Know-how for Horticulture™

Common scab threshold on tuber seeds for processing potato crops

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Serve-Ag Research Pty Ltd

Project Number: PT02016

PT02016

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the potato industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the Potato industry.

ISBN 0 7341 1243 2

Published and distributed by:
Horticulture Australia Ltd
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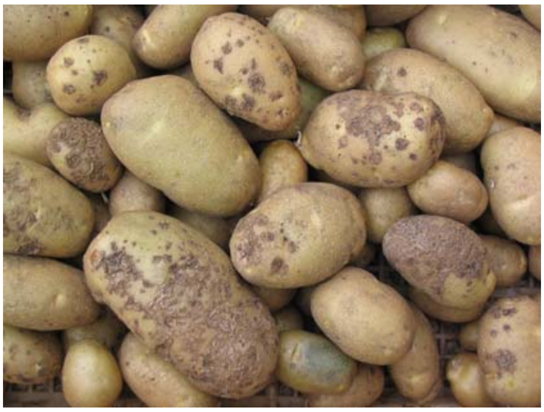

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Final Report PT02016

24 February 2006

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Horticulture Australia Project

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Acknowledgements
This project was funded by Australian potato growers and processors with matching funds from the Australian government through Horticulture Australia Ltd. Support from the potato growers, David Addison, John Lillico, Scott Langton, Denis Roling, Wallace Anderson, Greg Murphy, Russell Bell and Michael Fralley, in providing trial sites and crop management in the project studies is gratefully acknowledged. The assistance of Sarah Badcock, Pam Cox, Glen Marriot, Laura Cowles and Diane Sward in potato harvesting and assessments is also gratefully acknowledged. We are also thankful to Professor Glen McPherson for his advice on statistics and sampling, and Mary Trebilco for administration and proof-reading of this report. We would also like to acknowledge the assistance of: Frank Mulcahy, Jason Ritchie, Wayne Meagher of Simplot Australia Pty Ltd; Steve Cook and Greg Bullock of McCain Foods (Aust.) Pty Ltd; Peter Broun and Mark Rayner of Brouns seed store, Andrew Langmaid of Cherry Hill seed store; Fraser Mearns of Harvest Moon; and Peter Aird, Doug Green and James Burbury of Serve-Ag Pty Ltd; and all seed growers who supplied seed samples for our trial studies.

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Media Summary

Throughout the world, the certification standards for *Streptomyces scabies* (common scab) on seed potatoes generally evolved from expectations from seed buyers and what is practical and achievable for seed producers. Moreover, although tubers with deep pitted scab, high scab incidence and high scab coverage had been shown to be an important source of common scab transmission, there have been no studies to determine the impact of common scab infected tubers that have shallow scab, low scab incidence and low scab coverage that are more typical of infected seed lines in Australia. This project aimed to determine the effects of infected seeds with superficial and low scab coverage, and to establish achievable and meaningful common scab threshold levels on seed lines that reflect field performance, regional conditions and market acceptability. A series of trial studies were conducted over three growing seasons in Tasmania and Victoria. Quantitative data and the knowledge gained in this project could enable the Australian potato industry to re-examine the maximum common scab threshold levels on seed potatoes, and the cost benefits of seed sorting to meet seed certification requirements for the disease.

Common scab infected seed lines

Although infected seeds can be a source of inoculum for common scab, most of these infected seeds from commercial seed crops have very few lesions (typically one to three small and shallow scab lesions), and the level of scab transmitted is only evident when they are planted in soil that is free of the common scab pathogen. Therefore, the importance of infected seeds must be taken in the context of where they are planted.

This project showed that in new ground that was relatively free of scab inoculum, there were no obvious common scab transmissions due to infected seed lines with 2%, 4% and 8% visible scabs. Substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines, indicating that 10% infected seeds may be the meaningful threshold incidence for common scab on seed lines in soils that are free of the scab pathogen.

Findings in this project also raise questions on whether the maximum limits for common scab on seeds, and seed sampling for seed certification, are meaningful to seed buyers and fair to seed growers. In the former question, the maximum limits of 1% to 4% infected seeds did not appear to be meaningful, and we could not detect any obvious differences between seed lines with these levels and a non-infected seed line. In the latter question, seed sampling places a very high risk of wrongfully rejecting a seed line that is within the maximum limits. An increase in seed sampling numbers will increase the cost of assessments, yet brings little or no benefit in improving sampling accuracy. However, an increase in the common scab threshold, from 4% to 10%, has a much greater impact in improving sampling accuracy and preventing wrongful rejections of seed lines that have very low common scab incidence.

Common scab in seed certification

A worldwide review of seed certification schemes for potato scab shows that it is common for most schemes to accept a certain level of common scab on tubers and place greater importance on scab coverage. These is in sharp contrast to the Australian schemes that places great importance on seeds with any visible scab lesions, and yet make no distinction between scab coverage and severity of the infected seeds. Other than Australia, only South Africa consider and count the presence of common scab lesions on a tuber as being *scabby* for the purpose of assessment in seed certification. In South Africa, the maximum tolerance level for any common scab on seed lines is 10%. In Australia, the maximum limit of acceptable common scab is 1% in New South Wales, 2% in Victoria and Western Australia, and 4% in South Australia and Tasmania. There has been no previous quantitative study in Australia to support these low maximum tolerance levels of 1% to 4%. In trial studies conducted in this project, there was no supporting evidence for these limits either.

Common scab coverage in certification standard

This project also demonstrates a strong correlation between seed lines' common scab coverage and their transmission on to daughter tubers. Substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or more tubers had greater than 5 lesions or greater than 2% surface cover. This suggests that 4% tubers with more than 2% surface cover could be a useful benchmark.

With more than 2% surface cover, infected tubers are easier to detect and assess with greater accurately compared to those tubers with less than 2% surface cover. When considering a new standard for common scab on seeds, the Canadian certification scheme, which gives consideration to both scab coverage and incidence, may be a suitable compromise. The Canadian certification scheme accepts up to 10% of light scab (less than 5% surface cover) and up to 5% moderate scab (5% to 10% surface cover) in a seed lot. Most of the infected seeds in Australian seed lines have light scab cover of less than 5% surface cover.

Seed sorting and washing

Research findings in this project seriously challenged the current practice of systematically sorting and removing disease infected seed after harvest in a grading shed by some seed growers. This project has demonstrated that for common scab, there is little or no benefit in such sorting. Instead, it can be counter-productive, as careful sorting can disguise the inherent levels of *Streptomyces scabies* inoculum within a seed line. This may give the false impression that the seed line has 0% common scab, and will not be potentially infective to new ground. Moreover, the practice of sorting seed is very labour intensive and adds significantly to the overall cost of seed production. This project has raised serious questions as to the cost benefits of sorting, not only for common scab but also for other tuber diseases such as *Rhizoctonia solani* (black scurf) and *Spongospora subterranae* (powdery scab). Some seed growers also used seed washing as a commercial practice in preparing their early generation seed for planting. In this project, washing of common scab infected seed lines did not reduce common scab transmission.

Seed management

Chemical seed treatments to control seed borne common scab have been shown to be effective in controlling common scab transmission over several field trials. There were no obvious differences in the levels of disease control between fludioxinil (Maxim 100FS®) treated seeds in comparison to mancozeb treated seeds. This indicates that where mancozeb dusting treatment poses an occupational hazard to seed operators, Maxim® liquid spray application may be used as an alternative. Maxim® spray application is also regularly used for seed borne *Rhizoctonia* control. As a result of efficacy studies conducted in a previous project and in this project, Maxim® was registered in Australia in 2005 for use in seed treatment to suppress seed borne common scab. This is the first record in the world, on the novel use of Maxim® for common scab management of infected seeds.

In field trials, in soils that appear to have low levels of inoculum, the mancozeb treated infected seeds resulted in a similar scab levels as control seeds that had no visible common scab. These results may have important implications for seed growers in managing seed crops for minimal common scab. It shows that while the disease remains at low levels and as surface cover only, chemical treatment is as effective as planting clean seed. Since seed sorting to remove infected seed is not effective, seed growers should not attempt to sort and remove scab infected seed on early generation seed lines, but should ensure that these seed lines are chemically treated before planting. Chemical treatment probably should not be delayed until the generation prior to certification or certified seed itself, as the scab levels may be increasing in successive generations, and treating G4 or G5 seed may not be effective if high scab incidence and coverage, or deep scab develops in the later seed generations. Seed growers need to manage scab control in early generations, and chemically treat early generations to prevent scab.

Technical Summary

Throughout the world, the certification standards for *Streptomyces scabies* (common scab) on seed potatoes generally evolved from expectations from seed buyers and what is practical and achievable for seed producers. Moreover, although tubers with deep pitted scab, high scab incidence and high scab coverage had been shown to be an important source of common scab transmission, there have been no studies to determine the impact of common scab infected tubers that have shallow scab, low scab incidence and low scab coverage that are more typical of infected seed lines in Australia. This project aimed to determine the effects of infected seeds with superficial and low scab coverage, and to establish achievable and meaningful common scab threshold levels on seed lines that reflect field performance, regional conditions and market acceptability. A series of trial studies were conducted over three growing seasons in Tasmania and Victoria. Quantitative data and the knowledge gained in this project could enable the Australian potato industry to re-examine the maximum common scab threshold levels on seed potatoes, and the cost benefits of seed sorting to meet seed certification requirements for the disease.

Common scab infected seed lines

Trial studies in this project demonstrated that common scab infected seed was an important source of transmission onto daughter tubers only in new ground that is relatively free of soil borne inoculum. In old grounds where potatoes had been planted in crop rotations, most common scab on daughter tubers was caused by soil borne inoculum. Due to the difficulty of finding new ground where potatoes had never been planted before, many field trials in this project were located in paddocks that had a history of potato growing over a long period, but did not have a history of major scab problems. In these paddocks, common scab incidence due to seed borne inoculum was relatively small in comparison to that caused by the soil borne scab inoculum. These observations demonstrate that although infected seeds can be a source of inoculum for common scab, most of these infected seeds have very few lesions (typically one to three small and shallow scab lesions) and the level of scab transmitted is only evident when they are planted in soil that is relatively free of common scab pathogen. Therefore, the importance of infected seeds must be taken in the context of where they are planted. Moreover, on potatoes produced for processing, only tubers with 25% surface cover or deep scab are considered to be important and can impact on the cost of processing in crisping or French fries.

This project showed that in new ground that is relatively free of scab inoculum, there were no obvious common scab transmissions due to infected seed lines with 2%, 4% and 8% visible scabs. Substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines. This indicates that 10% infected seeds may be the meaningful threshold incidence for common scab on seed lines in soils that are free of the scab pathogen.

There was a strong correlation between seed lines' common scab incidence and scab transmission. This correlation, however, was dependent on the exact or precise common scab incidence of the seed lines that was determined by examining every seed tubers used in the trial studies. With the less precise common scab incidence of the seed lines that were determined by small sub-samples of a whole seed crop for the seed certification process, there was no obvious correlation. These findings raised serious questions on whether the maximum limits and seed sampling for seed certification are meaningful to seed buyers and fair to seed growers. In the former question, the maximum limits of 1% to 4% infected seeds did not appear to be meaningful, and we could not detect any obvious differences between these seed lines when compared with a non-infected seed line. In the latter question, seed sampling places a very high risk of wrongfully rejecting a seed line that is within the maximum limits. When examining a sample of 100 tubers per seed line, there is a 32% probability or chance of rejecting a seed line with 2% infected tubers at a maximum limit of 2%. Similarly, there is a 37% chance of rejecting a seed line with 4% infected tubers at a maximum limit of 4%. These values demonstrate that seed growers face very high chances of not meeting the relatively low maximum threshold limits that are set in the Australian seed schemes. An increase in the number of seeds examined for seed certification will not substantially reduce the chances of wrongfully rejecting a seed line. An increase in seed sampling numbers is more likely to increase the cost of assessments, yet brings little or no benefit in improving sampling accuracy. However, an increase in the common scab threshold, from 4% to 10%, has a much greater impact in improving sampling accuracy and preventing wrongful rejections of seed lines that have very low common scab incidence.

Common scab in seed certification

A worldwide review of seed certification schemes for potato scab shows that it is common for most schemes to accept a certain level of common scab on tubers and place greater importance on scab coverage. This is in sharp contrasts to the Australian schemes that places great importance on seeds with any visible scab lesions and yet make no distinction between scab coverage and severity of the infected seeds. In the general standards of European Union countries, more than one third of the tuber surface needs to be covered (either common scab or powdery scab) for the tuber to be counted as *scabby*. In Scotland, the level of surface cover needs to extend to 25% before the tuber is regarded as *scabby*. The various United States of America (USA) certification schemes all differ but most deem that seeds with less than 5% of the tuber surface covered by scab lesions are not important and hence not counted in scab assessment, but any presence of pitted scab on a tuber is regarded as being *scabby*. Among eight national certification schemes examined, other than Australia, only South Africa consider and count the presence of common scab lesions on a tuber as being *scabby* for the purpose of assessment. In South Africa, the maximum tolerance level for any common scab on seed lines is 10%. In Australia, the maximum limit of acceptable common scab is 1% in New South Wales, 2% in Victoria and Western Australia, and 4% in South Australia and Tasmania. These maximum limits means that, compared with other certification schemes around the world, the Australian thresholds for maximum levels are unusually harsh and also set very low. There has been no previous quantitative study in Australia to support the low maximum tolerance levels of 1% to 4%. In trial studies conducted in this project, there was no supporting evidence for these limits either.

Most certification schemes among the major potato producing countries imply that certification standards for common scab have evolved to what is practical and achievable for seed producers. Moreover, in many parts of Europe, USA and Canada that have long traditions of potato growing, where *Streptomyces scabies* (common scab) and *Spongospora subterranae* (powdery scab) are already common in soils, it is unrealistic to produce scab free seeds. In Australia, seed production initially tends to occur on land with little or sometimes no history of potato production, so a much higher certification standard may be achievable. But in recent years, as new land becomes increasingly difficult to find or too costly, the majority of seed crops are planted in lands that have a tradition of potato growing in rotation with other crops. Seeds are also often sold to traditional potato growers and planted in areas that have a history of potato production. Therefore, seed production and ware potato production in Australia is becoming similar to conditions in North American and European countries. With these changes, it may be time to review the strict and demanding standards within Australia that are increasingly impractical and costly to seed growers.

Common scab coverage in certification standard

This project also demonstrates a strong correlation between seed lines' common scab coverage and their transmission on to daughter tubers. Substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or more tubers have greater than 5 lesions or with greater than 2% surface cover. This suggests that 4% tubers with more than 2% surface cover could be a useful benchmark. With more than 2% surface cover, infected tubers are easier to detect and assess with greater accurately compared to those tubers with less than 2% surface cover. Sometimes, soil on seed tubers can obscure a few common scab lesions. In Canada, U.S.A. and Europe, scab severity based on the percentages of tubers with high surface covered by common scab or deep scab are typically used as benchmark levels instead of the presence of any scab lesions. When considering a new standard for common scab on seeds, the Canadian certification scheme, which gives consideration to both scab coverage and incidence, may be a suitable compromise. The Canadian certification scheme accepts up to 10% of light scab (less than 5% surface cover) and up to 5% moderate scab (5% to 10% surface cover) in a seed lot. Most of the infected seeds in Australian seed lines have light scab cover of less than 5% surface cover.

Seed sorting and washing

Seed sorting to remove and reduce the scab level in infected seed lines is a practice that is regularly used by some seed growers, especially in Victoria, to achieve the acceptable limit for seed certification. Harvested seeds with obvious and high scab coverage of 20% or more are also easily spotted and, therefore, removed. As a result of seed sorting, seed lines that have different levels of common scab at harvest could result in little or no scab after careful sorting, and look similar. For the first time, extensive research studies had been conducted in field trials, over three growing seasons, to examine the impact of sed sorting. In this project, the sorting of seeds that had relatively high common scab incidence, ranging from 20% to 75% infected tubers to 0%, 2% 25% or 50% infected tubers, was shown to give no beneficial effects in reducing seed borne common scab transmission. Seed lines with 20% or more infected tubers before sorting, consistently caused substantial increases in common scab transmissions compared to control seeds that had no visible common scab lesions.

