effects of hot water dip treatments on blackleg of cv. Sebago seed potatoes, 1992/93

Treatment	Healthy Plants (%)[A]		
	Uninoculated	Artificially inoculated	Naturally infected
Pre-dormant 1992/93			
Not dipped	84	50	94
48°C 30 min	90	80	83
48°C 45 min	87	78	80
55°C 5 min	68	58	93
55°C 10 min	44	48	70
l.s.d. (P=0.05)		26.4	
Post-dormant 1992/93			
Not dipped	75	32	NT
48°C 30 min	33	43	NT
48°C 45 min	30	23	NT
55°C 5 min	54	56	NT
55°C 10 min	36	51	NT
l.s.d. (P=0.05)		32.0	

[NT]Not tested
[A]Number of plants emerged minus the number of plants with symptoms of blackleg.

Table 4. Effects of hot water dip treatments on blackleg of cv. Sebago seed potatoes, 1993/94
Means followed by the same letter do not differ significantly from each other at P<0.05

Seed treatment (pre-dormant)	Healthy plants (%)[A]	
	Uninoculated	Artificially inoculated
Not dipped	99a	6c
48°C 30 min	100a	38b
55°C 5 min	NT	8c

[NT]Not tested.
[A]Number of plants emerged minus the number of plants with symptoms of blackleg.

Table 5. Effect of hot water dip treatments of cv. Sebago seed potatoes on the fresh weight (kg) of daughter tubers

Seed treatment	Mean weight of daughter tubers (kg)
Not infected	
No dip	48.4
48°C 30 min	39.9
Infected	
No dip	3.4
48°C 30 min	8.1
55°C 5 min	2.5
l.s.d. (P=0.05)	11.0

Table 6. Effect of a hot water dip treatment of cv. Sebago seed potatoes on silver scurf, black scurf and common scab of daughter tubers

Seed treatment	Tubers affected (%)				
	Silver scurf			Black scurf	Common scab
	Disease category				
	<5% of tuber surface affected	6-30% of tuber surface affected	>30% of tuber surface affected		
Not dipped	25	27	48	17.4	1.5
Dipped, 48°C 30 min	15	24	61	8.7	1.5
P value	n.s.	n.s.	P<0.05	P<0.05	n.s.

[n.s.]F-test not significant at P>0.05.

Table 7. Effect of copper oxychloride on Blackleg of cv. Sebago seed potatoes
Numbers followed by the same letter are not significantly different at P>0.05

Seed treatment	Emergence (%)[A]	
	No chemical treatment	Copper oxychloride
Uninoculated	87[b]	87[b]
Inoculated	55[c]	48[c]

[A]Number of plants emerged minus the number of plants with symptoms of blackleg

2.3.2 Evaluation of post-harvest fungicide treatments for the control of gangrene

Gangrene was the predominant rot encountered on potatoes from either Beech Forest or Kinglake in trials both in 1992 and 1993. Dry rot caused by *Fusarium* spp. was not evident in these trials.

2.3.2.1 *Effects of tuber dip treatments*

Tubers from Trial 1, Beech Forest did not develop symptoms of gangrene after nearly 4 months cool storage. However, the majority of tubers were affected with silver scurf with more than 50% of the surface of diseased potatoes affected. Silver scurf incidence was not assessed.

An average of 59% and 13% of untreated control tubers from Trial 2, Beech Forest and Kinglake, respectively, developed gangrene (Table 7). The fungicide dip treatments of thiabendazole, imazalil or prochloraz significantly reduced ($P<0.05$) the incidence and severity of the disease in comparison with the untreated control in both trials. However, no treatment completely controlled the disease. The incidence and severity of gangrene in tubers from Beech Forest was less ($P<0.05$) when treated with thiabendazole compared with either imazalil or prochloraz. Otherwise there were no significant ($P>0.05$) differences in disease incidence and severity between fungicide treatments. At Kinglake the incidence and severity of gangrene did not differ significantly ($P>0.05$) between fungicide treatments.

2.3.2.2 *Effects of fungicide treatments and method of application*

Gangrene developed in tubers from both sources after 4 months cool storage with 47% and 11% of untreated control tubers from Trial 1 and 2, respectively, becoming diseased (Table 8). Severity of rot was generally low with average disease ratings of 1 and 0.3, on a scale of 0-3, for Trial 1 and 2, respectively. With the exception of the incidence of gangrene for Trial 1, there were no significant statistical interactions ($P>0.05$) between treatments, fungicides and method of application (Table 9). On average, the incidence and severity of gangrene was significantly less ($P<0.001$) in tubers treated with fungicides than in the untreated controls (Table 8) with the exception of the imazalil ULV spray in Trial 1 which did not control the disease (Table 9). No treatment eliminated the disease. Generally, imazalil was as effective in controlling gangrene as thiabendazole (Table 9). The incidence of gangrene was consistently less ($P<0.001$ and $P<0.1$ for Trial 1 and 2, respectively) in tubers that were dipped in fungicide solutions that in those treated with a ULV spray (Tables 8 & 9).

Silver scurf and black scurf were common on tubers harvested from both Trials. One hundred percent of tubers from both trials were affected with silver scurf. Severity ratings were greater than 2 on a scale of 0-3 (Table 10). Fungicide treatments had no effect ($P>0.05$) on the incidence or severity of silver scurf. Up to 3% and 23% of tubers from Trial 1 and 2, respectively, were affected with black scurf (Table 10). Overall, the incidence and severity of black scurf were not affected by fungicide treatments. However, disease incidence and severity were less after dip treatments (average of 1.4% and 20% of tubers affected from Trial 1 and 2, respectively) than after ULV treatments (average of 2.4% and 23% of tubers affected from Trial 1 and 2, respectively).

Table 8. Effects of post-harvest fungicide tuber dip treatments on gangrene (*Phoma exigua* var. *foveata*) of potatoes (cv. Sebago) from two locations in Victoria, 1992

Treatment	Active ingredient	Rate of application/100L	Beech Forest			Kinglake		
			Tubers affected (%)	Severity of rot (%)[A]	Severity of lesions[B]	Tubers affected (%)	Severity of rot (%) [A]	Severity of lesions[B]
Nil	-	-	59	5.6	1.3	13.1	1.9(0.243)[C]	1.2
Tecto Flowable Fungicide®	450 g/L thiabendazole	444 mL	17	1.1	1.0	3.4	0.6(-0.323)	1.0
Fungaflor 750 WSP®	750 g/L imazalil	133 g	28	2.6	1.2	2.5	0.2(-0.870)	1.1
Sportak®	450 g/L prochloraz	444 mL	29	2.9	1.2	4.2	0.5(-0.396)	1.2
l.s.d. (P=0.05)			8	0.9	0.2	3.0	(0.468)	0.1
F-test			P<0.001	P<0.001	P=0.04	P<0.001	P=0.002	n.s.

[A]Proportion of tuber rotted.
[B]No. of lesions per tuber/No. of affected tubers.
[C]$Log_{10}(x+0.01)$ transformation.
[n.s.]F-test not significant (P>0.05).

Table 9. Effects of post-harvest fungicide treatments on the incidence (% tubers affected) and severity of gangrene (*Phoma exigua* var. *foveata*) of potatoes (cv. Sebago) from two trials at Beech Forest in 1993

Treatment	Active ingredient	Method of application	Rate of application	Trial 1		Trial 2	
				Tubers affected (%)	Severity[A]	Tubers affected (%)	Severity[A]
Nil				46.6	1.1	10.8	0.05
Tecto Flowable Fungicide®	450 g/L thiabendazole	Dip	444 mL/100L	22.6	0.4	2.4	0.03
Imazalil 100 SL®	100 g/L imazalil	Dip	752 mL/100L	16.6	0.3	0.4	0.01
Tecto Flowable Fungicide®	450 g/L thiabendazole	ULV[B]	100 mL/t	29.0	0.8	5.0	0.05
Imazalil 100 SL®	100 g/L imazalil	ULV[B]	112 mL/t	43.6	0.9	3.8	0.04
l.s.d. (P=0.05)				7.3	0.3	4.7	0.03
F-test				n.s.	n.s.	n.s.	n.s.

[A]Severity rated on a scale of 0-3: 0, no disease; 1, <5% of tuber rotted; 2, 6-30% of tuber rotted; 3, >30% of tuber rotted.
[B]Ultra Low Volume; Mafex®(Mantis ULV-Sprühgeräte GmbH, Germany) Mantis Ultra Low Volume Spinning disk Sprayer.
[n.s.]F-test not significant at P>0.05.