These findings seriously challenge the current practice of systematically sorting and removing disease infected seed after harvest in a grading shed by seed growers. This practice has continued for many generations without any scientific evidence of its impact. This project has demonstrated that for common scab, there is little or no benefit in such sorting. Instead, it can be counter-productive, as careful sorting can disguise the inherent levels of *Streptomyces scabies* inoculum within a seed line. This may give the false impression that the seed line has 0% common scab and will not be potentially infective to new ground. Moreover, the practice of sorting seed is very labour intensive and adds significantly to the overall cost of seed production. This project has raised serious questions as to the cost benefits of sorting, not only for common scab but also for other tuber diseases such as black scurf and powdery scab. The methodology used in this project to study the effects of sorting on common scab, should also be used to examine the cost benefits of sorting for other tuber diseases.

Some seed growers also use seed washing as a commercial practice in preparing their early generation seed for planting. There is a view that washing helps to remove some of the scab inoculum as well as other pathogens from the seed surface, thus reducing the risk of transferring the disease to the next generation. In this project, washing of common scab infected seed lines did not reduce common scab transmission.

Seed management

Chemical seed treatments to control seed borne common scab have been shown to be effective in controlling common scab transmission over several field trials. Mancozeb and fludioxinil (Maxim 100FS®) seed treatments were shown to be effective and consistent in Tasmanian and Victorian field trials in controlling common scab from infected seeds that have low scab coverage of less than 5%. The chemical treatments appeared to be more effective on infected seeds with superficial and low scab coverage than on those with deep pitted scab and with high scab coverage (>5% scab cover). There were no obvious differences in the levels of disease control between Maxim® treated seeds in comparison to mancozeb treated seeds. This indicates that where mancozeb dusting treatment poses an occupational hazard to seed operators, Maxim® liquid spray application may be used as an alternative. Maxim® spray application is already regularly used for seed borne *Rhizoctonia* control. As a result of efficacy studies conducted in a previous project and in this project, Maxim® was registered in Australia in 2005 for use in seed treatment to suppress seed borne common scab. This is the first record in the world, on the novel use of Maxim® for common scab management of infected seeds.

In field trials in soils that appear to have low levels of inoculum, the mancozeb treated infected seeds resulted in a similar scab levels as control seeds that had no visible common scab. These results have important considerations for seed growers in managing seed crops for minimal common scab. It shows that while the disease remains at low levels and as surface cover only, chemical treatment is as effective as planting clean seed. Sorting to remove infected seed is not effective. Therefore, seed growers should not attempt to sort and remove scab infected seed on early generation seed lines, but should ensure that these seed lines are chemically treated before planting. Chemical treatment probably should not be delayed until the generation prior to certification or certified seed itself, as the scab levels may be increasing in successive generations, and treating G4 or G5 seed may not be effective if high scab incidence and coverage, or deep scab develops in the later seed generations. Seed growers need to manage scab control in early generations, and chemically treat early generations to remove scab.

Powdery scab

Field trials conducted within commercial crops to examine the impact of scab incidence, coverage and severity on seed lines in Tasmania in 2003-2005, resulted in high levels of powdery scab on their daughter tubers. Over this period, substantial improvements in cultural practices adopted by growers led to powdery scab becoming the prevalent scab disease in all these trials. Regular soil moisture monitoring led to increased frequency of irrigation, hence creating conditions that favour powdery scab instead of common scab. These changes resulted in the increased prevalence of powdery scab on seed lines, and appeared to reduce the importance of common scab on seed lines. In Victoria, powdery scab also appeared to be more widespread in seed production areas. Chemical seed treatments with mancozeb or Maxim 100FS® were also shown to help reduce powdery scab levels on daughter tubers. The chemical treatments, however, were not effective against soil borne inoculum.

S. subterranae (powdery scab), produces large quantities of spore balls that can become soil borne and air borne. Spore balls may be in soil dust that accumulates in seeds and seed stores. Therefore, powdery scab could still be carried on seeds that have no visible powdery scab lesions. Certification standards for common scab are also used for powdery scab in Australia. Similarly, these limits for powdery scab are also very low and unusually harsh in comparison to standards used by North American and European Union countries, where only infected tubers with high scab coverage are counted in scab assessments for seed certifications.

Recommendations

In view of findings from this project, the following recommendations are suggested to the Australian potato seed advisory committee, potato seed growers and buyers to consider:

- Seeds to be planted in new ground or in ground that is known to be free of common scab pathogen, must be held to a higher standard than seeds to be planted in traditional grounds that have a history of potato production.
- Seeds completely free of common scab should be planted in new grounds. A premium value could be assigned to disease free seeds.
- In traditional potato production grounds, a change to a maximum common scab threshold of 10% of infected tubers with any common scab lesions.
- Changes to a new system where only seeds with superficial scab and obvious surface cover of 5% or more would be counted as *scabby* tubers in seed certification assessment. If only seeds with 5% or more surface cover are considered as *scabby*, then the maximum limit could be set at 4% or less *scabby* seeds.
- Sorting of seeds to reduce and adjust common scab incidence must be discouraged. Assessments of seeds for seed certifications must be based on unsorted tubers.
- Chemical seed treatments (mancozeb or fludioxinil) should be applied to common scab infected seeds with superficial and low surface cover of less than 5% surface cover.
- Chemical seed treatments should be used on high quality seeds (G1, G2 and G3), as standard practice to prevent or reduce common scab in subsequent seed generations.
- The potato industry should undertake further investigations into the practices of manually removing tubers that show other skin diseases such as black scurf and powdery scab from a seed line, with a view to changing and modernizing Australian seed potato production.

Introduction

A number of diseases can be transmitted in infected potato tubers, including viruses, bacteria, and fungal pathogens. Certified tuber seeds are not guaranteed to be disease-free. They are certified to have no more than a specific percentage of disease symptoms during the inspections required by a seed certification scheme. The tolerance level of symptom expression for each disease usually varies, not only from one country to another, but it can also vary within different regions in a country. These variations are usually based on the relative importance of a disease, how common and widespread it is, and on what is achievable in a practical sense as a target for the certification standards and market acceptability. Although various studies have shown that common scab infected tubers with high scab coverage or deep pitted lesions can transmit the disease onto their daughter tubers (Pung & Cross 2000a, Wilson et al 1999), no research studies have been conducted to examine the effects of infected seed lines with low incidence of 10% or less and with low scab cover of 5% or less. Many infected seed lines grown under seed certification protocols generally have less than 10% infected tubers and less than 5% scab cover.

Potato scab caused by *Streptomyces scabies* (common scab) and *Spongospora subterranae* (powdery scab) are common in production areas throughout the world (Hooker 1981). In Tasmania and Victoria, common scab is widespread, occurring in many crops. However, the majority of affected crops have low disease incidence and severity. If grown for processing, the affected potatoes will not normally impact in any substantial way on yield and quality unless there are deep scab lesions or greater than 25% scab coverage. High scab coverage and deep lesions on potatoes will increase the processing cost to remove the deeply infected tissues. There is less tolerance on potatoes produced for the fresh market as the lesions affects their visual appeal and value. Seed potatoes that have greater than the threshold levels set for scab cannot be sold as certified seed, and may have to be sold as low quality non-certified seeds, as ware potatoes or to be used for stock feed.

In recent years, as the disease has become more widespread in Tasmania and Victoria, an increasing number of seed crops have not been certified due to an unacceptably high number of tubers with common scab lesions. In order to ensure continuity in the long-term supply of seeds, the processing industry may have to consider a review of the certification standards for tuber seeds destined for use in regions where common scab is already widespread. In some years, when weather conditions have favoured common scab development, there has been an inadequate supply of certified seed because many seed crops exceeded the threshold limit, and tubers from non-seed crops were used as seeds instead. This in turn may create other problems, as certified seed crops are grown to a higher set of standards for minimising disease occurrence and are of better intrinsic quality than those from non seed crops, even though they may be visually unacceptable due to the presence of common scab. In paddocks where soil borne scab is already widespread and relatively high, there may be no benefit to be gained from using scab free seeds. Soil borne inoculum is expected to have a much greater impact on crops in comparison to seed borne inoculum. In these situations, the use of disease severity rather than disease incidence may be more appropriate, and could result in major savings in seed production. Studies conducted recently have shown that the use of mancozeb seed treatment may negate the requirement for a common scab threshold level (Pung & Cross 2000b). Other studies conducted (Wilson, 1995, Wilson et al. 1999) showed that the fungicides fluazinam and flusulfamide have the potential to control common scab.

In Europe and the USA, where common scab is widespread, this disease is not considered to be important even on tuber seeds unless potatoes have high scab coverage or deep pitted scab lesions. In recent studies on common scab in Tasmania, disease severity rather than disease incidence was shown to be more important in disease transmission (Pung & Cross 2000a, Wilson et al 1999). This could be related to the pathogen's inoculum levels; high levels of inoculum were found in deep scab lesions, whereas superficial scab lesions had very low to undetectable levels of inoculum. Furthermore, a chemical seed dressing such as mancozeb was found to be effective in controlling common scab transmission from tuber seeds that had superficial common scab.

This project was aimed at conducting a series of field and pot trials in Tasmania and Victoria to determine the effects of infected seeds with superficial and low scab coverage, and to establish achievable and meaningful common scab threshold levels on seed lines that reflect field performance and market acceptability.

1. Common scab incidence and coverage on seed lines

Abstract

This study examined the common scab incidence and coverage of the seed samples taken from each seed line, in order to investigate the relationship between them and the resulting scab levels on their daughter tubers in subsequent trials (Section 2). Differences between the certified common scab levels and the precise common scab levels in the seed lines were demonstrated. The differences indicate that seed samples taken from a seed line are subject to sampling variations. The implications of sampling and sampling size are discussed.

Aims

Seeds for field trials were obtained from Tasmanian commercial seed lines that had been assessed for common scab, as well as other tuber diseases, according to the Tasmanian certification scheme. This study examined the common scab incidence and coverage of the seed samples taken from each seed line, in order to investigate the relationship between them and the resulting scab levels on their daughter tubers in subsequent trials (Section 2).

Materials & Methods

Tubers in seed lines T1-T5 were from Tasmanian commercial seed lines with different common scab levels, as determined by the Tasmanian seed certification process. Tubers from T6 and T7 were from a batch of infected ware potatoes, in order to include seeds with higher common scab incidence and coverage.

In the seed certification process, sub-samples of 50 tuber seeds per seed line were visually assessed for scab and other tuber diseases (certification incidence). In this study, all tubers in each of the seed lines used in the trial studies were assessed for their precise scab levels as well as for scab coverage (precise incidence and precise coverage). All scab-infected tubers used in this study were infected with common scab.

Table 1.1: Levels of common scab incidence and coverage on tuber seed lines according to sub samplings in seed certification and assessment of all seeds for precise levels

	Scab incidence (% Tubers with common scab lesions)		High scab coverage (% Tubers with more than 5 common scab lesions)
Seed line code[1]	**Certification incidence[2]**	**Precise incidence[3]**	**Precise coverage[3]**
T1	0	5	0
T2	2	11	4
T3	4	8	3
T4	8	1	0
T5	13	20	7
T6	-	30	2
T7	-	73	39

[1] Seed lines T1-T5 were from certified seed lines. Seed lines T6-T7 were from the same lot of ware potatoes that were sorted into high and low common scab lesion incidence and coverage.

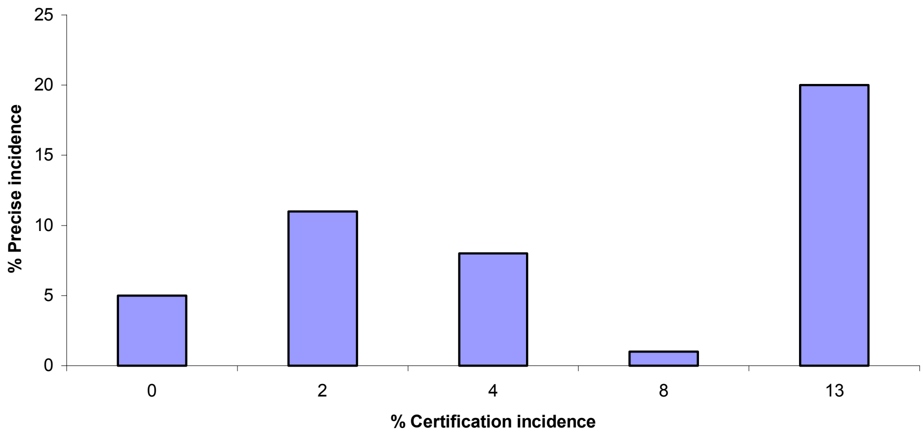
[2] Scab incidence based on sub-samples of 50 tubers taken from whole seed crop for seed certification assessment.

[3] Scab incidence based on whole sample assessment of approximately 160 seeds obtained for trial studies.

Results & Discussion

Currently, common scab thresholds for seed lines are set at 2% and 4% tubers with common scab lesions in Victoria and Tasmania, respectively. In Tasmania, seed lines with 4% or less common scab incidence are certified seed lines, whereas those with more than 4% incidence are not certified but may be sold in lower values as approved seed lines or if there is an inadequate supply of certified seed lines.

Figure 1.1: Differences in common scab incidence on seed lines as determined with seed certification and assessment of all seeds used in trial studies



With T1-T5 commercial seed lines, this study showed substantial differences in the certification incidence of common scab in comparison to the precise common scab incidence (Table 1.1, Figure 1.1). The seed lines T1-T3, which had a certification common scab incidence ranging from 0% to 4% had 5% to 11% precise common scab incidence. Seed line T4, which had 8% certification scab incidence had 1% precise common scab incidence. This indicates that a relatively low common scab threshold set at 4% made little allowance for sampling variations between samples of the same seed line and, therefore, seed lines may be wrongfully rejected or wrongfully accepted. It is not surprising that there are variabilities in the disease levels with different sub-samples of seeds, as scab incidence in a seed crop also tends to be variable within a paddock. Currently, in Tasmania, a minimum of 100 tubers per 12 tonnes seed or 200 tubers per 25 tonnes seed are visually inspected for common scab and other tuber diseases. Based on the low threshold limits set at a maximum of 4% for the Australian national standard, there is a relatively high risk of wrongfully rejecting seed lines that are below the threshold limit because, by chance, the sample obtained from the truck load of seeds in the inspection process has a percentage that is above the acceptable limit. In light of these findings, researchers in this project sought the advice of a biometrician (Professor Glen McPherson) on the implications of sampling differences to the potato industry and to discuss sampling options that would be fair to both seed suppliers and seed buyers. An overview on the background and questions in regard to the potato inspection sampling are outlined in "A. Examining the suitability of sampling inspection plans" (see next page).

Examining the suitability of sampling inspection plans

Background

The sampling inspection scheme currently in operation involves taking a sample of potatoes from a seed crop and determining the percentage of infected potatoes in the sample. The seed crop is accepted if the sample percentage infected is less than a prescribed value.

Questions

Under current regulations, the seed crop is accepted if the percentage of infected potatoes in a sample of 50 potatoes does not exceed 4%.

1. *"Is the 4% maximum level in the sampling plan reasonable?"*
2. *"Can an inspection plan be constructed that is fair to both suppliers and consumers, and if so, what are the conditions of that sampling plan?"*

Required information

Statistical analysis can provide the basis on which these questions can be answered, and can identify the practical considerations involved in answering the questions. However, input from suppliers and regulators on matters concerning risk and cost is necessary if an optimal sampling scheme is to be obtained. Below is an outline of the type of information required to answer the above questions: Further discussion is needed to determine the best way to proceed in specific situations.

1. *Risk of wrong acceptance (consumer's risk):* A seed crop might be accepted by the inspection plan when the infection rate in the seed crop is above an **acceptable upper limit for the consumer** (e.g. 5% infected) because, by chance, the sample obtained from the truck in the inspection process has a percentage of infected potatoes that is not above the acceptable limit.

2. *Risk of wrong rejection (supplier's risk):* A seed crop might be rejected by the inspection plan when the infection rate in the seed crop is below an **acceptable lower limit for the supplier** (e.g. 2% infected) but, by chance, the sample obtained from the truck in the inspection process has a percentage of infected potatoes that is above the acceptable limit.

If values are provided for the bolded terms above, then an inspection plan can be constructed that ensures that these requirements are met (at least approximately). The inspection plan defines the sample size and the acceptable upper limit of the number of infected potatoes in the sample for acceptance of the sample. Once you have a sampling plan in place there is presumably interest in exploring the costs associated with the sampling plan. These comprise:

3. *Cost of wrong acceptance:* If a seed crop is accepted there is a **cost to the consumer** that increases as the percent infected in the seed crop increases.
4. *Cost of wrong rejection:* If a seed crop is rejected there is a **cost to the supplier**. What that cost is depends on what is done with the rejected seed crop.
5. *Cost of inspection:* The **cost of inspection** is presumably the sum of a fixed base cost plus an additional expense for each additional potato tested. Since the cost of inspection applies whether a seed crop is accepted or not, an increase in the number of potatoes tested increases the cost for every seed crop tested but decreases the cost through a lowering of the proportion of seed crops that are wrongly accepted or wrongly rejected.

The total cost is determined from all of the bolded elements listed above plus the actual percent defective in a seed crop.

Maximum limits and probabilities of wrongful rejections

Because of the number of parameters involved and the different interests of suppliers and consumers in judging the suitability of the inspection plan, the best approach is to consider the risks or chances of wrongful rejections based on a sample size of 100 tubers and the maximum limits. Table 1.2 lists the probability values that the infection level of a seed line will exceed the limit by chance. The lower the probabilities, the lower the risk of exceeding the limits. The risks increase when a seed line's scab level is close to the maximum limit, e.g. seed lines with 2% scab have probabilities of being rejected at 0.323 with the 2% maximum limit, 0.051 with the 4% maximum limit and 0 with the 10% maximum limit. An increase of the sample size to 200 tubers changes the probabilities to 0.371 at the 2% maximum limit, 0.020 at the 4% maximum limit and 0 at the 10% maximum limit. Therefore, there is little or no real advantage to be gained by increasing the sample size. A change in the maximum limit has a much greater impact in reducing the probabilities and risks of making wrong decisions.

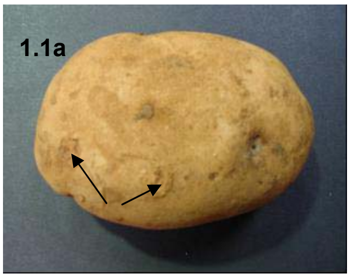
Table 1.2: Probabilities of detection with a sample size of 100 or 200 tubers

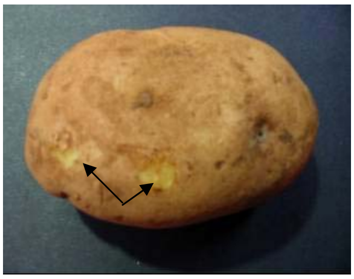
		In a sampling inspection of 100 tubers		In a sampling inspection of 200 tubers	
Maximum limit	**% Infected tubers in a seed line**	**Maximum number of infected tubers allowed**	**Probabilities infection in sample will exceed limit**	**Maximum number of infected tubers allowed**	**Probabilities infection in sample will exceed limit**
2%	0	2	0	4	0
	1		0.079		0.052
	2		0.323		0.371
	3		0.580		0.719
	4		0.768		0.905
	5		0.882		0.974
	6		0.942		0.994
	7		0.974		0.999
	8		0.989		1.000
	9		0.995		1.000
	10		0.998		1.000
4%	0	4	0	8	0
	1		0.003		0
	2		0.051		0.020
	3		0.182		0.150
	4		0.371		0.407
	5		0.564		0.673
	6		0.723		0.853
	7		0.837		0.944
	8		0.910		0.982
	9		0.953		0.995
	10		0.976		0.999
10%	0	10	0	20	0
	1		0		0
	2		0		0
	3		0		0
	4		0.002		0
	5		0.011		0.001
	6		0.038		0.009
	7		0.091		0.042
	8		0.176		0.122
	9		0.288		0.262
	10		0.412		0.441

Common scab incidence vs severity

An assessment for the high scab coverage incidences showed that most of the common scab infected tubers has less than five lesions. Some small common scab lesions were not obvious on unwashed tubers until most soil particles had been brushed off as shown in Photograph 1.1a. Most of the common scab infected seeds had only 1-3 small lesions, and most of these lesions were superficial (Photographs 1.1a & 1.1b). Seed lines T2, T3 and T5 had 4%, 3% and 7% tubers with more than 5 lesions (high scab coverage), respectively (Table 1.1). Seed line T5 had a relatively high incidence, as well as a greater percentage of infected seeds with greater than 5 lesions. Infected seeds with more than 5 lesions were much easier to detect and accurately assess compared to those with less than 5 lesions on unwashed tubers.

A typical common scab infected seed tuber with less than 5 lesions (Photograph 1.1a) and shallow lesions (Photograph 1.1b)

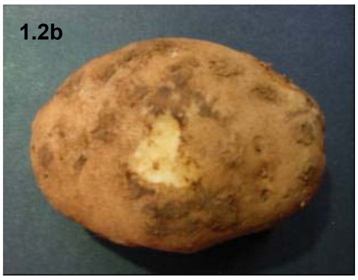




1.1b

Seed lines T6-T7 came from the same lot of ware potatoes produced for processing, in order to include seeds with high common scab incidence and coverage for trial studies. The tubers were re-sorted so that T6 had 30% scab incidence and 2% high scab coverage, while T7 had 73% incidence and 39% high scab coverage. The common scab lesions on these tubers were shallow lesions that were only skin deep (Photographs 1.2a & 1.2b).

A common scab infected seed tuber from T7 with very high scab coverage (Photograph 1.2a) and shallow lesions (Photograph 1.2b)



2. Common scab on seeds, and effects of seed and soil treatments

Abstract

Four field trials were conducted in 2002/03 to examine the relationship between common scab incidence and coverage of seed lines and the resulting scab levels on their daughter tubers. This study showed that common scab infected seed was an important source of transmission onto daughter tubers only in new ground that was free of soil borne inoculum. In old ground, where potatoes had been planted in crop rotations, most common scab was caused by soil borne inoculum, and seed borne inoculum had little or no significant impact.

In new ground, a strong correlation was found between the seed lines' common scab incidences and scab coverage, and the common scab and deep scab incidence on their daughter tubers. This relationship, however, is dependent on the exact or precise common scab incidence of the seed lines. With the less precise common scab incidence of the seed lines that were determined by small sub-samples of a whole seed crop for the seed certification process, there was only a weak correlation.

Substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines, indicating that this may be the critical threshold incidence for common scab on seed lines. In the relationship between seed lines' scab coverage and their daughter tubers' common scab incidence, substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or more tubers had greater than 5 lesions, or with greater than 2% surface cover. This suggests that 4% tubers with more than 2% surface cover could be a useful benchmark.

This study also showed that mancozeb seed treatments negate the importance of infected seeds as a source of transmission. This indicates that seed treatment could be used successfully to prevent common scab transmission from infected seed lines.

Aims

This study was conducted to determine the relationship between common scab levels in seed lines and the resulting common scab levels on daughter tubers, to establish the critical threshold levels for common scab incidence or coverage for seed lines when scab transmission becomes important. The trials also aimed to determine whether mancozeb seed treatment could help break the cycle of carryover of the common scab organism from seeds tuber to daughter tubers.

Summary of trials

Table 2.1: Field trials conducted in Tasmania

	TRIAL 2.1	TRIAL 2.2
Location	Forth, Tasmania	Moriarty, Tasmania
Variety	Russet Burbank	Russet Burbank
Surrounding Crop	Russet Burbank (French fry processing)	Russet Burbank (French fry processing)
Soil Type	Ferrosol	Ferrosol
Trial Design	Randomised complete block	Randomised complete block
Replicates	6	6
Total No. Treatments	18	18
Plot Size	1.6 m x 2.4 m	1.6 m x 2.4 m
Row Spacing	800 mm	800 mm
Plant Spacing	300 mm	300 mm
Planting Density	10 setts/plot	10 setts/plot
Total No. Plots	216	216
Seed Treatment Date	21/10/02	21/10/02
Planting Date	29/10/02	22/10/02
Harvest Date	07/05/03	30/04/03

Table 2.2: Field trials conducted in Victoria

	TRIAL 2.3	TRIAL 2.4
Location	Ballarat, Victoria	Warragul, Victoria
Variety	Russet Burbank	Russet Burbank
Surrounding Crop	French fry processing	Fresh chipping
Soil Type	Reddish brown clay loam over clay	Reddish brown clay loam over clay
Trial Design	Randomised complete block	Randomised complete block
Replicates	6	6
Total No. Treatments	16	12
Plot Size	1.85 m X 1.72 m	1.85 m X 1.67 m
Row Spacing	860 mm	810 mm and 860 mm
Plant Spacing	370 mm	370 mm
Sowing Date	21/11/02	04/12/02
Harvest Date	20/05/03	14/05/03

Materials & Methods

Two trials were conducted in Tasmania and two in Victoria. Summaries of all the trials are presented in Tables 2.1-2.2. The seed lines and treatments for the trials are listed in Tables 2.3-2.4. The seeds used came from the same seed lines that were previously examined for common scab incidence and severity (Section 1). Cut seed pieces were used in all trial studies.

In Tasmania, seed and soil treatments were applied as described in Table 2.3, onto freshly cut seeds. For fir bark + 6% mancozeb, Tato dust® was mixed with Nubark® (Douglas fir bark), and then coated onto seed pieces. Fir bark (Nubark only) was applied in the same manner, and was used as the control on the same seed lines.

Photograph 2.1

In Victoria, seed was cut by hand and placed in open weave onion bags to be cured in a humid store for one week prior to planting. After curing, the seed was removed from storage, and the additional treatments of dusting and/or washing were made, as described in Table 2.4. The dusting treatment was four grams of 6% mancozeb in Nubark® applied onto seed pieces in a paper bag, which was then shaken vigorously. This gave a full coating of the seed dust to the seed pieces. Two of the seed lines were chosen for washing treatments and this involved hosing the seed pieces in a plastic container with clean water and then allowing the seed to soak for 5 minutes. Seed-pieces were then dried and two treatments were also dusted with fir bark and mancozeb.

The trial design was a randomised complete block, with 6 replicates in the field trials and 10 replicates in the pot trial. In field trials, seed-pieces were planted in small plots of 10 plants/plot (Photograph 2.1) in order to keep the trial areas relatively small and minimize variability in soil properties and conditions. Desiree seed pieces were sown at the ends of each treatment to mark the plot area and provide normal competition for the end plants. There was a 1 m wide walkway between each replicate. All the field trials were set up within commercial crops and were grown in the same manner as the commercial crop.

At harvest, all tubers were harvested, washed and assessed for incidence of tubers with common scab, powdery scab and deep scab lesions. The incidence of common scab or powdery scab was recorded as presence or absence of scab lesions on tubers and expressed as a percentage of total tubers assessed. In the assessment for deep scab, scab lesions that were obviously deep or that could only be removed with 2 or more scrapes of a vegetable peeler were rated as deep scab. Although the weights of scab infected and non-infected tubers were also measured, their mean values followed a similar pattern to those based on tuber numbers, although subject to greater variabilities between plots. Therefore, the data values based on tuber weights were not presented or analysed.

In Victorian trials, scab infected tubers were also rated for scab coverage according to the number of tubers with approximately 1%, 2%, 5%, 10%, 15%, 20% and 40% surface covered by scab lesions. A description of the percent coverage of surface tubers is included in Appendix i. An index for scab cover of the infected tubers was then calculated using the formula:

$$\textbf{Scab cover index} = \frac{[\ (\text{Numbers with 1\% cover x 1}) + \ \ldots\ldots + (\text{Numbers with 40\% cover x 40})\ ]}{[\ \text{Total numbers of scab tubers}\ ]}$$

Results from each trial were collated and analysis of variance was conducted on data values using StatGraphics Plus 2.0, and comparisons were made of mean values using Least Significant Difference (LSD) Test.

Table 2.3: Treatment lists for Trials 2.1 & 2.2

Seed line *	Scab incidence on seed line	Treatment	Application method
T1 T2 T3 T4 T5 T6 T7	0 2 4 8 13 22 28	Fir bark only (seed treatment)	Freshly cut seed-pieces coated with Douglas fir bark (Nubark) at 4 kg/tonne seed.
T1 T2 T3 T4 T5 T6	0 2 4 8 13 22	Fir bark + 6% mancozeb (seed treatment)	Freshly cut seed-pieces coated with with fir bark + 6% mancozeb (Nubark + Tato Dust mixture) at 4 kg/tonne seed.
T4 T6	8 22	In-furrow mancozeb (soil & seed treatment)	Mancozeb spray applied onto seed-piece and soil at planting with a single full cone nozzle sprayer. Dithane DF 750 applied at 21.5 kg product /ha or 16.1 kg mancozeb active/ha.
T4 T6 T7	8 22 28	1% formaldehyde (seed treatment)	Freshly cut seed-pieces dipped into formalin suspension for 5 minutes, and air dried. The formalin, containing 40% formaldehyde, was applied at a rate of 25 mL/L water. Severe phytotoxic reaction occurred on the cut surfaces.

Table 2.4: Treatment lists for Trial 2.3 & Trial 2.4

Seed line	Scab incidence on seed line	Seed treatment	Trial 2.3 (Ballarat)	Trial 2.4 (Warragul)
T1 T2 T3 T4 T5* T6	0 2 4 8 13 62	Fir bark	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ na ✓
T1 T2 T3 T4 T5* T6	0 2 4 8 13 62	Fir bark + 6% mancozeb	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ na ✓
T5* T6	13 62	Washed only	✓ ✓	na ✓
T5* T6	13 62	Washed and dusted with fir bark + 6% mancozeb	✓ ✓	na ✓

* Note: T5 seed line only used in Trial 2.3

Results

Effects of common scab levels and mancozeb seed treatment on seed lines

Table 2.5: The effects of seed lines and seed treatments in Trial 2.1

	Seed lines				Daughter tubers		
Seed line[1]	**Certification incidence (%)[2]**	**Precise incidence (%)[3]**	**Precise coverage (%)[3]**	**Seed treatment**	**% Common scab**	**% Deep scab**	**% Powdery scab**
T1	0	5	0	Fir bark only (Fir bark)	16	5	7
T2	2	11	4		48	22	6
T3	4	8	3		18	8	10
T4	8	1	0		13	5	15
T5	13	20	7		70	39	4
T6	30	30	2		28	10	6
T7	73	73	39		39	16	11
T1	0	5	0	Fir bark + 6% mancozeb (Fir bark + Mz)	12	7	8
T2	2	11	4		24	7	4
T3	4	8	3		11	3	11
T4	8	1	0		6	1	5
T5	13	20	7		15	9	6
T7	73	73	39		12	3	11
Analysis on main effects and P-values							
Seed line					< 0.0001	< 0.0001	0.667
Seed treatment					< 0.0001	< 0.0001	0.414

[1] Seed lines T1-T5 were from commercial seed lines. Seed lines T6-T7 were from the same lot of ware potatoes that had been sorted into high and low common scab lesion incidence and coverage.

[2] Scab incidence based on seed certification assessment.

[3] Scab incidence based on assessment of all seeds obtained for trial studies.