Table 10. Effects of post-harvest fungicide treatments on the incidence (% tubers affected) and severity of gangrene (*Phoma exigua* var. *foveata*) of potatoes (cv. Sebago) from two trials at Beech Forest in 1993 - main treatment effects

Treatment	Trial 1		Trial 2	
	Tubers affected (%)	Severity[A]	Tubers affected (%)	Severity[A]
Treatment				
Nil	46	1.1	10.7	0.25
Fungicide	28	0.6	2.9	0.06
F-test	P<0.001	P<0.001	P<0.001	P<0.001
Fungicide treatment				
Tecto Flowable Fungicide®	26	0.6	3.7	0.08
Imazalil 100 SL®	30	0.6	2.1	0.04
F-test	n.s.	n.s.	n.s.	n.s.
Method of application				
Dip	20	0.4	1.4	0.03
ULV[B]	36	0.9	4.4	0.09
F-test	P<0.001	P<0.001	P=0.07	n.s.

[A]Severity rated on a scale of 0-3: 0, no disease; 1, <5% of tuber rotted; 2, 6-30% of tuber rotted; 3, >30% of tuber rotted.
[B]Ultra Low Volume; Mafex®(Mantis ULV-Sprühgeräte GmbH, Germany) Mantis Ultra Low Volume Spinning disk Sprayer.
[n.s.]F-test not significant at P>0.05.

Table 11. Effects of post-harvest fungicide treatments on the incidence (% tubers affected) and severity of silver scurf (*Helminthosporium solani*) and black scurf (*Rhizoctonia solani*) of potatoes (cv. Sebago) from two trials at Beech Forest in 1993

Treatment	Active ingredient	Method of application	Rate of application	Trial 1				Trial 2			
				Silver scurf		Black scurf		Silver scurf		Black scurf	
				Tubers affected (%)	Severity[A]	Tubers affected (%)	Severity[B]	Tubers affected (%)	Severity[A]	Tubers affected (%)	Severity[B]
Nil				100	2.1	2.4	0.05	100	2.3	23.1	0.4
Tecto Flowable Fungicide®	450 g/L thiabendazole	Dip	444 mL/100L	100	2.1	1.8	0.03	100	2.3	19.1	0.3
Imazalil 100 SL®	100 g/L imazalil	Dip	752 mL/100L	100	2.1	1.0	0.01	100	2.2	20.5	0.3
Tecto Flowable Fungicide®	450 g/L thiabendazole	ULV[C]	100 mL/t	100	2.1	2.6	0.05	100	2.3	22.8	0.4
Imazalil 100 SL®	100 g/L imazalil	ULV[C]	112 mL/t	100	2.1	2.2	0.04	100	2.3	22.7	0.4
l.s.d. (P=0.05)				n.a.	n.a.	1.6	0.03	n.a.	n.a.	4.3	0.2
F-test				n.a.	n.a.	n.s.	n.s.	n.a.	n.a.	n.s.	n.s.

[A]Severity rated on a scale of 0-3: 0, no disease; 1, <5% of tuber surface affected;, 6-30% of tuber surface affected; 3, >30% of tuber surface affected.
[B]Severity rated on a scale of 0-3 based on frequency and size of sclerotes of *Rhizoctonia solani*: 0, slight infection; 2, moderate infection; 3, severe infection.
[B]Ultra Low Volume; Mafex®(Mantis ULV-Sprühgeräte GmbH, Germany) Mantis Ultra Low Volume Spinning disk Sprayer.
[a]Not applicable.
[a]F-test not significant at P>0.05.

2.3.3 Evaluation of fungicide treatments for the control of rhizoctonia stem canker and black scurf of potatoes

2.3.3.1 *Glasshouse trial 1991/92*

Although plant emergence varied with treatments there was no evidence of stem canker caused by *R. solani* throughout the growing period of plants. There were no hyphae of *R. solani* or sclerotes of the fungus on harvested tubers.

2.3.3.2 *Field trial 1992/93*

There were no apparent above-ground symptoms of rhizoctonia stem canker (poor emergence and patches of stunted plants) at 100% emergence, although the disease was evident in a crop planted one month before the trial. *R. solani*, however, was found sporulating as the perfect state *Thanetephorus cucumeris* at the soil/stem interface on some plants in the trial plots.

There were no significant statistical interactions ($P>0.05$) between fungicide treatments and method of application. Plant growth and yield were not affected by method of application and, therefore, only the main effects of treatments (average of method of application for each fungicide treatment) are presented in the Tables of Results. Compared with the untreated control, fungicide treatments did not significantly ($P>0.05$) affect the number of plants emerged/plot, the number of stems/plant, total yield or marketable seed and processing yields (Table 10). The yield of marketable seed (average 37.8 t/ha) was greater than the yield of processing potatoes (average of 18.9 t/ha) indicating that, overall, tubers harvested for the trial were small.

Approximately 8% of tubers from the untreated control plots were found to have symptoms of black scurf after harvest (Table 11). The severity of infection was generally very low (≤ 0.2 on a scale of 0-5). A general trend in the data suggested that the incidence of tubers with black scurf was less after treatment with fungicides (average of 6% tubers affected) than in the untreated control. However, this difference was not significant ($P>0.05$).

Between 97% and 100% of tubers were affected with black dot. Treatments had no significant ($P>0.05$) effect on the incidence and severity of this disease (Table 11). An average of 49% of tubers of the untreated control were affected with silver scurf. Generally, the incidence and severity of silver scurf tended to be less ($P<0.1$) after treatment with fungicides (average of 38% of tubers affected) than in the untreated control (Table 11).

2.3.3.3 *Field trial 1993/94*

Damage caused by *R. solani* was evident at 100% emergence as patches of missing plants in rows and as patches of stunted plants. When unemerged sets and stunted plants were removed from the soil, characteristic symptoms of stem canker were evident on shoots and stems. At senescence the disease was apparent as green plants with thickened stem bases and small tubers in many of the leaf/stem axils. (Healthy plants had by this time senesced).

Fungicide treatments had no significant (P>0.05) effect on plant emergence (Table 12). A general trend indicated a reduction in plant diameter with most fungicide treatments compared with the untreated control (Table 12). However, this reduction (10% compared with the untreated control) was significant (P=0.002) only for the Shirlan and Rizolex 100D seed treatments and the Sumisclex 0.8 L/ha seed/furrow treatment. Similarly, a consistent, though non-significant (P>0.05), trend indicated a reduction in the number of stunted plants at emergence in treated plots when compared with the untreated control (Table 12 and Fig. 1). The greatest reductions (35-40%) were in plots treated with the seed/furrow treatments of Rizolex 50 WP and 2757 at 1 and 2 L/ha. The number of malformed plants at senescence varied (P<0.001) with treatment (Table 12 and Fig. 1). Plots treated with Monceren 12.5 DS and 2757 has significantly less malformed plants/plot than did the untreated control. In contrast, Rovral Liquid at 0.8 L/ha had 30% more malformed plants than the untreated controls. Fungicide treatments did not significantly (P>0.05) affect the numbers of tubers, marketable yields and average weights of tubers/plot in comparison with the untreated control (Figs. 2-5).

Between 21-39% of harvested tubers were affected with black scurf. The severity of the disease was very low with ratings varying from 0.1 to 0.3 on a scale of 0-5. Neither the incidence nor severity of black scurf were affected significantly (P>0.05) by the fungicide treatments (Table 14). The fungicide treatments Shirlan and the two treatments of 2757 significantly reduced the severity of silver scurf (Table 14) compared with the untreated control. However, only 2757 at the highest rate significantly (P<0.05) reduced (P<0.05) the incidence of silver scurf. Similarly, 2757 at both rates, caused a small but significant (P<0.05) reduction in the incidence and severity of black dot. Although a small but significant proportion of tubers (18-28%) were affected with powdery scab, fungicide treatments did not significantly (P>0.05) reduce either the incidence or severity of scab (Table 14). However, 2757 at the high rate increased (P<0.05) the incidence of scab when compared with the untreated control.