Figure 2.1: Effects of seed lines on common scab and deep scab incidence on daughter tubers in Trial 2.1 (Means and LSD Intervals at 95% Confidence Level)

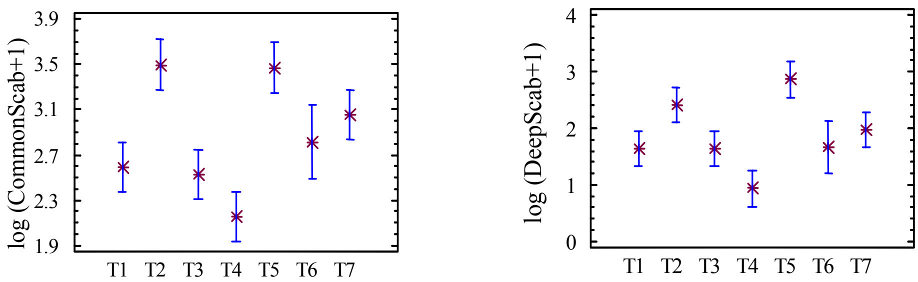
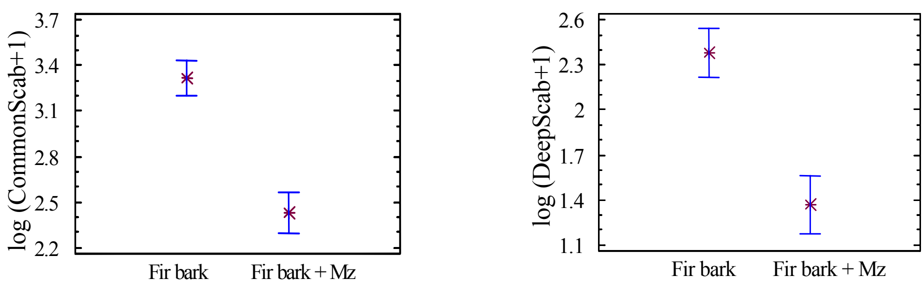


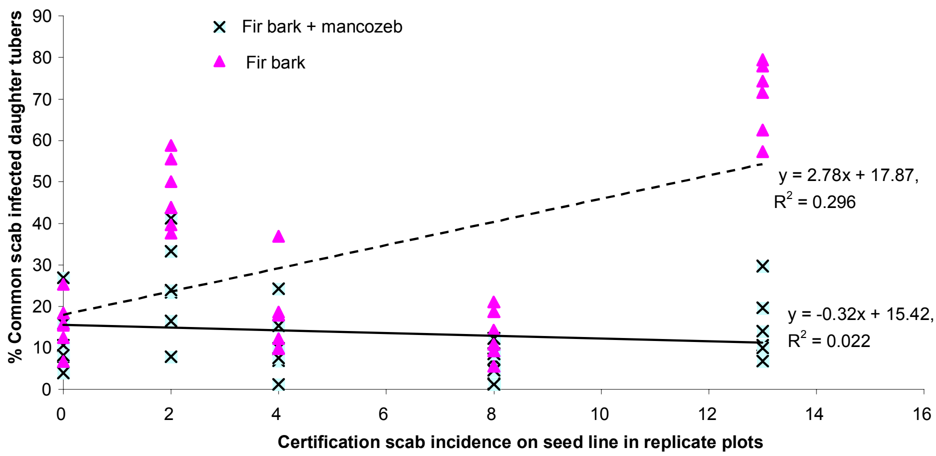
Figure 2.2: Effects of seed treatments on common scab and deep scab incidence on daughter tubers in Trial 2.1 (Means and LSD Intervals at 95% Confidence Level)



Trial 2.1 at Don, Tasmania was conducted in a paddock that had been under long-term pasture, and had not been sown with potatoes for at least 10 years. Common scab was the main tuber borne disease in Trial 2.1, and most of the common scab lesions were deep scab lesions (Table 2.5). In Tasmania, common scab infected tubers generally have less than 1% to 2% surface covered by lesions. An analysis of T1-T7 seed lines showed highly significant differences in common scab incidence and deep scab incidence between the seed lines ($P < 0.0001$), and highly significant differences for both parameters between seed treatments ($P < 0.0001$). There were no significant differences in the powdery scab incidence ($P = 0.667$) between the seed lines or seed treatments (Table 2.5). Seeds from the T2 and T5 seed lines produced significantly higher common and deep scab incidence in comparison to the other seed lines. The seed lines' trends in the levels of common scab and deep scab incidence were closely related. Seed line T6 and T7, which came from a ware potato crop, appeared to behave quite differently from the commercial seed lines T1-T5. Therefore, T6 and T7 were omitted in subsequent analysis for correlations between the common scab levels in the seed lines and their daughter tubers.

A plot of all data from replicated plots in Trial 1 showed only a weak relationship between the fir bark treated seed lines' certification common scab incidence and the common scab incidence on daughter tubers (R^2 = 29.6%) (Figure 2.3). In contrast, there was a strong relationship between the seed lines' precise common scab incidence and the common scab incidence on daughter tubers (R^2 = 80.5%) (Figure 2.4). This indicates that the accuracy of the assessment of the common scab level on the seed line is critical in determining whether or not a seed line has a greater or lesser risk of passing the common scab onto the next generation of tubers. The assessment has to be precise, in order to relate to the levels of scab transmission onto daughter tubers. It is, however, not practical to examine every seed tuber for a precise scab level on a seed line.

Figure 2.3: The relationships between the certification common scab incidence on seed lines and the common scab incidence on daughter tubers in Trial 2.1



In determining critical common scab threshold levels on seed lines, substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines (Figure 2.4). This indicates that the critical common scab threshold level may be at approximately 10%. At less than 10% infected seeds, common scab transmission from the infected seed line appeared to be insignificant, and could not be distinguished from low levels of soil borne inoculum. A relatively consistent incidence of approximately 10% common scab on daughter tubers produced by the same seed lines treated with mancozeb indicates that there could be a background common scab, which could be due to soil borne infection.

Figure 2.4: The relationships between precise common scab incidence on seed lines and common scab incidence on daughter tubers in Trial 2.1

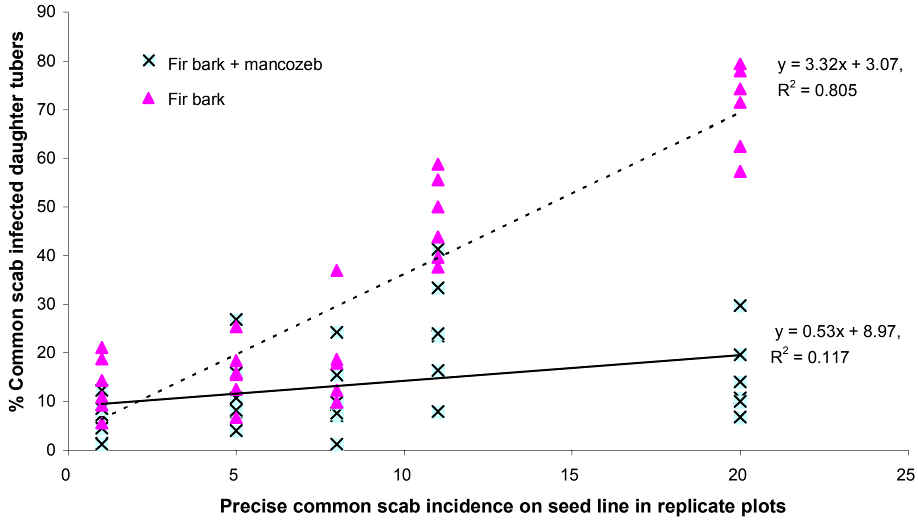
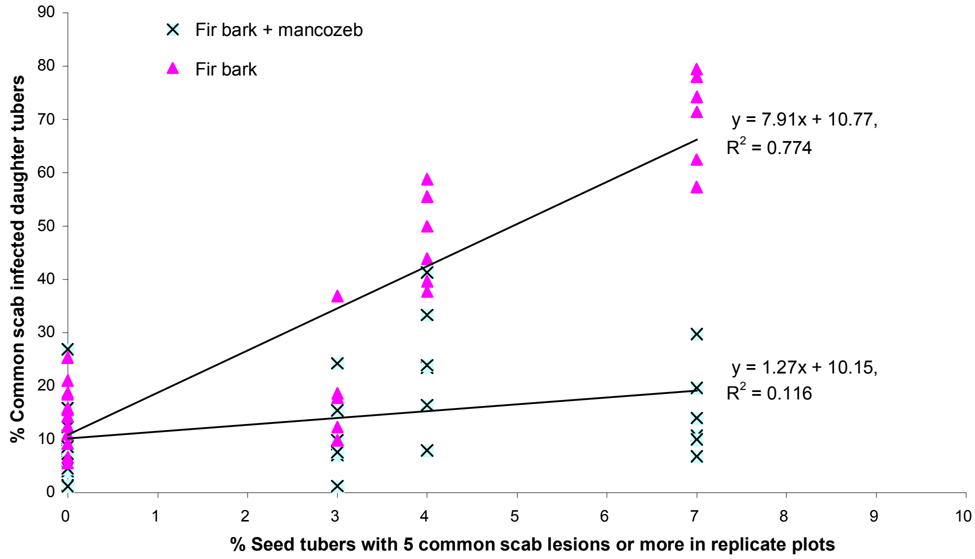


Figure 2.5: The relationship between precise common scab coverage on seed lines and common scab incidence on daughter tubers in Trial 2.1



Based on the data from Trial 2.1, a meaningful threshold level for common scab on seed lines could be 10% rather than the 2% or 4% that are currently set for seed certification in Victoria and Tasmania, respectively. The relatively low common scab threshold set at 2% and 4% also made no allowance for variability between samples within a seed line and therefore, increases the probability of wrongfully rejecting or wrongfully accepting a seed line. In this study, a re-examination of the seed lines showed that T1, T2 and T3, which had 4% or less common scab in the seed certification assessment, and 5%, 11% and 8% common scab in the more precise assessment, would have been wrongfully accepted as certified seeds. In contrast, T4, which had 8% common scab in the seed certification assessment and 1% common scab in the more precise assessment, would have been wrongfully rejected as certified seeds.

There was also a strong relationship between the precise high scab coverage on the fir bark treated seeds and the common scab incidence on daughter tubers (R^2 = 81.7%) (Figure 2.5). The seed lines with 0% or 3% tubers with high scab coverage, of more than 5 lesions, showed little or no difference in the incidence of common scab on their daughter tubers. The seed lines with 4% and 7% tubers with high scab coverage showed substantial increases in the incidence of common scab on their daughter tubers. This indicates that the critical high scab coverage on seed lines may be approximately 4%. At 4% high scab coverage, only one seed line (T2) would have been wrongfully accepted, and no seed lines were wrongfully rejected. This suggests that a common scab threshold based on high scab coverage may be more appropriate. With more than 5 lesions, infected tubers are also easier to detect and assess with greater accurately compared to those tubers with only 1 to 3 lesions.

Substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or higher percentage of tubers have more than 5 lesions indicating that 4% tubers with high scab cover may be the critical scab severity threshold. With more than 5 lesions, the scab coverage is approximately 2% or more of the surface cover. At less than 4% tubers with high scab cover, common scab transmission from the infected seed line appeared to be insignificant.

With fir bark + mancozeb treated seeds, there were no obvious relationships between all the seeds' common scab incidence or coverage and the common scab incidence on daughter tubers (R^2 < 12%) (Figures 2.3-2.5). This indicates that the mancozeb seed treatment blocks the transmission of common scab from infected seeds onto daughter tubers. This finding demonstrates that mancozeb seed treatment is effective for the control of seed borne common scab. Seed lines that have shallow common scab lesions but exceed the limits set for common scab incidence or high scab coverage could still be used as seeds provided that they are first treated with mancozeb. This is important, as there are seasons, when weather conditions are highly favourable to common scab, that there could be a shortage of certified seed lines if many of the seed crops exceed the threshold limit.

Table 2.6: Seed lines and seed treatments effects on scab levels on daughter tubers in Trial 2.2

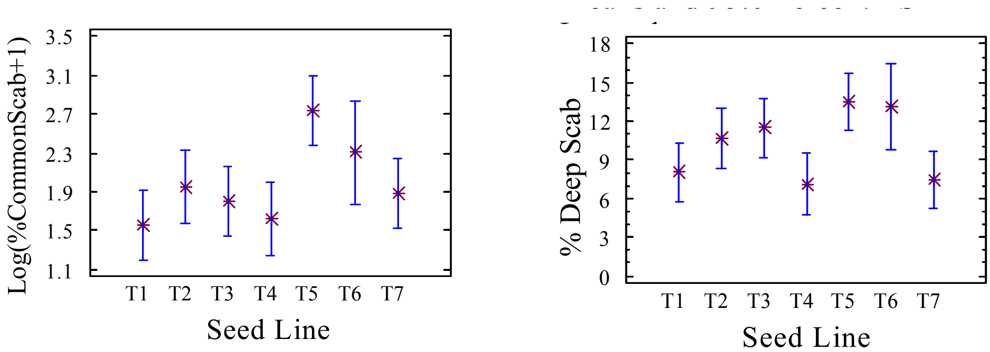
Seed line[1]	Certification incidence (%)[2]	Precise incidence (%)[3]	Precise coverage (%)[3]	Seed Treatment	% Common scab	% Deep scab	% Powdery scab
T1	0	5	0		6	11	58
T2	2	11	4		14	14	47
T3	4	8	3		9	13	51
T4	8	1	0	Fir bark only (Fir bark)	6	6	57
T5	13	20	7		20	17	45
T6	na	30	2		12	15	56
T7	na	73	39		9	7	59
T1	0	5	0		7	5	59
T2	2	11	4		5	8	54
T3	4	8	3	Fir bark + 6% mancozeb (Fir bark + Mz)	9	10	49
T4	8	1	0		8	10	59
T5	13	20	7		16	10	49
T7	na	73	39		7	8	50
Analysis on main effects and P-values							
Seed lines					0.034	0.035	0.207
Seed treatment					0.760	0.019	0.698

[1] Seed lines T1-T5 were from commercial seed lines. Seed lines T6-T7 were from the same lot of ware potatoes that had been sorted into high and low common scab lesion incidence and coverage.

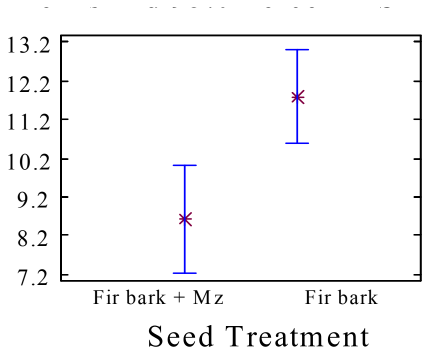
[2] Scab incidence based on seed certification assessment.

[3] Scab incidence based on assessment of all seeds obtained for trial studies.

Figure 2.6: Effects of seed lines and seed treatments on common scab and deep scab incidence on daughter tubers in Trial 2.1 (Means and LSD Intervals at 95% Confidence Level)



Trial 2.2 at Moriarty, Tasmania, was conducted in a paddock where potato crops were sown in a rotation of no more than 1 year in at least 4 years. Both common scab and powdery scab were present on daughter tubers in Trial 2.2. Most of the powdery scab lesions were superficial, while many of the common scab lesions were deep lesions. Powdery scab was the dominant scab disease, with incidence ranging from 47% to 59% (Table 2.6), and it was widespread in the paddock, both in the trial area and in the commercial crop outside the trial area.



In Trial 2.2, an analysis of T1-T7 seed lines for differences between the seed lines and their seed treatments showed significant differences in the common scab incidence and deep scab incidence between the seed lines (P = 0.034) (Figure 2.6), but no significant differences in the powdery scab incidence (p > 0.2) (Table 2.6). As in Trial 2.1, the highest common scab incidence in Trial 2.2 was recorded on daughter tubers produced from the T5 seed line (Figure 2.6). Tuber seeds from T5 came from a commercial seed line that had the highest scab incidence compared to the other commercial seed lines, at 13% and 20% common scab infected tubers in the seed certification assessment and precise assessment, respectively. Mancozeb seed treatment significantly reduced the incidence of deep scab on daughter tubers (Figure 2.6).

A plot of all data from replicate plots showed a very weak correlation between the common scab incidence on daughter tubers and precise common scab incidence on the seed lines on fir bark treated seeds (R^2 squared = 32.2%) and fir bark + mancozeb treated seeds (R^2 = 8.7%) (Figure 2.7).

Figure 2.7: The relationship between precise common scab incidence on seed lines and common scab incidence on daughter tubers in Trial 2.2

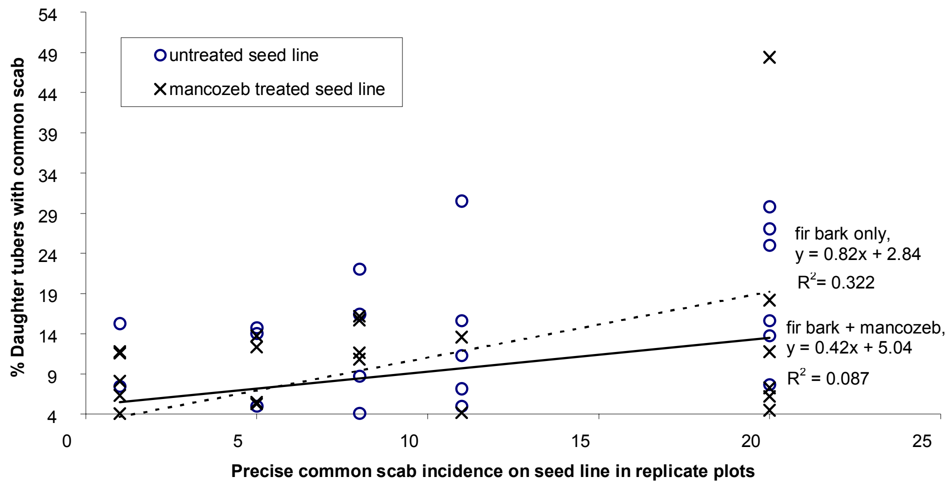


Table 2.7: Seed lines and seed treatment effects on scab levels on daughter tubers in Trial 2.3

Seed line[1]	Certification incidence (%)[2]	Treatment	% Common scab	Scab cover index
T1	0	Fir bark only	3.4	2.0
T2	2		5.4	2.1
T3	4		6.2	2.7
T4	8		6.4	1.9
T7	na		7.2	1.2
T1	0	Fir bark + 6% mancozeb seed treatment	2.3	4.5
T2	2		7.1	1.7
T3	4		3.5	2.0
T4	8		0.7	0.3
T7	na		1.5	3.0
Analysis on main effects and P-values				
Seed lines			0.536	0.690
Scab treatment			0.045	0.730

Trials 2.3 and 2.4 were conducted in Ballarat and Warragul, Victoria. In Trial 2.3, the incidence of common scab was relatively low, ranging from 3% to 7% (Table 2.7). Mancozeb seed treatment significantly reduced common scab incidence on daughter tubers (Table 2.7, Figure 2.8). Most of the infected tubers had low scab coverage of 1-5%, and there was no significant difference between the scab cover index on the infected daughter tubers with the scab level on the seed lines.

In Trial 2.4, the incidence of common scab was relatively high, ranging from 22% to 39% (Table 2.8). There were no significant differences in the common scab incidence or scab cover index between seed lines or seed treatments. It is possible that the common scab in this trial was mainly caused by soil borne inoculum, which appears to have masked any seed line or seed treatment effects.

Figure 2.8: Seed treatment effects in Trial 2.3

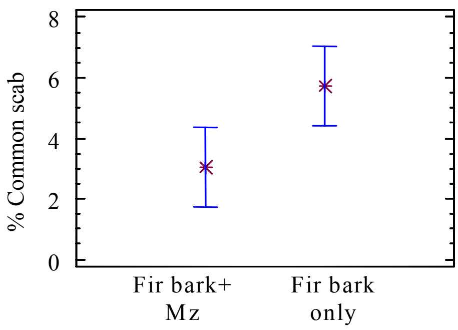


Table 2.8: Seed lines and seed treatment effects on scab levels on daughter tubers in Trial 2.4

Seed line[1]	**Certification incidence (%)**[2]	**Treatment**	**% Common scab**	**Scab cover index**
T1	0	Fir bark only	24	1.8
T2	2		23	1.7
T3	4		34	1.7
T4	8		28	1.4
T5			39	1.6
T7	na		25	1.4
T1	0	Fir bark + 6% mancozeb seed treatment	27	1.3
T2	2		27	1.4
T3	4		26	1.2
T4	8		22	1.2
T5			24	1.4
T7	na		27	1.5
Analysis on main effects and P-values				
Seed lines			0.370	0.678
Scab treatment			0.229	0.010

Efficacy of seed and soil treatments for seed borne scab control

The effects of chemical seed and soil treatments, as well as washing of seeds, were also examined in Trials 2.1 to 2.4. Analysis of variance and comparisons were conducted separately on these treatments with the same seed lines in each trial.

Figure 2.9: Treatment effects on the incidence of common scab and deep scab in Trial 2.1
(Different letter on each colour bar denotes significant difference in comparison to the fir bark control according to LSD test)

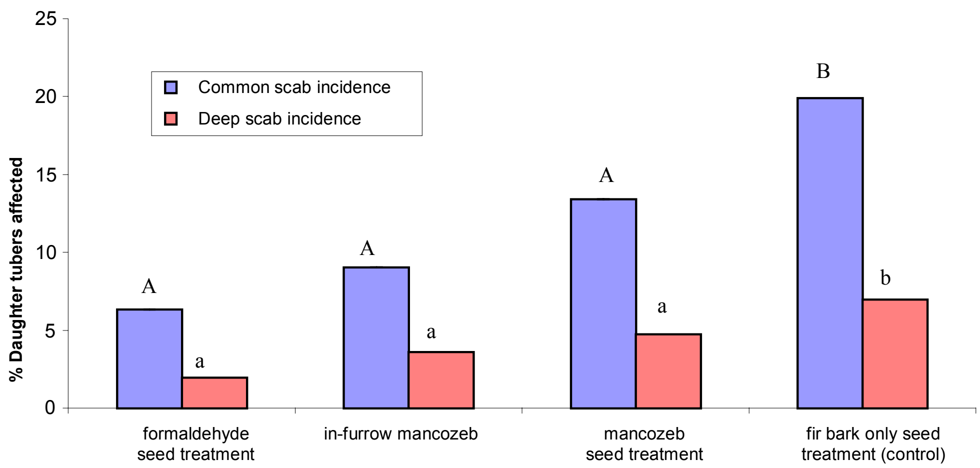
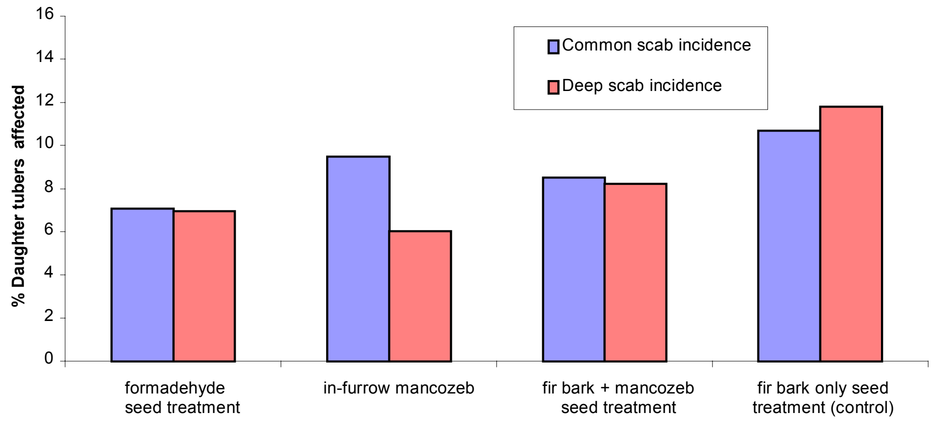


Figure 2.10: Treatment effects on the incidence of common scab and deep scab in Trial 2.2



In Trial 2.1, the seed lines T4, T6 and T7 were treated with mancozeb in a dust application, formaldehyde as a dip application, and an in-furrow spray application of mancozeb. All of these treatments significantly reduced the common scab and deep scab incidences on daughter tubers (Figure 2.9). Common scab incidence was reduced by 35%, 55% and 70% in comparison to the fir bark control by the mancozeb seed treatment, in-furrow mancozeb and formaldehyde seed treatment, respectively. Deep scab incidence was reduced by 28%, 43% and 71% in comparison to the fir bark control by the mancozeb seed treatment, in-furrow mancozeb and formaldehyde seed treatment, respectively (Figure 2.9). There were no significant differences between the chemical treatments. This indicates that within the sensitivity of this trial, the formaldehyde seed treatment, the mancozeb seed treatment and the in-furrow mancozeb application at planting gave similar levels of common scab control on daughter tubers from the infected seed lines. Formaldehyde applied onto the freshly cut seed pieces caused severe phytotoxic effect on the cut surfaces and delayed sprouting and plant emergence. However, no such phytotoxic effects were noted on whole seeds treated with formaldehyde.

In Trial 2.2, analysis on the on the same seed lines T4, T6 and T7, showed no significant differences in common scab incidence (P = 0.104) or deep scab incidence (P = 0.164) between treatments (Figure 2.10). Although not significant, there is a trend of lower common scab and deep scab incidences with the chemical treatments compared to fir bark control. There were no obvious differences in the daughter tubers' powdery scab levels between the chemical treatments and the fir bark control seeds in Trials 2.1 and 2.2.

Figure 2.11: Treatment effects on the incidence of common scab and deep scab in Trial 2.3

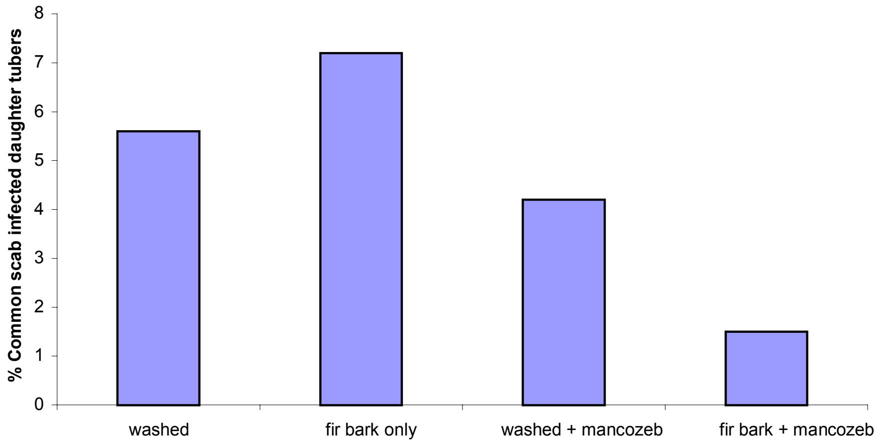
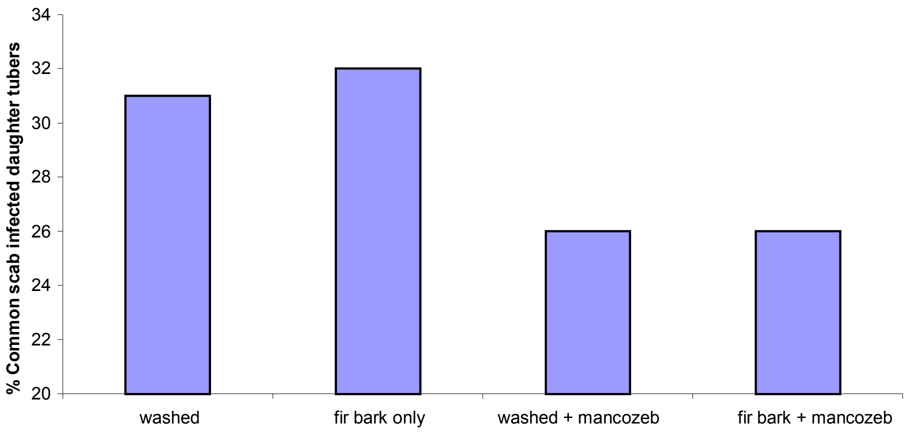


Figure 2.12: Treatment effects on the incidence of common scab and deep scab in Trial 2.4



In Trials 2.3 and 2.4, there were no significant differences in common scab incidence on daughter tubers between treatments (P = 0.093 in Trial 2.4 and P = 0.332 in Trial 2.3) (Figures 2.11-2.12). Washing of seeds had little or no impact in reducing common scab on daughter tubers. Although not significant, there was a trend of lower common scab incidence on tubers produced from seeds treated with mancozeb.

Discussions

Common scab incidence and certification standard

Trial studies showed that common scab infected seeds are an important source of transmission onto daughter tubers only in new ground. These findings are consistent with those from other studies that pathogenic *Streptomyces* from infected seeds can establish in soil and cause scab, and that their populations decline with distance from the infected seeds (Bahme & Schroth 1987, Ryan & Kinkel 1997, Wang 2005). There was a strong correlation in some of the trials between the seed lines' common scab incidence and scab coverage, and the common scab and deep scab incidence on their daughter tubers. This relationship, however, is dependent on the exact or precise common scab incidence of the seed lines. With the less precise common scab incidence of the seed lines that were determined by small sub-samples of a whole seed crop for the seed certification process, there was only a weak correlation.

The certification standards for common scab on certified seed vary considerably between certification schemes. A summary of the published standards for a collection of schemes in Australia is shown in Table 2.9. Within Australia, the national standard is a maximum of 4% of tubers, based on the number of seeds with any visible presence of common scab. The various state based seed schemes have each adopted their own standard within this maximum, so that for Victoria and South Australia the maximum tolerance is 2%, while in NSW the maximum number of tubers with common scab is just 1%. Tasmania has adopted the national standard of 4%.

Table 2.9: Australia certification standards for common scab

State	Certification Authority	Maximum Number of Tubers Affected by Common Scab
New South Wales	New South Wales Seed Potato Advisory Committee	1%
South Australia	Primary Industries of South Australia (PIRSA)	4%
Tasmania	Tasmanian Department of Primary Industries (DPIWE)	4%
Victoria	Victorian Certified Seed Potato Authority (ViCSPA)	2%
Western Australia	Western Potatoes	2%
National Standards	Seed Potato Advisory Group (SPAG)	4%

In this study, substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines, indicating that this may be the critical threshold incidence for common scab on seed lines (Figure 2.13). At less than 10% infected seeds (i.e. 0%, 2%, 4% and 8% infected seed lines), common scab transmission from the infected seed line were insignificant and could not be distinguished from low levels of soil borne inoculum in the new ground. There were no obvious differences in the levels of common scab on daughter tubers between the seed lines with 0%, 2%, 4% and 8% infected seeds. If there were no obvious differences between these seed lines with relatively low common scab incidence, is the current national standard of 4% meaningful and relevant? Furthermore, these relatively low levels are also subject to sampling variations, as discussed in Section 1. The risk of wrongfully rejecting or accepting a seed line is also high when the maximum tolerance level is low.

Table 2.10: Certification standards for common scab in Australia in comparison to other countries

Country	Certification Agency	Deeming of *scabby* tubers	Maximum of tolerance of scabby tubers	Method of Assessment	Comments
Australia	SPAG (Seed Potato Advisory Group)	Any presence of common scab	4%	By number	See Table 2.9 for state differences
Canada	CFIA (Canadian Food Inspection Agency)	Light scab (<5% surface covered) Moderate scab (5% to 10% surface covered)	10% light scab 5% moderate scab	By number	
EU (Economic Commission for Europe)	Working Party on Agricultural Quality Standards	>$33^1/_3$ % of the tuber surface covered with common scab	5%	By weight	A stricter tolerance applies for pre basic seed - tubers deemed to be *scabby* if more than 10% of tuber surface is covered. This standard is a base, and member states often set more demanding standards.
Northern Ireland	DANI (Department of Agriculture, Northern Ireland)	>10% of the tuber surface affected by common scab	10%		No distinction between common scab and powdery scab - assessed together.
Netherlands	NAK (Nederlandse Algemene Keuringsdienst)	>12.5% of the tuber surface covered with common scab 25% cover for very superficial common scab (including netted scab)	5%	By weight	Stricter standards apply according to importing country requirements.
Great Britain	DEFRA (Dept. for Environment, Food and Rural Affairs)	>$33^1/_3$ % of the tuber surface covered with common scab	4%	By weight	These conditions were relaxed to 5% tolerance for the 2005 harvest, subject to buyer's agreement.
Scotland	SOAEFD (Scottish Office of Agriculture Environment and Fisheries Department)	>25% of the tuber surface covered	4%	By weight	More demanding tolerance for VISC and pre basic seed.
South Africa	Independent Certification Council	Any presence of common scab	10%		More demanding tolerance for Elite and Class 1 seed.
United States	State based agencies	Any presence of pitted scab >50% tuber surface covered with Russet scab	5% 5% of tuber surface		Difference states have their own standards based on and around this general US standard.

The use of common scab coverage in certification standard

In the relationship between seed lines' scab coverage and their daughter tubers' common scab incidence, substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or more tubers had greater than 5 lesions or with greater than 2% surface cover. This suggests that 4% tubers with more than 2% surface cover could be a useful benchmark. With more than 2% surface cover, infected tubers are easier to detect and assess with greater accurately compared to those tubers with less than 2% surface cover. In Canada, U.S.A and Europe, scab severity based on the percentages of tubers with high surface covered by common scab or deep scab are typically used as benchmark levels instead of the presence of any scab lesions.

Compared with other certification schemes around the world (Table 2.10), the Australian thresholds for maximum levels are set very low. It is common in most schemes to accept a certain level of common scab on tubers and to place greater importance on scab coverage. Thus, for example, in Northern Ireland, only those tubers with more than 10% surface cover of scab lesions are counted as being "*scabby"*. Tubers with less than 10% surface cover are not counted. In Scotland, the level of surface cover needs to extend to 25% before the tuber is regarded as scabby, and in the general EU standards, more than one third of the tuber surface needs to be covered for the tuber to be counted as *scabby*. The various United States certification schemes all differ but most deem that seeds with less than 5% of the tuber surface covered by scab lesions are not important, and hence not counted in scab assessment, but any presence of pitted scab on a tuber is regarded as being scabby. Of eight national certification schemes examined, other than Australia, only South Africa consider and count any presence of common scab lesions on a tuber as being *scabby* for the purpose of assessment.