Table 14. Effects of fungicide treatments of seed and seed/furrow on plant emergence, plant diameter and disease of potatoes (cv. Russet Burbank) caused by *Rhizoctonia solani* (No. of stunted plants and No. of malformed plants) in a field trial in the Central Highlands, 1993/94

Treatment	Active ingredient	Rate of application		Emergence			Senescence
		Rate/t potatoes	Rate/ha	No. of plants emerged/10 m row	Plant diameter (cm)	No. stunted plants/plot[A]	No. of malformed plants/plot[A]
Untreated control	-	-	-	24.4	33.5	90.7	106.2
Seed							
Shirlan®	500 g/L fluazinam	1.0 L	-	25.9	29.5	89.7	86.5
Monceren 12.5 DS®	125 g/kg pencycuron	2.0 kg	-	25.5	31.1	72.5	50.3
Monceren FS 250®	250 g/L pencycuron	0.6 L	-	27.4	31.5	74.0	82.7
Rizolex 100D®	100 g/kg tolclofos-methyl	2.0 kg	-	25.5	29.9	97.5	94.0
Seed/Furrow							
Rizolex 50 WP®	500 g/kg tolclofos-methyl	0.4 kg	0.8	24.8	31.8	59.0	89.2
Rovral Liquid®	250 g/L iprodione	0.25 L	0.8	25.7	32.0	73.7	157.0
Rovral Liquid®	250 g/L iprodione	0.5 L	1.2	25.7	32.2	70.0	127.0
Rovral Liquid®	250 g/L iprodione	0.75 L	1.6	26.4	31.2	66.7	104.2
Sumisclex®	500 g/L procymidone	0.125 L	0.4	25.2	32.8	74.7	89.5
Sumisclex®	500 g/L procymidone	0.25 L	0.6	25.8	34.6	66.2	79.0
Sumisclex®	500 g/L procymidone	0.375 L	0.8	24.8	31.3	66.0	104.5
2757®	n.a.	0.5 L	1.0	25.9	32.5	53.5	7.3
2757®	n.a.	1.0 L	2.0	25.4	31.8	55.5	5.8
l.s.d. (P<0.05)				2.0	2.1	30.6	37.5
F-test				P=0.368	P=0.002	P=0.167	P<0.001

[A]Plot size: 2 rows x 240 m.
[n.a.]Not available.

Table 13. Effects of fungicide treatments on the potato tuber (cv. Russet Burbank) blemishing diseases black scurf (*Rhizoctonia solani*), black dot (*Colletotrichum coccodes*) and silver scurf (*Helminthosporium solani*), post-harvest, in a field trial in the Central Highlands, 1992/93

There were no significant interactions (P>0.05) between fungicide treatments and method of application and therefore only the main effects of treatments are presented

Treatment	Black scurf		Black dot		Silver scurf	
	Tubers affected (%)	Severity (0-5)[A]	Tubers affected (%)	Severity (0-3)[B]	Tubers affected (%)	Severity (0-3)[B]
Untreated control	8.4	0.2	100	1.4	49	0.5
Rizolex 50 WP®	6.2	0.1	97	1.4	36	0.4
Monceren FS 250®	3.8	0.1	98	1.4	44	0.5
Rovral Liquid Fungicide®	6.4	0.1	99	1.5	34	0.4
Sumisclex®	6.2	0.1	99	1.5	38	0.4
l.s.d. (P=0.05)	7.3[n.s.]	0.1[n.s.]	3[n.s.]	0.2[n.s.]	14[n.s.]	0.2[n.s.]

[A]Severity scale 0-5: 0, no detectable sclerotes of *R. solani*; 1, lenticels occasionally infected; 2, frequent infection of lenticels; 3 (slight), occasional raised sclerotes on tuber surface; 4, moderate covering of small to large sclerotes on tuber surface; 5, severe covering of large, raised sclerotes on tuber surface.
[B]Severity scale 0-3: 0, no apparent disease, 1, <5% of tuber surface affected; 2, 6-30% of tuber surface affected; 3, >30% of tuber surface affected.
[n.s.]F-test not significant (P>0.05).

Table 14. Effects of fungicide treatments of seed and seed/furrow on plant emergence, plant diameter and disease of potatoes (cv. Russet Burbank) caused by *Rhizoctonia solani* (No. of stunted plants and No. of malformed plants) in a field trial in the Central Highlands, 1993/94

Treatment	Active ingredient	Rate of application		Emergence			Senescence
		Rate/t potatoes	Rate/ha	No. of plants emerged/10 m row	Plant diameter (cm)	No. stunted plants/plot^	No. of malformed plants/plot^
Untreated control	-	-	-	24.4	33.5	90.7	106.2
Seed							
Shirlan®	500 g/L fluazinam	1.0 L	-	25.9	29.5	89.7	86.5
Monceren 12.5 DS®	125 g/kg pencycuron	2.0 kg	-	25.5	31.1	72.5	50.3
Monceren FS 250®	250 g/L pencycuron	0.6 L	-	27.4	31.5	74.0	82.7
Rizolex 100D®	100 g/kg tolclofos-methyl	2.0 kg	-	25.5	29.9	97.5	94.0
Seed/Furrow							
Rizolex 50 WP®	500 g/kg tolclofos-methyl	0.4 kg	0.8	24.8	31.8	59.0	89.2
Rovral Liquid®	250 g/L iprodione	0.25 L	0.8	25.7	32.0	73.7	157.0
Rovral Liquid®	250 g/L iprodione	0.5 L	1.2	25.7	32.2	70.0	127.0
Rovral Liquid®	250 g/L iprodione	0.75 L	1.6	26.4	31.2	66.7	104.2
Sumisclex®	500 g/L procymidone	0.125 L	0.4	25.2	32.8	74.7	89.5
Sumisclex®	500 g/L procymidone	0.25 L	0.6	25.8	34.6	66.2	79.0
Sumisclex®	500 g/L procymidone	0.375 L	0.8	24.8	31.3	66.0	104.5
2757®	n.a.	0.5 L	1.0	25.9	32.5	53.5	7.3
2757®	n.a.	1.0 L	2.0	25.4	31.8	55.5	5.8
l.s.d. ($P<0.05$)				2.0	2.1	30.6	37.5
F-test				$P=0.368$	$P=0.002$	$P=0.167$	$P<0.001$

^Plot size: 2 rows x 240 m.
n.a. Not available.

Table 15. Effects of fungicide treatments of seed and seed and furrow on the incidence and severity of the potato tuber (cv. Russet Burbank) blemishing diseases black scurf, black dot, silver scurf and powdery scab caused by *Rhizoctonia solani*, *Colletotrichum coccodes*, *Helminthosporium solani* and *Spongospora subterranea*, respectively, in a field trial in the Central Highlands, 1993/94

Treatment	Active ingredient	Rate of application		Black Scurf		Black Dot		Silver Scurf		Powdery scab	
		Rate/t potatoes	Rate /ha	Tubers affected (%)	Severity (0-5)[A]	Tubers affected (%)	Severity (0-3)[B]	Tubers affected (%)	Severity (0-3)[B]	Tubers affected (%)	Severity (0-3)
Untreated control	-	-	-	25	0.3	98	2.1	63	0.8	28	0.3
Seed											
Shirlan®	500 g/L fluazinam	1.0 L	-	20	0.3	99	2.0	47	0.5	23	0.3
Monceren 12.5 DS®	125 g/kg pencycuron	2.0 kg	-	21	0.3	98	2.0	65	0.8	23	0.2
Monceren FS 250®	250 g/L pencycuron	0.6 L	-	23	0.4	99	2.0	53	0.6	27	0.3
Rizolex 100D®	100 g/kg tolclofos-methyl	2.0 kg	-	35	0.6	98	2.0	68	0.8	18	0.2
Seed/Furrow											
Rizolex 50 WP®	500 g/kg tolclofos-methyl	0.4 kg	0.8	26	0.4	98	2.1	75	0.9	25	0.3
Rovral Liquid®	250 g/L iprodione	0.25 L	0.8	39	0.5	99	2.1	62	0.7	33	0.4
Rovral Liquid®	250 g/L iprodione	0.5 L	1.2	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.
Rovral Liquid®	250 g/L iprodione	0.75 L	1.6	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.
Sumisclex®	500 g/L procymidone	0.125 L	0.4	25	0.3	98	1.9	67	0.8	36	0.4
Sumisclex®	500 g/L procymidone	0.25 L	0.6	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.
Sumisclex®	500 g/L procymidone	0.375 L	0.8	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.	n.as.
2757®	n.a.	0.5 L	1.0	21	0.3	85	1.6	47	0.5	26	0.3
2757®	n.a.	1.0 L	2.0	9	0.1	77	1.3	32	0.3	41	0.4
l.s.d. (P<0.05)				19	0.3	6	0.3	23	0.3	13	0.2
F-test				P=0.166	P=0.151	P=0.002	P<0.001	P=0.021	P=0.017	P=0.047	P=0.084

[A]Severity scale 0-5: 0, no detectable sclerotes of *R. solani*; 1, lenticels occasionally infected; 2, frequent infection of lenticels; 3 (slight), occasional raised sclerotes on tuber surface; 4, moderate covering of small to large sclerotes on tuber surface; 5, severe covering of large, raised sclerotes on tuber surface.
[B]Severity scale 0-3: 0, no detectable disease; 1, <5% of tuber surface affected; 2, 6-30% of tuber surface affected; 3, >30% of tuber surface affected.
[n.a.]Not available. [n.as.]Not assessed.