As well as tolerance for significant levels of surface cover on seed tubers, many of the international schemes also have high tolerances for the number of scabby tubers within a seed lot. The Canadian certification scheme, for example, accepts up to 10% of light scab (less than 5% surface cover) and up to 5% moderate scab (5% to 10% surface cover) in a seed lot. The South African scheme accepts up to 10% of *scabby* tubers in a seed lot. Northern Ireland also accepts up to 10% *scabby* tubers.

These variations between schemes imply that certification standards for common scab have evolved in different parts of the world based on what is practical and achievable for seed producers, rather than what is meaningful. Thus, in parts of Europe where there is a long tradition of potato growing in rotation with other crops, it may be unrealistic to impose anything approaching the certification standards in use in Australia. In Australia, a lot of seed production occurs on land with little or sometimes no history of potato production, so a much higher certification standard is achievable. Thus, it is possible to impose a strict and demanding standard within Australia that might be totally impractical in Europe.

While these standards might be achievable in Australia, the presence of common scab is nevertheless critical in determining whether individual crops will pass the standards demanded for certification. Each year, a number of crops are bypassed for certification in Victoria and Tasmania due to unacceptably high levels of common scab, and the crop is redirected for processing rather than for seed use. In Tasmania, 4% is the maximum tolerance and in Victoria it is just 2%. Unlike other industry sectors where a lot of commercial crops are grown on extremely long rotation, the processing industry is located in particular production areas where there is a long history of potato growing. Therefore, the Australian potato seed advisory committee may need to consider the following questions:

- Are the standards of 2% and 4% presence of common scab infected tubers justifiable where there is a long history of potato production?
- Are the sources of inoculum on seed really relevant at this level of tolerance compared to likely sources of inoculum in soil where potatoes are grown on a 1 in 4 year rotation or less for at least the past 50 years?
- Is scab coverage a better criteria for setting tolerance levels?
- Are 2% to 4% maximum tolerance levels set too low when there is high variability between sub-samples within the same seed line?

Seed treatment for seed borne common scab control

This study showed that mancozeb seed treatments gave effective control of common scab when seed borne transmission is an important source of disease onto daughter tubers (Figure 2.14). The levels of common scab and deep scab reduction by these treatments, however, could be masked by infections due to soil borne inoculum, which they cannot control. The use of an effective seed treatment was shown to negate the importance of infected seeds as a source of transmission. This indicates that seed treatment could be used successfully to prevent common scab transmission from seeds from infected seed crops that have low scab incidence and coverage.

Figure 2.13: The relationships between common scab incidence on untreated seed lines and common scab incidence on daughter tubers

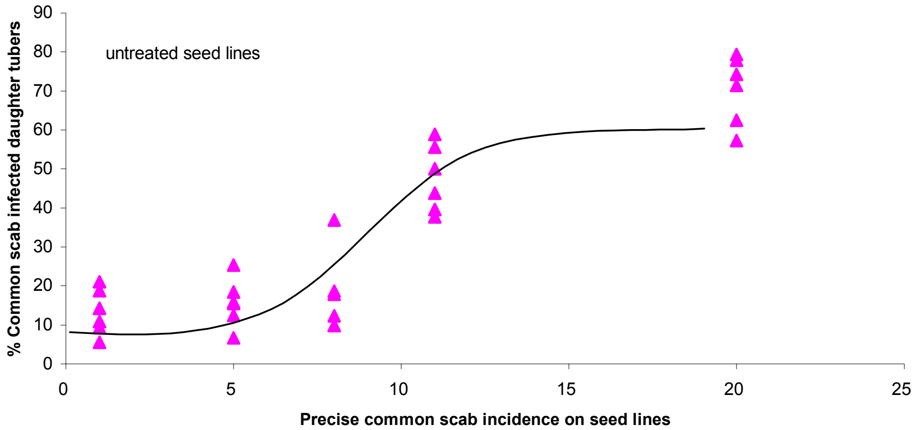
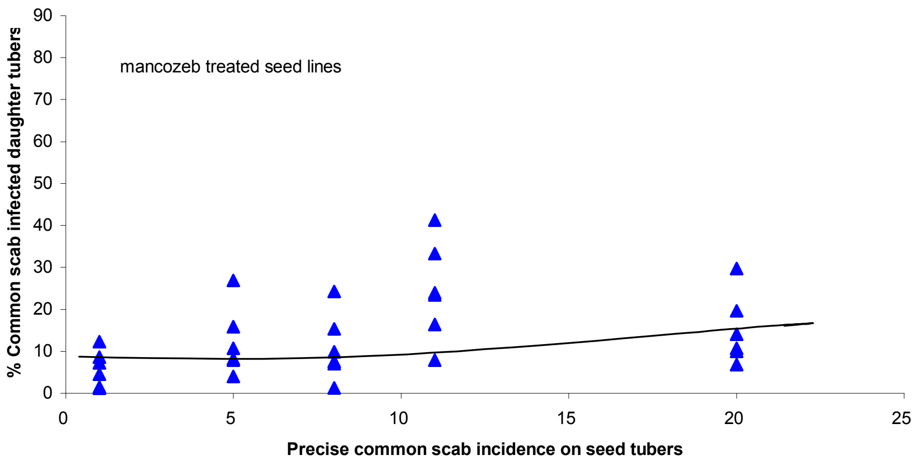


Figure 2.14: The relationships between common scab incidence on mancozeb treated seed lines and common scab incidence on daughter tubers



3. The influence of seed sorting and grading

Abstract

Five field trials were conducted to investigate the effects of seed sorting, with and without chemical seed treatments, to reduce visible scab levels on seeds. The results of these studies confirm the importance of infected seed lines in transmitting common scab. Sorting of seeds that have relatively high common scab incidence, ranging from 20% to 75% infected tubers to 0%, 2% 25% or 50% infected tubers, was shown to give little or no beneficial effects in reducing seed borne common scab transmission. Washing of infected seed lines also gave no obvious benefits. Mancozeb and Maxim® seed treatments were effective in controlling common scab from infected seeds. However, chemical seed treatments were not as effective when used on seeds that had relatively severe scab (5% or greater scab cover). Infected seed lines with low scab coverage should be treated with either mancozeb or Maxim® chemical seed treatments to control seed borne common scab.

Introduction

The maximum limits of acceptable scab levels in Australian certified seed are set at 2% or 4% of tubers with presence of scab lesions, depending on the certifying authority. Seed sorting to remove and reduce the scab level in infected seed lines is a practice that is regularly used by seed growers in Victoria to achieve the acceptable limit for seed certification. Seed lines that have different levels of common scab at harvest, can have little or no scab after careful sorting and look similar to seed lines with lower infection levels. There is no quantifiable data to indicate whether the removal of scab infected seeds will help reduce scab transmission onto daughter tubers. Therefore, five field trials were conducted in Victoria in 2002-2005 to investigate the effects of infected seed lines before and after sorting to different scab levels.

Anecdotally, when a seed line has 10% scab infected seeds or higher, seed sorting to reach the acceptable limit of 2% or 4% is deemed to be wasteful, time consuming, and costly. A seed crop grown according to seed certification protocols but with 10% or higher incidence of scab at harvest would be downgraded as lower value potatoes for use other than as seeds. It is possible that seed lines with a high incidence of scab, but which do not have high scab coverage or deep scab, may still be acceptable if seed treatments could provide effective seed borne scab control. Trials reported in Section 2 showed that after mancozeb seed treatment, there were no differences in common scab incidence on daughter tubers produced from the treated infected seeds in comparison to seed lines that had no scab. Therefore, trials in this section also examined the effects of Mancozeb seed treatment on sorted seed lines.

Some seed growers use seed washing as a commercial practice in preparing their early generation seed for planting. There is a view that washing helps to remove some of the scab inoculum from the seed surface, thus reducing the risk of transferring the disease to the next generation. Washing of seed is normally undertaken with a low-pressure system and is often accompanied by some sort of chemical treatment in conjunction with the washing. The effect of seed washing on common scab transmission was therefore examined in this section.

Soil borne common scab and seasonal conditions are important factors in scab levels on potatoes. Potatoes are typically grown in paddocks that already have a history of potato cropping. As a result, many soil borne potato pathogens, including *Streptomyces scabies* (common scab) and *Spongospora subterranae* (powdery scab) occur in most paddocks. Soil borne scab levels in old potato paddocks are generally present and may be a more important source of disease inoculum than seed borne sources. Scab caused by the soil borne inoculum could potentially mask any effects due to infected seeds or seed treatments. Changes in seasonal weather conditions are also critical factors on whether soil and crop conditions are favourable to scab development. Generally, common scab is favoured by dry soil conditions and vice versa for powdery scab. Trials in this section were conducted over three growing seasons and in different districts. Although all of the trials were located in paddocks that have a history of potato growing over a long period, these paddocks did not have a history of major scab problems.

Summary of trials

Table 3.1: Trials conducted in 2002-2004

	TRIAL 3.1	TRIAL 3.2	TRIAL 3.3
Location	Cora Lynn, Victoria	Ballarat, Victoria	Ballarat, Victoria
Soil Type	Black organic clay loam over grey clay	Reddish brown clay loam over basalt	Reddish brown clay loam over basalt
Commercial crop	Crisp processing	French fry	French fry
Variety	Atlantic	Russet Burbank	Russet Burbank
Trial Design	Complete randomised block	Complete randomised block	Complete randomised block
Replicates	6	3	3
Total No. Treatments	12	11	11
Plot Size	2.2 m X 1.62m	4.07 m X 1.72 m	4.07 m X 1.72 m
Row Spacing	810 mm	860 mm	860 mm
Plant spacing	200 mm	370 mm	370 mm
Sowing Date	10/12/02	27/11/2003	2/12/2003
Harvest Date	7/4/2003	31/3/2004	7/5/2004

Table 3.2: Trials conducted in 2003-2005

	TRIAL 3.4	TRIAL 3.5
Location	Warragul, Victoria	Warragul, Victoria
Soil Type	Reddish brown clay loam over basalt	Reddish brown clay loam over basalt
Commercial crop	Fresh chipping	Fresh chipping
Variety	Shepody	Shepody
Trial Design	Complete randomised block	Complete randomised block
Replicates	3	3
Total No. Treatments	10	19
Plot Size	4.07 m X 1.67 m	6.2 m X 1.7m
Row Spacing	810 and 860 mm	850 mm
Plant spacing	370 mm	350 mm
Sowing Date	18/12/2003	23/11/2004
Harvest Date	7/4/2004	12/4/2005

Materials & Methods

A total of five trials were conducted over three seasons in 2002/03, 2003/04 and 2004/05 within processing potato crops in Victoria. Summaries of all the trials are presented in Tables 3.1 and 3.2. A descriptive summary of seed lines used in the trials is provided in Table 3.3. The seed lines and treatments for the trials are listed in Tables 3.4, 3.5, 3.6 and 3.7. Seeds were sorted to simulate the sorting process that takes place in a seed grower's shed. All trials were located within commercial potato crops and were managed as part of the normal management that applied to the whole field.

Table 3.3: Seed lines for 2002/03, 2003/2004 and 2003/2005 seasons

Season (Trial)	Cultivar	Seed line	Generation	Description of seed line's common scab incidence and surface coverage
2002/03 (Trial 3.1)	**Atlantic**	**A**	G5	High incidence of common scab, with approximately 18% of tubers with deep lesions.
		D	G5	Infected seeds sorted out of a seed line by grower. The sorted seeds had 77% tubers with more than 5% of the surface area covered by common scab.
		F	G3	Control seed line with no visual symptoms of common scab.
2003/04 (Trials 3.2 and3.3)	**Russet Burbank**	**RB 1**	G1	No visible presence of common scab
		RB 2	G4	
		RB 3	G5	Approximately 25% of tubers with common scab lesions, mostly with 1 to 2% surface cover.
		RB 4	G5	Approximately 65% of tubers with common scab lesions; 45% with 1 to 2% cover, 20% with 2% cover.
		RB 5	G5	Approximately 60% of tubers with common scab lesions; 30% with 1 to 2% cover, 30% with more than 5% cover.
2003/04 (Trial 3.4)	**Shepody**	**S 1**	G1	No visible presence of common scab.
		S 2	G5	Significant visible common scab. The material had already been sorted by grower into 2% or less common scab incidence for saleable product. Estimated that inherent scab level was around 25% prior to sorting.
		S 3	G5	Some prior grading of this seed line. Approximately 75% of tubers with common scab lesions; 25% with greater than 15% cover, the rest with 2% to 15% cover. Estimated that inherent scab level was 75% of tubers infected.
		S 4	G5	Some prior grading of this seed line. Approximately 35% of tubers were free of common scab lesions; 45% with 1 to 2% cover, 20% with more than 2% cover. Estimated that inherent scab level was 65% of tubers infected
2004/05 (Trial 3.5)	**Shepody**	**S mini**	minitubers	No scab on seeds
		S G1	G1	No scab on seeds
		S 2	G6	Inherent scab level at harvest = 39%
		S 3	G6	Inherent scab level at harvest = 34%
		S 5	G6	Inherent scab level at harvest = 21%

In Trial 3.1, three separate seed lines of Atlantic seed were planted. Seed line A and seed line D both had heavy levels of scab, with 18% and 77% respectively of the tubers with more than 5% scab cover. Seed line A was sorted into three different seed lines prior to planting, to represent visually clear of scab at 0%, and with 10% and 50% scab incidence. The seed was cut by hand and placed in open weave onion bags to be cured in a humid store for one week prior to planting. After curing, the seed was removed from store and the additional treatments of dusting and/or washing were made, as described in Table 3.4. The dusting treatment was four grams of 6% mancozeb in fir bark (Nubark™) applied onto seed pieces in a paper bag that was then shaken vigorously. This gave a full coating of the seed dust to the seed pieces. The washing of seed pieces for Treatments 9 and 10 was achieved by hosing the seed pieces in a plastic container with clean water. Seed-pieces were then dried and dusted with fir bark only or fir bark + mancozeb.

Trials 3.2, 3.3 and 3.4 were based on seed lines of the cultivars Shepody and Russet Burbank collected from Victorian seed growers during the 2003 seed harvest. Each seed tuber was individually examined so that seed lines were carefully sorted into treatments with different levels of common scab present; the levels being 0%, 5% and 25% of seed tubers with between 2% and 5% cover. The 0% level had no visual scab on tubers.

Trial 3.5 was planted with Shepody seed sourced from a seed multiplication plot where seven different lines of certified seed had been planted in 2003 to compare their performance. The different lines of seed had differing levels of common scab on the seed at harvest in 2004. Other than this, the seed lines were similar in terms of physiological age, generations removed from minituber production and tuber size distribution. The different seed lines were assessed for the *'at harvest'* level of common scab and the results were used to select three of these seed lines for replanting into the 2004 trial. The three seed lines selected had been allocated the identification codes of S 5, S 3 and S 2 and they had an assessed level of common scab incidence at seed harvest of 21%, 34% and 39% respectively. Two control treatments were included, being Shepody minitubers (S mini) from the Toolangi minituber production facility, and G1 Shepody (S G1) seed from an early generation seed grower. Both control lines of seed were inspected visually and no common scab could be found.

All trial designs were randomised complete blocks. In field trials, seed-pieces were planted in small plots of 20 plants/plot in order to keep the trial areas relatively small and minimise variability in soil properties and conditions. Desiree seed pieces were sown at the ends of each treatment to mark the plot area and to provide normal competition for the end plants. There was a 1 m wide walkway between each replicate. All field trials were set up within commercial crops and were grown in the same manner as the commercial crop outside the trial areas.

Table 3.3: Treatment list for Trial 3.1

Treatment No.	Seed line	Scab incidence with >5% severity	Seed treatment
1	A	0	Fir bark only
2		10	
3		50	
4	D	77	
5	A	0	Fir bark + mancozeb
6		10	
7		50	
8	D	77	Fir bark + mancozeb
9		77	Washed
10		77	Washed and fir bark + mancozeb
11	F	0	Fir bark only
12		0	Fir bark + mancozeb

Table 3.5: Treatment list for Trials 3.2 and Trial 3.3

Treatment No.	Variety	Seed line	Scab incidence before sorting	Scab incidence after sorting	Sorting & grading of seed line
1	Russet Burbank	RB 1	0	0	Nil
2		RB 2	0	0	Nil
3		RB 3	25	0	Graded to a minimum of 0% and a maximum of 25% visible scab
4				5	
5				25	
6		RB 4	65	0	
7				5	
8				25	
9		RB 5	60	0	
10				5	
11				25	

Table 3.6: Treatment list for Trial 3.4

Treatment No.	Cultivar	Seed line	Scab incidence before sorting	Scab incidence after sorting
1	Shepody	S 1	0	0
2		S 2	Seeds already graded commercially	2
3				5
4				25
5		S 3	75	2
6				5
7				25
8		S 4	65	2
9				5
10				25

Table 3.7: Treatment list for Trial 3.5

Treatment No.	Seed line	Inherent level of scab at harvest (%)	Chemical treatment	Final incidence of scabby seed after sorting (%)
1	S mini	0	Nil	0
2	S G1	0	Nil	0
3			Mancozeb	0
4			Maxim	0
5	S 2	39	Nil	0
6				5
7				25
8			Mancozeb	25
9			Maxim	25
10	S 3	34	Nil	0
11				5
12				25
13			Mancozeb	25
14			Maxim	25
15	S 5	21	Nil	0
16				5
17				25
18			Mancozeb	25
19			Maxim	25

At harvest, all tubers were washed and assessed for incidence of tubers with common scab. Powdery scab and deep scab lesions were also assessed if in sufficient abundance. The incidence of common scab or powdery scab was recorded as presence or absence of scab lesions on tubers, and expressed as a percentage of total tubers assessed. In the assessment for deep scab, scab lesions that were obviously deep, or that could be removed only with 2 or more scrapes of a vegetable peeler, were rated as deep scab. Although the weights of scab infected and non-infected tubers were also measured, their mean values followed a similar pattern to the values based on tuber numbers, but were subject to greater variability between plots. Therefore, the data values based on tuber weights have not been separately presented.

In Victorian trials, scab infected tubers were also rated for scab coverage according to the number of tubers with approximately 1%, 2%, 5%, 10%, 15%, 20% and 40% surface covered by scab lesions. A description of the percentage coverage of surface tubers is in Appendix i. An index for scab cover of the infected tubers was then calculated using the formula:

Scab cover index = [(Numbers with 1% cover x 1) + …….+ (Numbers with 40% cover x 40)]
[Total numbers of scab tubers]

Results from each of trials were collated, and analysis of variance was conducted on data values using StatGraphics Plus 2.0, and comparisons were made of mean values using Least Significant Difference (LSD) Test.

Results

Trial 3.1

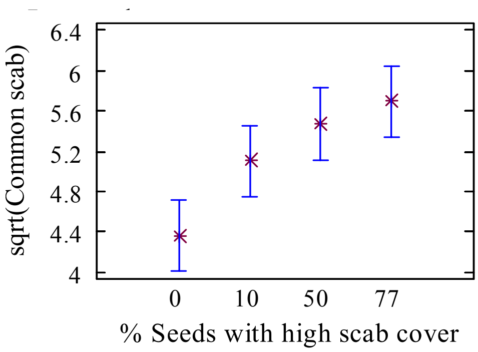
In Trial 3.1, the scab incidence ranged from 16% to 36%, and the average scab cover of the infected tubers was relatively low at 1%to 3% surface cover (Table 3.8). As this trial was aimed at determining the effects of tubers with high scab cover of 5% or greater, no initial assessment of common scab incidence was carried out. There were significant differences in the daughter tubers' common scab incidence and deep scab incidence between the proportions of tubers with high scab cover on seeds.

In seed line A, seeds sorted to have no tubers with high scab cover resulted in significantly lower common scab and deep scab incidence compared to seeds with 10% and 50% high scab cover (Figure 3.1). Seed line D, where seeds were sorted to have 77% high scab cover, resulted in similar incidence of common scab and deep scab as 10% and 50% high scab cover in seed line A. These findings indicate that the sorting of a common scab infected seed line to ensure that it had no tubers with high scab cover of 5% or greater is beneficial for the reduction of common scab in the following crop. There were significant seed treatment effects in this trial, where mancozeb treatments reduced common scab and deep scab incidence on the daughter tubers in seed lines A and D.

Table 3.8: Effects of high scab cover in Trial 3.1

Seed line	High scab cover incidence (> 5% cover)	Seed treatment	% Common scab incidence	Scab cover	% Deep scab incidence
	0		23	2.2	8
A	10	Fir bark only	33	2.8	12
	50		36	2.1	17
D	77		34	2.0	16
	0		16	1.4	5
A	10	Fir bark + mancozeb	22	2.5	9
	50		26	2.2	9
D	77		32	2.8	14
Analysis on main effects and P-values					
High scab cover			0.003		0.007
Seed treatment			0.006		0.034

Figure 3.1: High scab cover effects in Trial 3.1
(Means and 95% LSD intervals)



Seed line F was the control G3 seed line that had no visible common scab, and its daughter tubers had the lowest common scab incidence in the trial (Tables 3.8 and 3.9). This low scab incidence is likely to be background scab level due to soil borne inoculum. This may explain the lack of control by mancozeb, as mancozeb seed treatment on seed line F had no control effect on soil borne inoculum. With seed line D, the different seed treatments caused little or no reduction in common scab and deep scab incidence (P = 0.07) (Table 3.9). This indicates that there is no obvious benefit in the use of mancozeb seed treatments or washing of seeds that come from a seed line that has a high proportion of high scab cover.

Table 3.9: Seed treatment effects in Trial 3.1

Seed line	High scab cover incidence (> 5% cover)	Seed treatment	% Common scab incidence	Scab cover	% Deep scab incidence
D	77	Fir bark only	34	2.0	16
		Fir bark + mancozeb	32	2.8	14
		Washed	26	2.7	12
		Washed + mancozeb	29	1.9	14
F	0	Fir bark only	18	1.5	8
		Fir bark + mancozeb	19	1.4	9
Analysis on main effects and P-values					
Seed line			0.003		0.052
Seed treatment			0.073		0.495

Trial 3.2

In Trial 3.2, there were significant differences between seed lines and the level of scab incidence before sorting, on the common scab incidence on their daughter tubers (Table 3.10). The two control seed lines that had no visible scab on seeds (RB 1 and RB 2) had significantly less common scab incidence and scab cover than the visibly scab infected seed lines (Table 3.10, Figure 3.2). The common scab on tubers produced from RB 1 and RB 2 could be due to soil borne inoculum and could, therefore, be regarded as background scab levels. The higher scab levels with infected seed lines indicate that seed borne scab was important in transmitting common scab on to daughter tubers in this trial.

Before sorting, the infected seed line with 25% incidence of common scab generally had lower common scab incidence on daughter tubers compared to the seed lines with 60% and 65% infected seeds (Figure 3.3). A plot of all data from replicated plots in Trial 3.2 showed a moderate relationship between the seed lines' common scab incidence before sorting, and the common scab incidence on daughter tubers (R^2 = 21.7%) (Figure 3.4). This implies that 22% of the variation in common scab incidence on daughter tubers is attributable to the common scab levels on seed tubers.

In contrast, after seed sorting, there were no significant differences between the sorted seeds scab incidence and the resulting scab incidence on their daughter tubers (Figure 3.3). A plot of all data from replicated plots showed a weak relationship between the seed lines' common scab incidence after sorting and the common scab incidence on daughter tubers (R^2 = 4.0%) (Figure 3.5). These findings indicate that if there is any variation in harvested scab levels due to sorting of the seed into different scab tolerances, the effect is very small. This result has important implications for certification standards and the impact of sorting seed to certain defined levels of common scab.

The scab cover of infected tubers was relatively low, ranging from 1% to 4% (Table 3.10), and there were no significant differences in scab cover between the three infected seed lines, before or after sorting (Table 3.9)

Table 3.10: Effects of seed lines and sorting on common scab incidence and coverage in Trial 3.2

	Common scab incidence on seed line		Daughter tubers	
Russet Burbank seed line	Before sorting %	After sorting %	Common scab incidence (%)	Scab cover
1 RB 1	0	0	6	1.4
2 RB 2	0	0	6	1.1
3 RB 3	25	0	12	2.6
		5	12	3.2
		25	13	3.4
4 RB 4	65	0	16	3.7
		5	16	3.7
		25	17	3.9
5 RB 5	60	0	17	3.1
		5	19	3.2
		25	22	3.6
Analysis on main effects and P-values				
Seed lines			0.0001	< 0.0001
Scab incidence before sorting of seed lines 3-5			0.028	0.118
Scab incidence after sorting of seed lines 3-5			0.605	0.385

Figure 3.2: Seed line effects on scab incidence and scab cover for Trial 3.2 (Means and 95% LSD intervals)

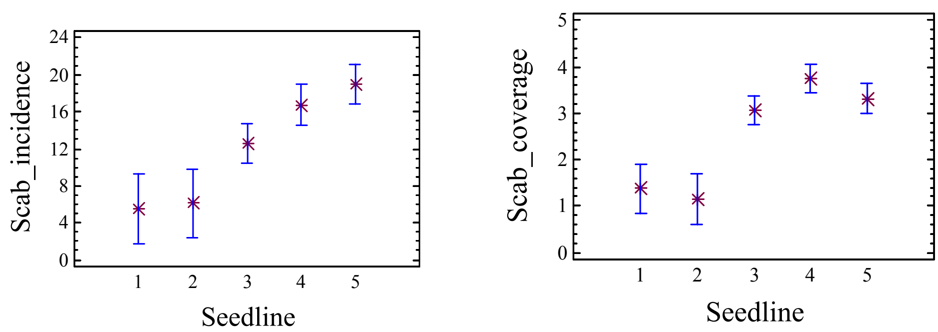


Figure 3.3: Before and after sorting effects of the seed lines 3-5 on scab incidence for Trial 3.2 (Means and 95% LSD intervals)

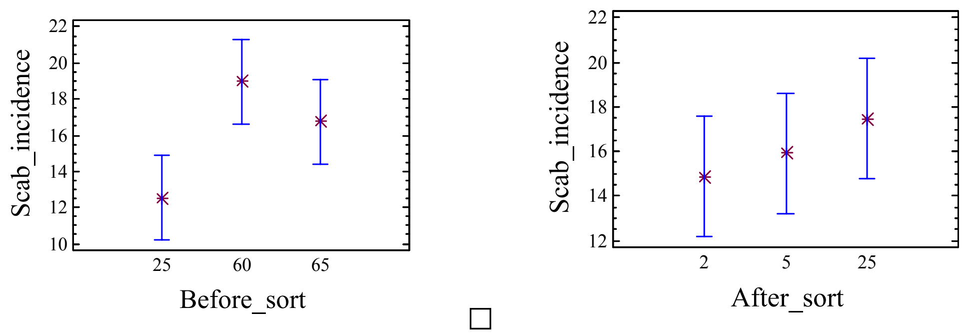


Figure 3.4: The relationship between scab incidence on mother seed before the sorting of seed lines 3-5, and scab incidence on daughter tubers, in Trial 3.2

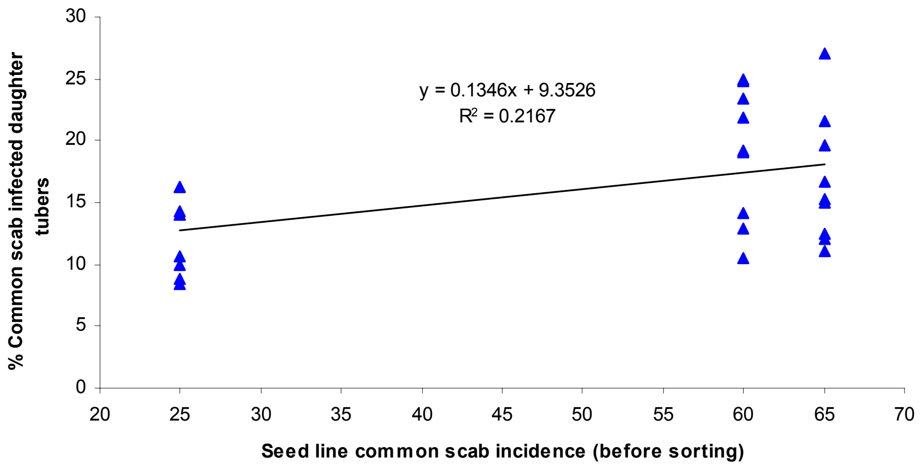
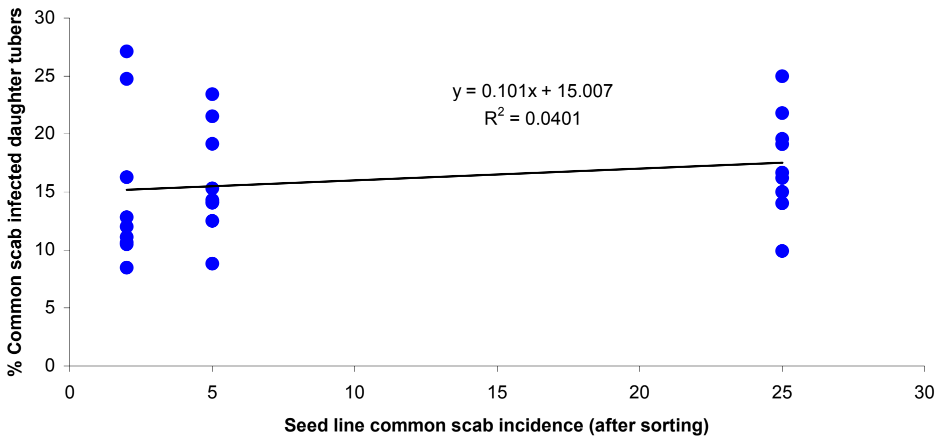


Figure 3.5: The relationship between scab incidence on mother seed after the sorting of seed lines 3-5, and scab incidence on daughter tubers, in Trial 3.2



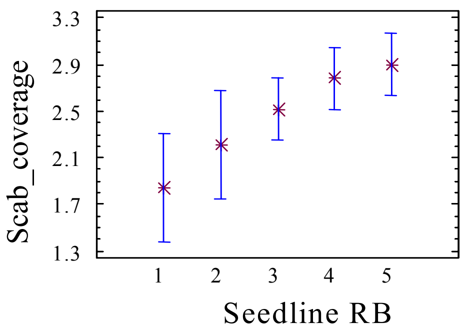
Trial 3.3

For Trial 3.3, the common scab incidence was high, ranging from 63% to 78% (Table 3.11). At such high common scab levels, it is likely that soil borne inoculum rather than seed borne inoculum was the main cause of common scab in the trial. Therefore, it is not surprising that there were no significant effects on scab incidence due to seed lines or seed sorting. There was, however, a significant effect on the scab cover of daughter tubers due to seed line (P = 0.051) (Table 3.11), mainly due to differences between lower scab cover on tubers produced from the two control seed lines (RB 1 and RB 2) compared to those produced from infected seed lines (Figure 3.7). There were no obvious differences in scab cover due to sorting (Table 3.11).

Table 3.11: The effects of seed lines and seed sorting on common scab incidence and cover in Trial 3.3

	Common scab incidence on seed line		Daughter tubers	
Russet Burbank seed line	**Before sorting**	**After sorting**	**Common scab incidence (%)**	**Scab cover**
1 RB 1	0	0	71	1.9
2 RB 2	0	0	70	2.2
3 RB 3	25	0	77	2.8
	25	5	69	2.5
	25	25	70	2.3
4 RB 4	65	0	63	3.1
	65	5	72	2.7
	65	25	72	2.6
5 RB 5	60	0	78	3.1
	60	5	68	2.4
	60	25	76	3.2
Analysis on main effects and P-values				
Seed lines			0.678	0.051
Scab incidence before sorting of seed lines 3-5			0.349	0.586
Scab incidence after sorting of seed lines 3-5			0.355	0.231

Figure 3.6: Effects of all seed lines on scab cover for Trial 3.3 (Means and 95 % LSD intervals)



Trial 3.4

The common scab incidence on daughter tubers in Trial 3.4 was relatively low, ranging from 6% to 26% (Table 3.12). The lowest incidence of scab infected daughter tubers was produced from seed line S1. Seed line S1, the control seed line, had no visible scab on seeds. There were significant effects by the seed lines, and their scab incidence before and after sorting, on the common scab incidence on their daughter tubers at the 90% confidence level (Table 3.12). The control seed line, with no scab on seeds (S1), had significantly less common scab incidence and scab cover on daughter tubers than the other scab infected seed lines (Table 3.12, Figure 3.7). Similar to Trial 3.2, the higher scab levels with infected seed lines indicates that the seed borne scab level prior to sorting is important in transmitting common scab on to daughter tubers.