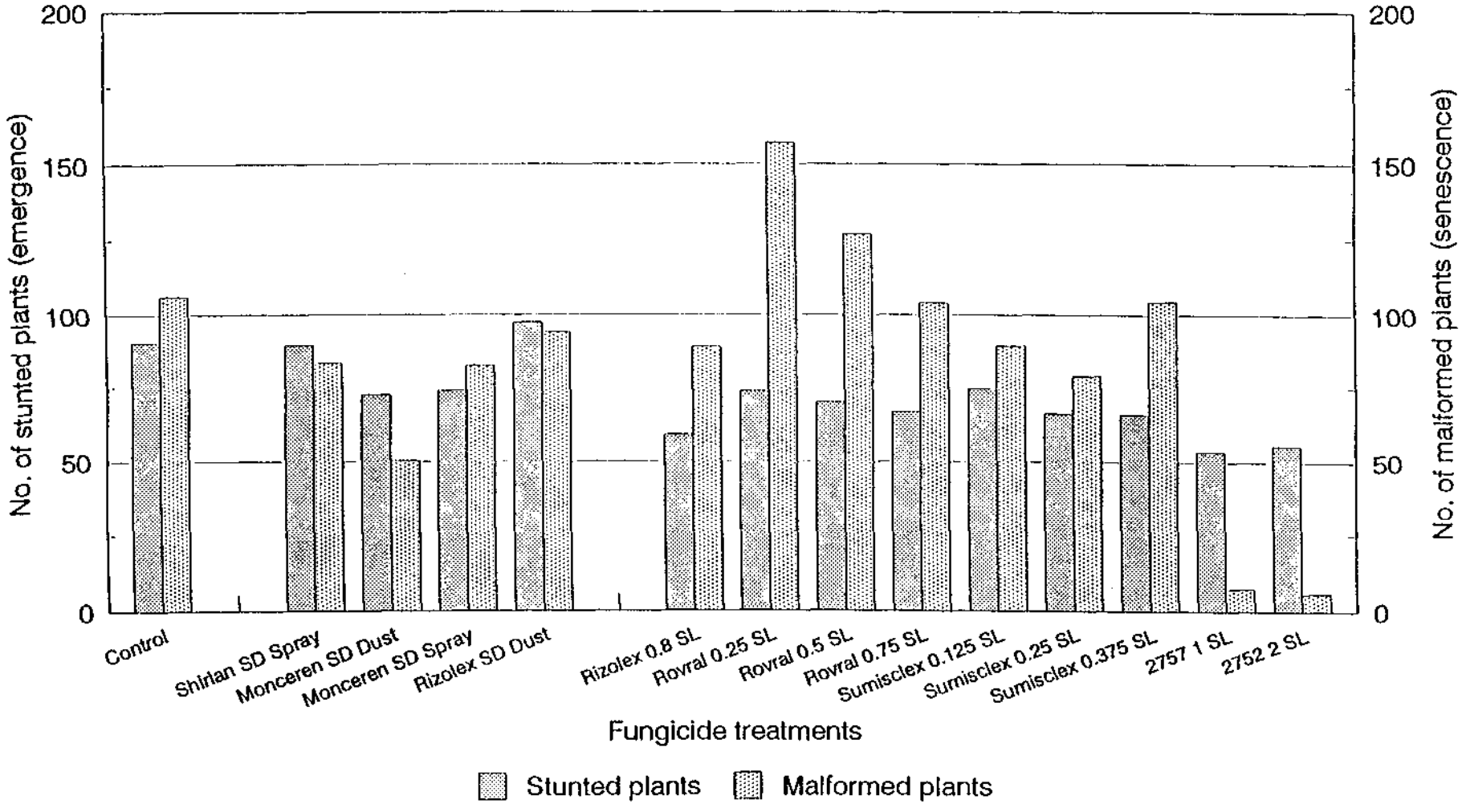

Figure 1. Effects of fungicide treatments of seed (SD) and seed/furrow (SL) on disease caused by *R. solani* (No. of stunted plants/plot at emergence and the No. of malformed plants/plot) at emergence and senescence in a field trial in the Central Highlands in 1993/94.

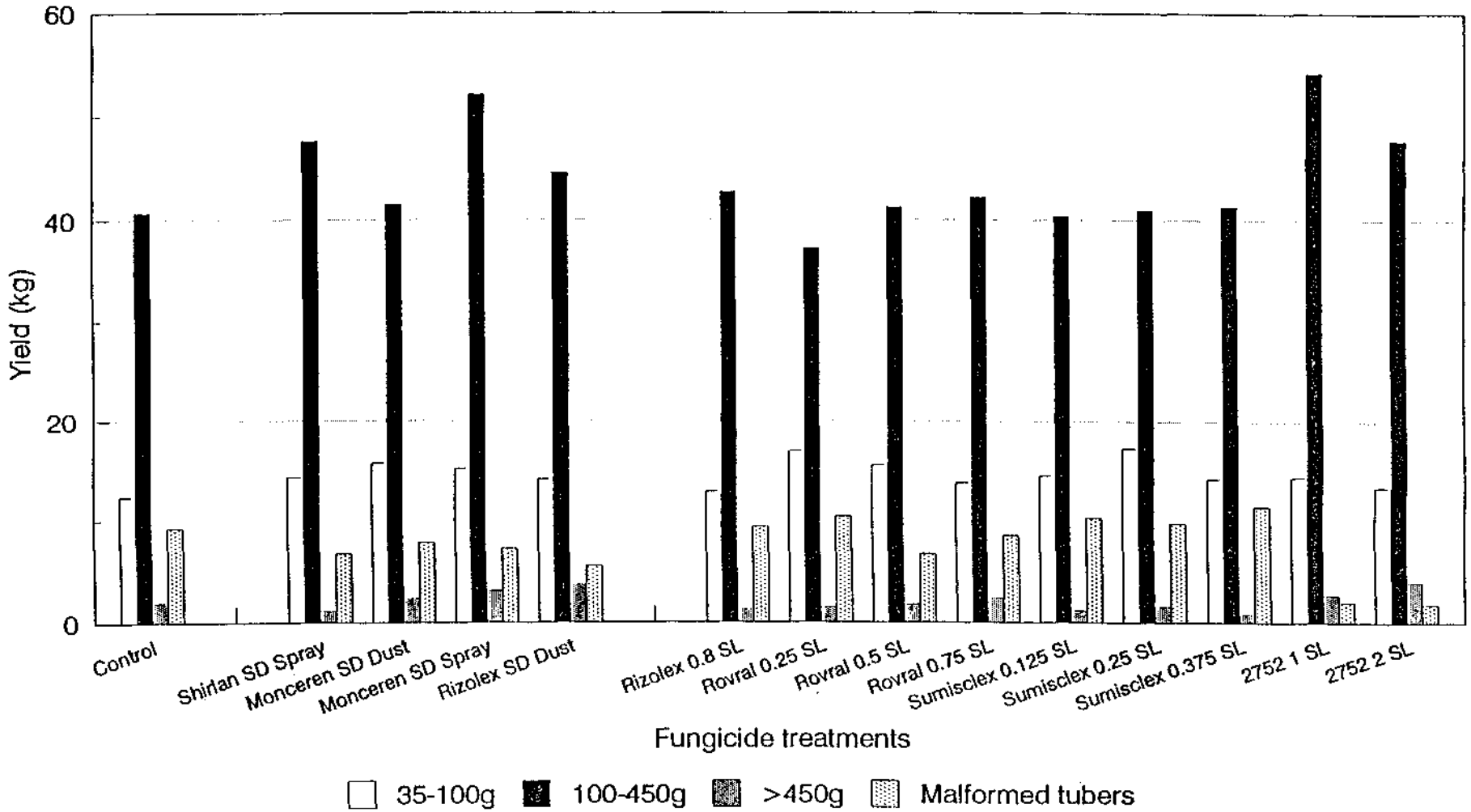

Figure 2. Effects of fungicide treatments of seed (SD) and seed/furrow (SL) on the yield of tubers in different size categories from 15 m of row/plot in a field trial in the Central Highlands, 1993/94.

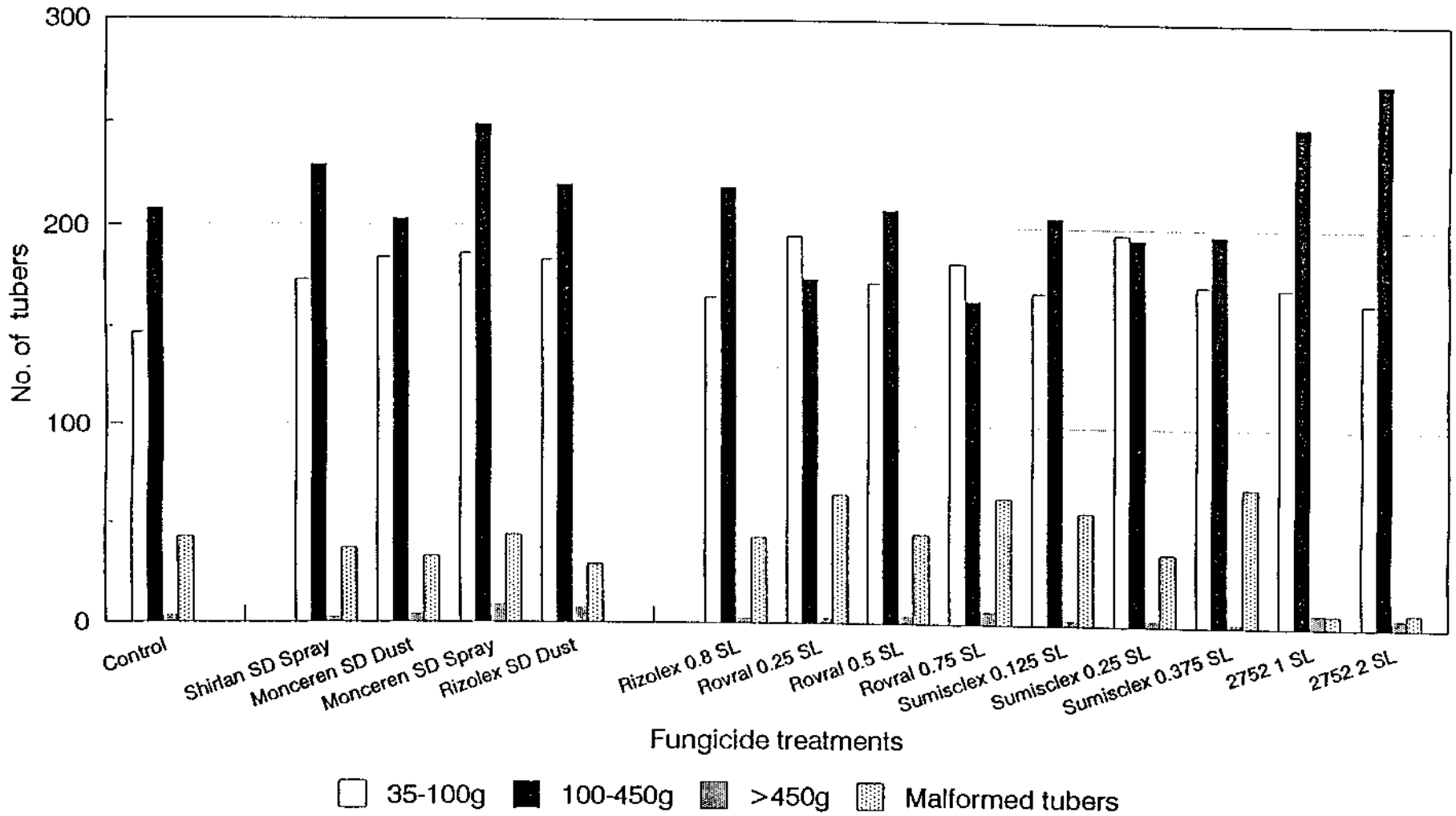

Figure 3. Effects of fungicide treatments of seed (SD) and seed/furrow (SL) on the number of tubers in 15 m of row length/plot in a field trial in the Central Highlands, 1993/94.

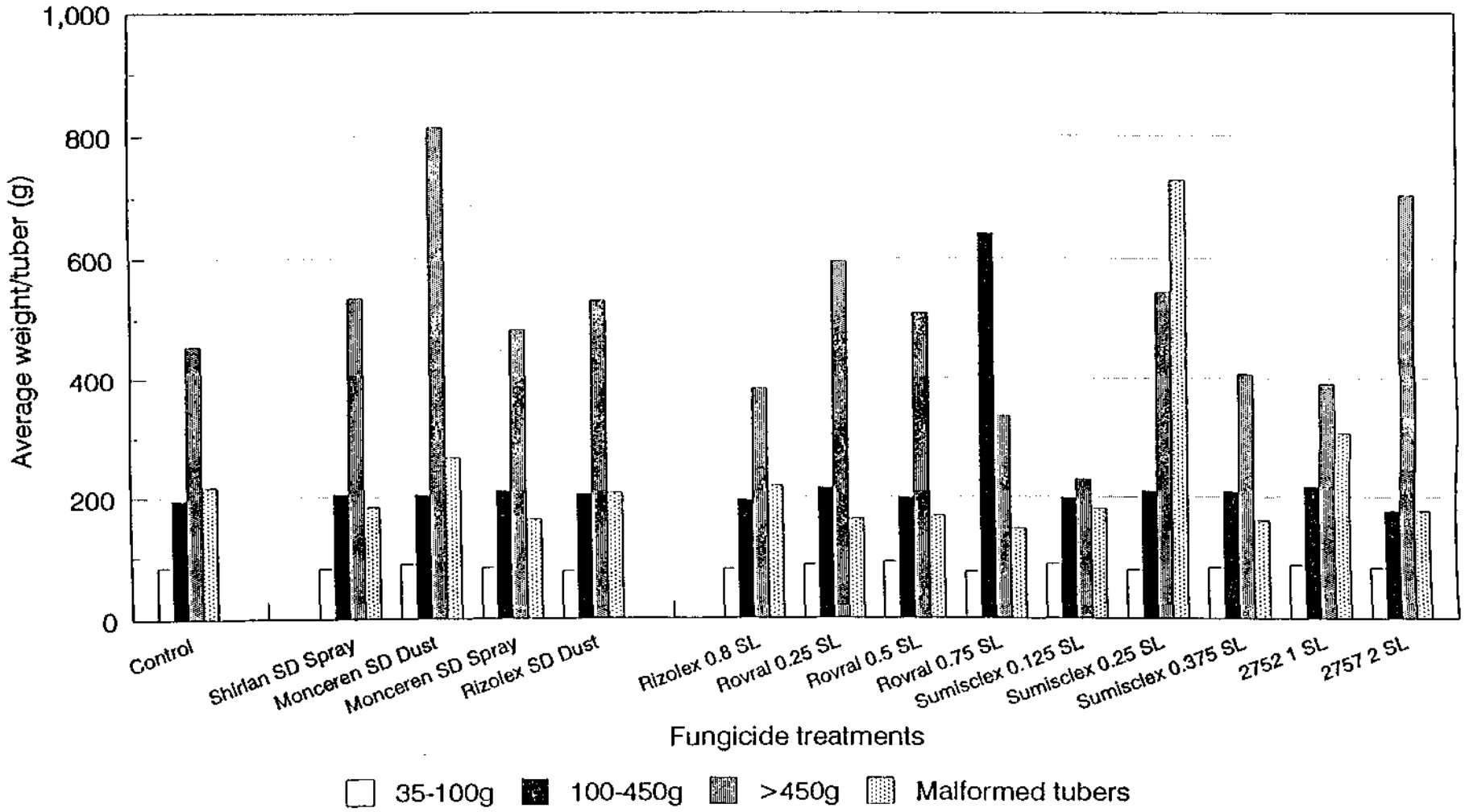

Figure 4. Effects of fungicide treatments of seed (SD) and seed/furrow (SL) on the average weight/tuber of potatoes taken from 15 m of row length/plot in a field trial in the Central Highlands, 1993/94.

2.4 Discussion

2.4.1 Blackleg

2.4.1.1 *Effects of heat treatments on blackleg*

These studies have shown the potential of hot water dip treatments of pre-dormant tubers to control blackleg on seed potatoes and confirm the results of studies overseas (Wale *et al.* 1986; Burnett *et al.* 1988). The greater numbers of healthy plants emerging after heat treatment infected seed at 48°C for 30 minutes over non heat treated infected seed, provide evidence that the treatment controlled the pathogen in an extensive field trial. Hot water dipping of post-dormant tubers proved detrimental to germination. Wale *et al.* (1986) and Burnett *et al.* (1988) also reported that hot water treating pre-dormant tubers was more feasible that treating post-dormant tubers. Ideally tubers would be treated after harvest and stored.

The results of the 48°C, 30 minute treatment could not be reproduced in a second field trial. There may be several explanations for this. Inoculum levels of Eca of 10^7-10^{10} cfu/mL was probably to high resulting in unrealistic and uncontrollable levels of the pathogen on tubers. Wale *et al* (1986) and Perombelon (1985) reported that blackleg develops rapidly when concentrations exceed 10^3 cells/tuber. An inoculum level of 10^{3-4} cells/tuber would have been more appropriate for our studies. Relatively large tubers were used in the second trial and although they are more tolerant to heat treatment vascular infections of Eca may be difficult to control on large tubers (Mackay and Skipton 1983). Perombelon and Melvin (1987) reported that the initial tuber temperature could influence the success of the dip. Tubers used in the Ellinbank trial were treated several hours after removal from cool storage. This could have affected heat penetration into tubers and consequently affected the control of the pathogen. The time between inoculation and hot water treatment was up to 14 days in the Ellinbank trial whereas, in the previous trial, treatments were applied immediately after all tubers were inoculated. The delay in inoculation would have given the bacterium ample time to establish in the tuber lenticels. Furthermore, insufficient drying of tubers after inoculation may have contributed to the artificially high Eca population on tubers (Wale and Robinson 1986). The times required to bring the water-bath to temperature after immersion of tubers ranged from 7 to 17 minutes and thereby resulting in more latent heat in the interior of the tuber. These times might have been influences by the initial temperatures of tubers at immersion. High internal temperatures may account for the detrimental effect of the 55°C, 5 minute treatments on germination. This is an inherent problem with the bulk hot immersion technique (Wale and Robinson 1986).

The thermal death point of Eca in liquid media (nutrient broth) was reported to be 53°C for 5 minutes and 51°C for 10 minutes (MacKay and Shipton 1983). In the study reported here we found death points for our Eca culture on liquid media (Kings' medium B broth) to be 53°C for 30 minutes, 54°C and 55°C for 15 minutes and greater than 10 minutes at 56°C. It is possible that the different broths used by us and others may account for the difference in thermal death points. Alternatively, the longer times required for the Australian Eca could suggest that it is more heat stable and, therefore, more difficult to inactivate with hot water treatments. MacKay and Shipton (1983) also reported variation in susceptibility of isolates to heat treatments.

It appears from this work that the cv. Sebago is particularly sensitive to hot water treatment; treatment at 55°C for short periods (5 minutes) was detrimental to germination. In other studies, however, this temperature is frequently recommended for dipping mother tubers (Perombelon 1990). Cultivars, other than Sebago, have been reported to be sensitive to hot water treatments (MacKay and Skipton 1983; Perombelon and Melvin 1987; Burnett *et al.* 1988; Perombelon 1994).

2.4.1.2 *Effects of hot water treatments on fungal diseases*

The hot water treatment of 48°C, 30 minutes reported here in did not control silver scurf. In fact it may have served to spread the fungus amongst the dipped mother tubers as there were more daughter tubers with ratings in the highest category in treated tubers. The likely source of infection of progeny of the treated tubers was the mother tuber since silver scurf is seed-borne (Jellis and Taylor 1977). Perombelon (1990) and Dashwood *et al.* (1991) reported that a hot water treatment of 55°C for 5 minutes controlled silver scurf and Dashwood and Duncan (1992) reported a reduction in incidence from 29% to 0% infected tubers. *H. solani* may be more sensitive to higher temperatures that those tested in our study. The work of Perombelon (1990) and Dashwood *et al.* (1991), however, was based on the ability to isolate the fungus from eye plugs after cold storage of treated tubers and not on disease levels on the progeny.

Hot water treatment of mother tubers at 48°C for 30 minutes reduced black scurf in daughter tubers by 50%. MacKay and Skipton (1983) also reported partial control of black scurf at 55°C for 10 minutes whilst Perombelon (1990) and Dashwood *et al.* (1991) reported control of the disease on tubers treated at 55°C for 5 minutes. Dashwood and Duncan (1992) recorded an reduction in incidence from 8 to 0% of diseased tubers. The temperature and time ranges which are effective in reducing black scurf suggest that this *R. solani* is sensitive to hot water treatments. These treatments may provide a useful alternative to chemical treatments for the control of the disease on seed.

Hot water treatment of Sebago mother tubers gave no apparent control of common scab. Inoculum of *Streptomyces scabies* in soil may have caused the disease in this case. An effect of hot water treatments on seed-borne powdery scab (*Spongospora subterranea*) has been reported (MacKay and Skipton 1983; Dashwood *et al.* 1981; Perombelon 1990).

2.4.1.3 *Chemical treatment for bacterial control*

In the study reported here the treatment of seed with copper oxychloride did not control blackleg. The chemical has successfully been used as a prophylactic foliar spray to control tuber contamination by air-borne erwinias (Elphinstone and Perombelon 1987). Harris (1979), reduced soft rotting on tubers by 91% with 5-nitro-8-hydroxyquinoline sulphate. As this chemical was extremely toxic it was not tested in our studies. However, a related chemical 8-hydroxyquinoline sulphate reduced rotting by 54%. It is used as a sterilant for control of soil-borne diseases and as a general disinfectant in horticulture. It is registered in Australia for control of *Botrytis* on grape wine cuttings. Consequently it may be informative to conduct further tests with this bactericide.

2.4.2 Gangrene

Experiments showed that the current industry standard for the control of post-harvest rots of potatoes effectively controlled gangrene of potatoes naturally infected with *P. exigua*. The fungicides, imazalil and prochloraz were equally effective in controlling gangrene. These results are consistent with those of Maughan *et al.* (1991) who tested the fungicides against artificially inoculated tubers. Similar results have been reported in overseas work (Hide and Cayley 1980;).

The Mantis® spinning disc ULV sprayer proved to be very practical for use on grading tables. Unlike high volume equipment often used by farmers, there was very little spray residue on the ground around the grading table and a curtain surrounding the equipment all but eliminated spray drift. Furthermore, the sprayer was easily calibrated and rates of application were easily adjusted for the rate of through put of potatoes. However, the results of the trials reported here show that although ULV could provide effective control of gangrene it was not as effective as dipping tubers in fungicides. This is probably related to relative differences in the amounts and distribution of fungicide deposits and the relative amounts on the tuber surface. Nevertheless, ULV sprayers provide an effective and practical means of applying fungicides and controlling tuber rots. Studies overseas have shown that electrostatic sprayers producing charged fungicide particles gave better control of tuber infection caused by common tubers diseases than did uncharged rotary atomisers and hydraulic sprayers (Cayley *et al.* 1987). Such equipment requires evaluation under Australian conditions.

The poor result of the ULV treatments in trial 1, 1993 can be attributed to less than satisfactory application of fungicides. Because of difficulties in placing the sprayer over the roller table the apparatus was suspended from roof struts. As a result the protective curtain around the sprayer could not be lowered adequately. The resultant drift of the fine spray reduced the amount of fungicide falling on tubers.

This study demonstrates the potential for severe losses due to gangrene in stored potatoes in some parts of Victoria. Up to 59% of tubers developed gangrene in one trial. This occurred when potatoes were sorted under cold conditions, when skins may be more brittle, storing them immediately at 5°C without allowing damaged skins to cure. Wounding of tubers is a prerequisite for the development of gangrene (Adams 1980) and wounds in which tissue is crushed rather than cut are the most susceptible to infection by the *P. exigua* (Adams 1980; Hide and Cayley 1989). Observations suggest that fine hair-line cracks are sufficient for infection to occur. Thus, gangrene can be avoided by careful harvesting and sorting of tubers and allowing curing of the skins before cool storage. Protective fungicides should be used if potatoes are sorted under conditions that prevent curing. Fungicide are most effective when they are applied immediately after sorting (Hide *et al.* 1989).

Thiabendazole and imazalil did not control silver scurf on tubers in trials in Beech Forest in 1993, even though these fungicides have been shown to effectively control this disease elsewhere (Cayley *et al.* 1983). Tubers were heavily diseased with silver scurf before treatments were applied and since the fungicides act as protectants they would not have controlled the disease in stored potatoes. Thiabendazole and imazalil

dip treatments resulted in a slight reduction of black scurf in storage. This has been reported elsewhere (Hall and Hide 1992).

Dry rot caused by *Fusarium* spp. did not occur in the rot trials reported here. Dry rot is common in the Gippsland region of Victoria where many growers routinely treat potatoes with thiabendazole for dry rot. Both thiabendazole and imazalil have been shown to be effective in the control of dry rot both overseas and in Australia (Hide and Cayley 1980; Maughan *et al.* 1991).

2.4.3 Stem canker and black scurf

Trials to evaluate fungicide treatments for the control of stem canker and black scurf of potatoes were not conclusive. Significant stem canker failed to develop in a trial in 1992/94, even though the disease was evident in the crop adjacent to the trial site. This crop was planted in early December and conditions during emergence and stem growth had been cool. Stem canker is favoured by cool, dry conditions (Bolkan *et al.* 1974; Hide and Firmager 1989). The trial site however, was planted in early January when conditions became hot and dry. Although there were no demonstrable effects of treatments on yields the fungicides tolclofos-methyl, pencycuron, iprodione and procymidone caused a slight, but not significant, reduction in the incidence and severity of black scurf. However, this was not demonstrated in the second trial in 1992/93 where black scurf was not affected by fungicide treatments. Observation from this trial suggest, however, that cv. Russet Burbank is only slightly susceptible to the black scurf, since only a light infection of small sclerotes was ever found on tubers of this cultivar.

In the in 1993/94 trial a general trend showed a reduction in the number of stunted plants in plots after emergence indicating that the fungicides were reducing the incidence and severity of stem canker. Only the tolclofos-methyl and the experimental chemical 2757 seed/furrow treatments significantly reduced the numbers of stunted plants. Pencycuron applied as a seed dust and 2757 applied to the seed/furrow were the only treatments to significantly reduce the number of malformed plants caused by *R. solani*. Even though some disease control by the fungicide treatments was demonstrated, there was no measurable effects on numbers of tubers, on total and marketable yields. Neither did the disease cause changes in the size distribution of potatoes as is often reported (Read *et al.* 1989). This suggests that either disease was not severe or that the potato crop can compensate for damage caused by the *R. solani*. Stem canker is reported to cause reduction in both yield and in tuber quality (Read *et al.* 1989; Scholte 1989). Further studies should be conducted on different cultivars and in different soil types before firm conclusions can be made on the effectiveness of fungicide treatments for the control of stem canker and black scurf.

The reason for a greater number of malformed plants than in the untreated control with the lowest rate of iprodione in the 1993/94 trial is not known.

2.4.4 Conclusions

This study has demonstrated the potential of hot water treatments to control blackleg on seed potatoes. However, it is clear that considerably more extensive testing is required to develop practical and reproducible hot water treatments. This study aimed to

completely eliminate Eca from seed potatoes. However, work overseas is aimed at reducing Eca to innocuous levels rather than to completely eliminate the pathogen (Robinson and Foster, 1987) and this is a more feasible approach.

The technique of immersing tubers in a large water bath is not practical for use by growers. The system is cumbersome to operate and the length of time required to treat seed (up to 30 minutes) is impracticable for commercial operations. Commercial continuous flow bulk hot water dipping system, operating at 55°C for 5 minutes is being trialled in Scotland for the control of blackleg and fungal pathogens of potato. A continuous flow hot water dip developed in Queensland by K.W. Engineering is used commercially to treat diseases of mango fruits at 55°C for 5 minutes (estimated cost $10,000) may be more appropriate. Such systems provide a more practical means of hot water treatment.

The study on the control of gangrene demonstrated the effectiveness of imazalil and thiabendazole in controlling this disease. The study provides useful information on the control of the disease under Australian conditions. Data on the efficacy of imazalil will aid in the registration of this fungicide for the control of gangrene.

The study on the effects of chemical treatments for the control of stem canker and black scurf are inconclusive. Trials demonstrated the potential of several registered and unregistered treatments to control these diseases.

At present there are only three registered treatments for the control of tuber diseases in Australia (Table 2, Appendix 1). Australia lags behind Europe in this regard and considerably more work is required to provide a suite of treatments for growers. The threat of pathogens developing resistance to fungicides make this imperative.

Several research programs funded by Australian Potato Growers and HRDC are aimed at providing methods of controlling fungal diseases of tubers. These include studies on the control of silver scurf, black dot and powdery scab in Victoria, the control of rhizoctonia stem canker and black scurf in South Australia and the control of black dot in Tasmania. Chemical companies are currently seeking registration of imazalil for the control of gangrene and pencycuron for the control of rhizoctonia stem canker and black scurf (Table 1, Appendix 1).

2.5 References

Anon. (1990). Chemical treatments of seed and ware potatoes. (Potato Marketing Board, Research and Development Department, Cowley, Oxford, UK).

Bolkan, H.A., Wenham, H.T., and Milne, K.S. (1974). Effect of temperature on severity of *Rhizoctonia solani* infection of potato shoots. *Plant Disease Reporter* **58**, 646-9.

Burnett, E.M., Melvin, S. and Perombelon, M.C.M. (1988). Hot water treatment of seed potato tubers. *Scottish Crop Research Institute, Annual Report 1988*, 107.

Cayley, G.R., Hide, G.A., Lewthwaite, R.J., Pye, B.J., and Vojvodic, P.J. (1987). Methods of applying sprays to potato tubers and description of use of a prototype electrostatic sprayer. *Potato Research* **30**, 301-317.

Cayley, G.R., Hide, G.A., Read, P.J., and Dunne, Y. (1983). Treatment of potato seed and ware tubers with imazalil and thiabendazole for the control of silver scurf and other storage diseases. *Potato Research* **26**, 163-73.

Cother, E.J. (1983). Response of potato in a semi-arid environment to chemical control of *Rhizoctonia solani*. *Potato Research* **26**, 31-40.

Cother, E.J., and Cullis, B.R. (1985). Tuber size distribution in cv. Sebago and quantitative effects of *Rhizoctonia solani* on yield. *Potato Research* **28**, 1-14.

Cupples, D. and Kelman, A. (1974). Evaluation of selective media for isolation of soft-rot bacteria from soil and plant tissue. *Phytopathology* **64**, 468-475.

Dashwood, E.P., Burnett, E.M. and Perombelon, M.C.M. (1991). Effect of a continuous hot water treatment of potato tubers on seed-borne fungal pathogens. *Potato Research* **34**,: 71-78.

Dashwood, E.P. and Duncan, J.M. (1992). Blemish diseases of potatoes: roots as sources of inoculum. *Scottish Crop Research Institute Annual Report 1992*, 75-78.

Elphinstone, J.G. and Perombelon, M.C.M. (1986). Contamination of potatoes by *Erwinia carotovora* during grading. *Plant Pathology* **35**, 25-33.

Elphinstone, J.E. and Perombelon, M.C.M. (1987). Control of contamination of potatoes with air-borne *Erwinia carotovora* by foliar application of copper oxychloride. *Annals of Applied Biology* **110**, 535-544.

Gudmestad, N.C. and Secor, G.A. (1983). The bionomics of *Erwinia carotovora* in North Dakota. *American Potato Journal* **60**, 759-771.

Hall, S.M., and Hide, G.A. (1992). Fungicide treatment of seed tubers infected with thiabendazole-resistant *Helminthosporium solani* and *Polyscytalum pustulans* for controlling silver scurf and skin spot on stored progeny tubers. *Potato Research* **35**, 143-147.

Harris, R.J. (1979). Chemical control of bacterial soft-rot of wounded potato tubers. *Potato Research* **22**, 245-249.

Harris, R.I. and Lapwood, D.H. (1978). The spread of *Erwinia carotovora* var. *atroseptica* (blackleg) from degenerating seed to progeny tubers in soil. *Potato Research* **21**, 285-294.

Harrison, M.D., Quinn, C.E., Sells, A. and Graham, D.C. (1977). Waste potato dumps as sources of insects contaminated with soft rot coliform bacteria in relation to recontamination of pathogen-free potato stocks. *Potato Research* **20**, 37-52.

Hide, G.A., and Cayley, G.R. (1980). Tests of fungicides for controlling gangrene (*Phoma exigua* var. *foveata*) and dry rot (*Fusarium solani* var. *coeruleum* and *F. sulphureum*) on potatoes during storage. *Potato Research* **23**, 395-403.

Hide, G.A., and Cayley, G.R. (1989). Factors influencing the control of potato gangrene by fungicide treatment. *Potato Research* **32**, 91-9.

Hide, G.A., and Firmager, J.P. (1989). Effects of soil temperature and moisture on stem canker (*Rhizoctonia solani*) disease of potatoes. *Potato Research* **32**, 75-80.

Jellis, G.J, and Taylor, G.S. (1977). The development of silver scurf (*Helminthosporium solani*) disease of potato. *Annals of Applied Biology* **86**, 19-28.

King, E.O., Ward, M.K. and Raney, D.E. (1954). Two simple media for the demonstration of pyrocyanin and fluorescein. *Journal of Laboratory and Clinical Medicine* **44**, 301-317.

Lojkowska, E. and Kelman, A. (1989). Screening of seedlings of wild *Solanum* species for resistance to bacterial stem rot caused by soft rot erwinias. *American Potato Journal* **66**, 379-390.

Mackay, J.M. and Shipton, P.J. (1983). Heat treatment of seed tubers for control of potato blackleg (*Erwinia carotovora* subsp. *atroseptica*) and other diseases. *Plant Pathology* **32**, 385-393.

McCarter-Zorner, N.J., Franc, G.D., Harrison, M.D., Michand, J.E., Quinn, C.E., Sells, I.A. and Graham, D.C. (1984). Soft rot *Erwinia* bacteria in surface and underground waters in southern Scotland and in Colorado, United States. *Journal of Applied Bacteriology* **49**, 175-181.

Mariais, L. (1990). Efficacy of fungicides against *Colletotrichum coccodes* on potato tubers. *Potato Research* **33**, 257-281.

Maughan, J.P., Shanmuganathan, N., and Hepworth, G. (1991). Fungicide treatments for the control of storage rots of seed potatoes. *Australasian Plant Pathology* **20**, 142-4.

Perombelon, M.C.M. (1985). The blackleg problem in the Mediterranean region. In: *Report of the International Conference on Potato Blackleg Disease 26-29 June 1984*. D.C. Graham and M.D. Harrison (Eds.). *Potato Marketing Board*, 57-59.

Perombelon, M.C.M. (1990). Hot water treatment to control seed borne blackleg and fungal blemish diseases of potatoes. *Scottish Crop Research Institute Annual Report 1990*: 69-72.

Perombelon, M.C.M. (1993). Progress and prospects for research. *Scottish Crop Research Institute Annual Report 1993*: 85-89.

Perombelon, M.C.M. (1994). Clean seed is still best bet on blackleg. *Potato Review*: November 34-37.

Perombelon, M.C.M. and Kelman, A. (1987) Blackleg and other potato diseases caused by soft rot erwinias: Proposal for revision of terminology. *Plant Disease* **71**, 283-285.

Perombelon, M.C.M. and Melvin, S. (1987). Control of potato Blackleg by hot water treatment of seed tubers. *Scottish Crop Research Institute Annual Report 1987*, 102-103.

Quinn, C.E., Sells, I.A. and Graham, D.C, (1980). Soft rot Erwinia bacteria in the atmospheric bacterial aerosol. *Journal of Applied Bacteriology* **49**, 175-181.

Read, P.J., Hide, G.A., Firmager, J.P., and Hall, S.M. (1989). Growth and yield of potatoes as affected by the severity of stem canker (*Rhizoctonia solani*). *Potato Research* **32**, 9-15.

Robinson, K. and Foster, G. (1987). Control of potato blackleg by tuber pasteurisation: the determination of time-temperature combinations for the inactivation of pectolytic Erwinia. *Potato Research* **30**, 121-125.

Scholte, K. (1989). Effects of soil-borne *Rhizoctonia solani* Kuhn in yield and quality of ten potato cultivars. *Potato Research* **32**, 367-376.

Shivsat, S.G., Thomas, P. and Nair, P.M. (1991). Evaluation of treatments with hot water, chemicals and ventilated containers to reduce microbial spoilage on irradiated potatoes. *Potato Research* **34**, 227-231.

Wale, S.J. and Robinson, K. (1986). Evaluation of large scale hot water dipping and forced ventilation of seed potatoes to reduce tuber contamination with blackleg bacteria (*Erwinia* spp.). *British Crop Protection Conference - Pests and Diseases* **8C-26**, 1137-1142.

Wale, S.J. Robertson, K., Robinson, K. and Foster, G. (1986). Studies on the relationship of contamination of seed potato tubers with *Erwinia* spp. to blackleg incidence and large scale hot water dipping to reduce contamination. *Aspects of Applied Biology* **13**, 285-291.

3. Recommendations

Although demonstrating the potential of hot water treatments, this study has not been able to provide specific recommendations for the control of blackleg. Blackleg on seed was once controlled with mercuric dips. At present there are no control measures for this disease on seed potatoes. Ultimately the control of this disease will involve resistant cultivars (Lojkowska and Kelman 1989; Perombelon 1993). However, interim control measures are required now.

The industry should consider its priorities for the control of blackleg and consider the feasibility of evaluating continuous hot water treatments, such as those described above, and chemical treatments.

It is recommended that the results of studies on the efficacy of fungicides be made available to chemical companies to assist in their registration. The evaluation of compounds that were tested and registered overseas, and new compounds, should be actively encouraged amongst the industry.

3.1 Extension

* Report to Victorian Certified Seed Potato Growers Committee who provided funds for this project.

* Provide a review of hot water treatment studies done in this project and overseas to explain the potential of this treatment through Industry Publications and Seminars.

* Write industry publications on the control of storage rots based on the work presented here.

Healthy seed is a prerequisite to a healthy crop. Pressure due to diseases in recent years has resulted in a renewed, although sometimes ill informed, interest in the health of seed. An extension program providing general and specific information on seed health, current control strategies and deficiencies in control strategies would be of great benefit to the industry.

3.2 Future Research

Blackleg is serious disease of potatoes and of increasing prevalence. Further studies on the epidemiology of blackleg and studies on determining the reasons for the increase are required.

Considerable money is spent by growers to control rhizoctonia stem canker and black scurf. This study and other published studies (Cother 1983; Cother and Cullis 1985) have not been able to demonstrate significant yield loss due to the disease or yield benefits from treatments. Research into the benefits to yield and quality of potatoes from fungicides applied to different cultivars and in different soil types would be very beneficial to growers.

3.3 Financial/Commercial Benefits

Not Applicable

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Appendix 1

Table 1. Details of fungicides and antagonists used in field trials

Registered Trade Names	Manufacturer
Tecto Flowable Fungicide	MSD AGVET a division of Merck Sharp and Dohme (Australia) Pty Ltd
Fungaflor 750 WSP	Janssen-Cilag Pty Ltd (Janssen Pharmaceutica NV Beerse, Belgium)
Imazalil 100 SL	Janssen-Cilag Pty Ltd (Janssen Pharmaceutica NV Beerse, Belgium)
Rizolex 100 D	Sumitomo Chemical Co. Japan (Cyanamide (Australia) Pty Ltd.
Rizolex 50 WP	Sumitomo Chemical Co. Japan (Cyanamide (Australia) Pty Ltd.
Monceren	Bayer Australia Limited
Monceren	Bayer Australia Limited
Shirlan	Crop Care Australia Pty Ltd
Sumisclex	Crop Care Australasia Pty Ltd
2757	Crop Care Australasia Pty Ltd
Sportac	Hoechst Schering Agrevo Pty Ltd
Rovral Liquid	Rhone Poulenc Rural Australia Pty Ltd
Conquer	Mauri Laboratories Pty Ltd, Moorebank, NSW

Table 2. Fungicides registered for the control of post-harvest diseases in Australia

Registered Trade Name	Active ingredient	Manufacturer	Target
Tecto Flowable Fungicide	450 g/100L thiabendazole	MSD AGVET a division of Merck Sharp & Dohome (Australia) Pty Ltd	Gangrene (*Phoma exigua)* Silver scurf (*Helminthosporium solani*) Dry rot (*Fusarium* spp.)
Rizolex 100 D	100 g/kg tolclofos-methyl	Cyanamide (Australia) Pty Ltd	Stem canker, black scurf (*Rhizoctonia solani*)
Rovral Aquaflo Fungicide	500 g/L iprodione	Rhone Poulenc Rural Australia Pty Ltd	Stem canker, black scurf (*Rhizoctonia solani*)