Significant effects were recorded due to seed lines, mostly due to the control seed line S1 resulting in much lower common scab levels than the infected seed lines. There were no obvious differences between different infected seed lines, before sorting (Figure 3.8). The data in Figure 3.8 indicates a possible relationship after seed sorting, and this was examined in further plots of all data from replicated plots in Figures 3.9 and 3.10. There was a very weak relationship between the seed lines' common scab incidence before sorting and the common scab incidence on daughter tubers (R^2 = 0.8%) (Figure 3.9). The linear relationship between the seed lines' common scab incidence after sorting and the common scab incidence on daughter tubers improved slightly but was still a weak one (R^2 = 6.6%), indicating that other causes of common scab are more important (Figure 3.10). These findings again indicate that the effect of seed sorting was negligible in this trial.

The scab cover of infected tubers was relatively low, ranging from 2% to 5% (Table 3.12), and there were no significant differences in scab cover between the three infected seed lines, before or after sorting.

Table 3.12: The effects of seed lines and sorting on common scab incidence and cover in Trial 3.4

	Common scab incidence on seed line		Daughter tubers	
Shepody seed line	**Before sorting**	**After sorting**	**Common scab incidence (%)**	**Scab cover**
1 S 1	0	0	6.1	1.27
2 S 2	25	0	16.5	2.81
		5	14.8	2.33
		25	19.6	4.59
3 S 3	75	0	11.8	2.24
		5	24.0	3.56
		25	17.9	3.16
4 S 4	65	0	13.9	1.98
		5	21.1	2.83
		25	26.4	2.27
Analysis on main effects and P-values				
Seed lines			0.089	0.260
Scab incidence before sorting of S2-S4			0.623	0.503
Scab incidence after sorting of S2-S4			0.097	0.438

Figure 3.7: Effects of seed line and inherent seed scab levels on the incidence of scab on daughter tubers in Trial 3.4 (means and 90% LSD intervals)

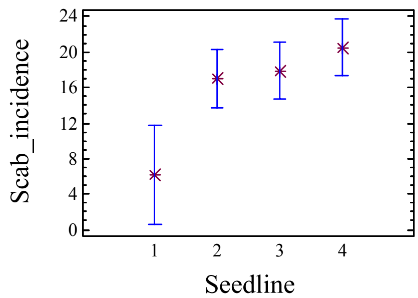


Figure 3.8: Effects of sorting seed lines 2-4 on the incidence of scab on daughter tubers in Trial 3.4 (means and 90% LSD Intervals)

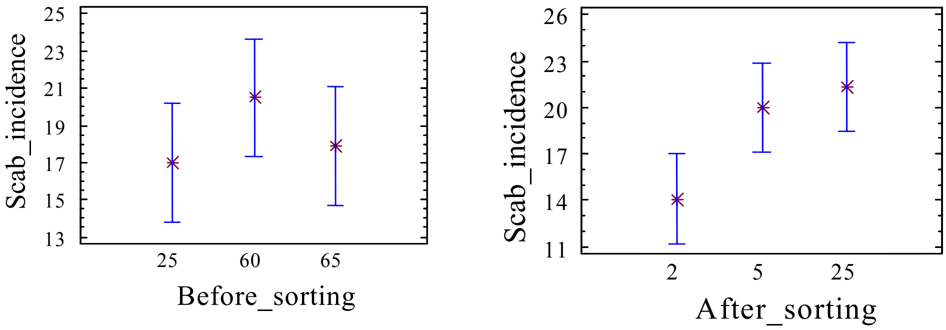


Figure 3.9: The relationship between seed lines' common scab incidence before sorting of seed lines 2-4 and scab incidence on their daughter tubers in Trial 3.4

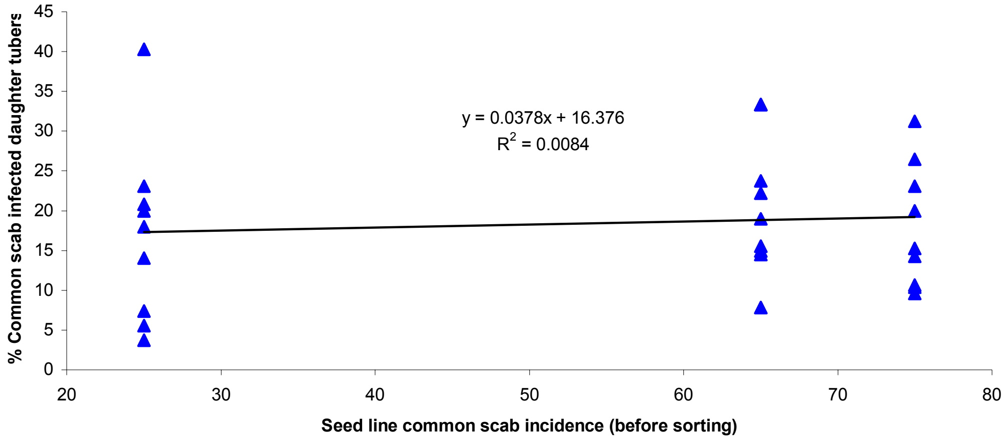
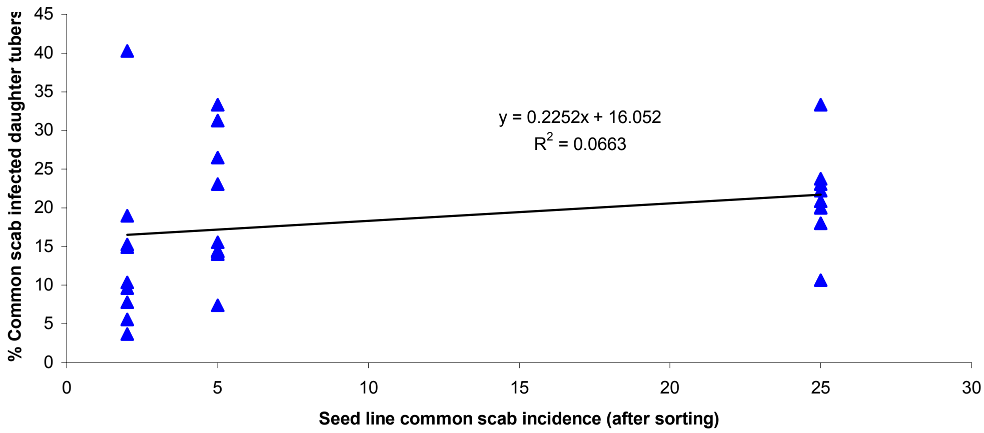


Figure 3.10: The relationship between seed lines' common scab incidence after sorting of seed lines 2-4 and scab incidence on their daughter tubers in Trial 3.4



Trial 3.5

In Trial 3.5, the common scab incidence on daughter tubers ranged from 0% to 21% (Table 3.13). With S1 minitubers and S2 control seed lines, which had no common scab on seeds, there was little or negligible incidence of common scab on their daughter tubers (Table 3.13, Figure 3.11). It is, therefore, reasonable to assume that there was negligible soil borne inoculum and that infected seeds were the main source of scab inoculum in this trial.

Although there were significant effects due to seed lines' scab incidence before seed sorting on their daughter tubers' common scab incidence and scab cover, the differences were mainly between infected seed lines and the control seed lines (Table 3.13, Figure 3.12). The infected seed lines of 21%, 34% and 39% infected seeds before sorting produced similar incidence of common scab and scab cover on their daughter tubers (Figure 3.13). After sorting of the infected seed lines, there was a trend of lower scab incidence on their daughter tubers (P = 0.03) (Table 3.13, Figure 3.13). However, a plot of all data values showed that the seed sorting process to the lower incidence of 0% and 5% appeared to reduce the variabilities in the daughter tubers' scab incidence, but gave no obvious advantage in reducing scab transmission.

The chemical seed treatments with mancozeb and Maxim 100FS® significantly reduced the incidence of common scab on daughter tubers (Table 3.13, Figure 3.14). With the exception of Treatment No. 9, the chemical seed treatments reduced the daughter tubers' common scab incidence by at least 81% in S2 seed line, 70% in S3 seed line and 54% in S5 seed line in comparison to those from 25% infected seeds and untreated. The Maxim® seed treatment in Treatment No. 9 produced highly variable results, ranging from 1% to 26% infected daughter tubers. As each treatment number was replicated only three times, the individual treatment results should be regarded with caution. The combined results of all similar treatments and seed lines would give a better representation on the seed treatment performance is shown in Figure 3.14. There were no obvious differences between mancozeb and Maxim® seed treatments. This indicates that Maxim® is a suitable alternative to mancozeb seed treatment for seed borne common scab control.

Table 3.13: The effects of seed lines, seed sorting and seed treatments on common scab incidence and cover in Trial 3.5

Treatment No	Shepody seed line	Before sorting	After sorting	Seed treatment	Common scab incidence (%)	Scab cover
1	S mini	0	0	Nil	1	0.7
2	S G1	0	0	Nil	0	0.0
3			0	Mancozeb	2	0.7
4			0	Maxim	0	0.0
5	S 2	39	0	Nil	8	3.2
6			5	Nil	13	5.4
7			25	Nil	21	3.6
8			25	Mancozeb	4	1.6
9			25	Maxim	14	1.6
10	S 3	34	0	Nil	9	2.9
11			5	Nil	10	1.8
12			25	Nil	12	4.0
13			25	Mancozeb	3	2.0
14			25	Maxim	4	2.4
15	S 5	21	0	Nil	7	1.1
16			5	Nil	12	2.8
17			25	Nil	13	4.8
18			25	Mancozeb	3	2.1
19			25	Maxim	6	2.6
Analysis on main effects and P-values						
Seed lines (all seed lines)					< 0.0001	< 0.0001
Scab incidence before sorting of S2-S5					0.161	0.925
Scab incidence after sorting of S2-S5					0.031	0.198
Chemical seed treatment of S2-S5					< 0.0001	0.059

Figure 3.11: Effects of seed lines on common scab incidence and scab coverage on daughter tubers in Trial 3.5 (means and 95% LSD intervals)

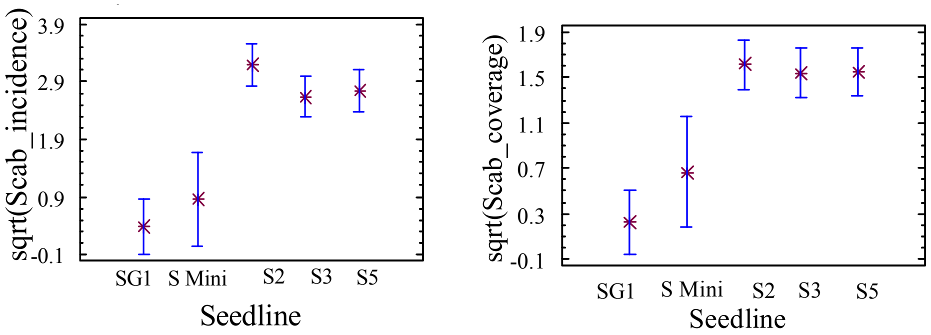


Figure 3.12: Effects of seeds' common scab incidence, before and after sorting, on common scab incidence and scab coverage on daughter tubers in Trial 3.5 (means and 95% LSD intervals)

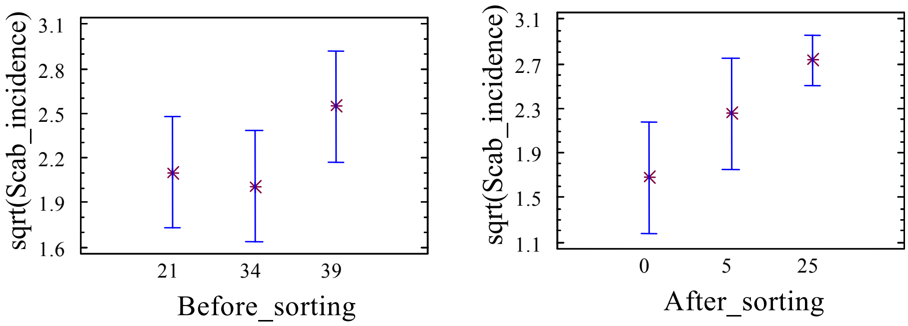


Figure 3.13: The relationship between seed lines' common scab incidence after sorting and their daughter tubers common scab incidence in Trial 3.5

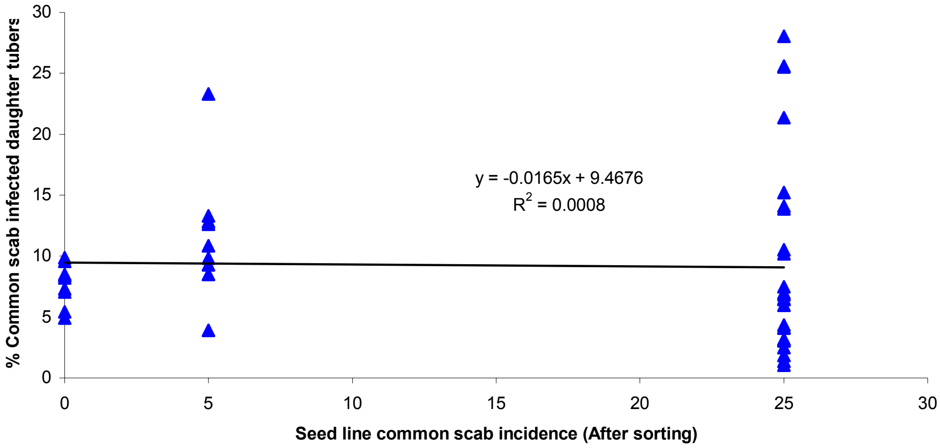
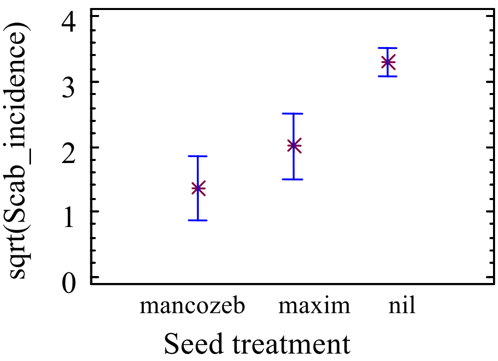


Figure 3.14: Effects of chemical seed treatments on common scab incidence on daughter tubers in Trial 3.5 (means and 95% LSD intervals)



Discussions

Importance of common scab transmission from infected seed lines

Field trials conducted in this section consistently demonstrated and confirmed the importance of infected seed lines in transmitting common scab. Control seed lines that had no common scab always resulted in significantly lower scab incidence on their daughter tubers compared to those produced from common scab infected seed lines. Sorting of seeds that had a relatively high common scab incidence ranging from 20% to 75% infected tubers, to 0%, 2% 25% or 50% infected tubers, was shown to give little or no obvious beneficial effects in reducing seed borne common scab transmission.

Seed sorting

There is no consistent relationship between the different common scab incidence of seed lines at harvest and before sorting to the incidence of common scab on their daughter tubers. One trial (Trial 3.2) showed a significant effect by infected seed lines before sorting but not after sorting. In contract, two trials (Trials 3.4 and 3.5) showed no significant effects by infected seed lines before sorting, and significant effects after sorting. In all instances, the changes in the levels of common scab transmitted by the infected seed lines before or after sorting were relatively small. In a study by Wang (2005), visually healthy seed tubers that have no scab were found to produce 60% common scab infected tubers in pasteurized soil. Any improvements due to seed sorting to reduce scab appeared to be negligible and, therefore, showed no obvious benefits. Similarly, washing also appeared to have no obvious impact in reducing scab transmission from infected seeds.

Chemical seed treatment

Chemical seed treatments with mancozeb or Maxim® consistently reduced the levels of common scab transmission from infected seed lines. The reductions in seed borne common scab transmission by the chemical treatments were generally much greater than those shown due to seed sorting. Therefore, seed treatments could be a much more effective and cheaper way of enabling infected seed lines with low common scab coverage to be used. In Trial 3.5, the chemical seed treatments of lines with 25% infected seeds reduced the daughter tubers' common scab incidence by approximately 50% to 80% in comparison to untreated seeds. There were no obvious differences between mancozeb and Maxim® seed treatments, indicating that Maxim® could be an alternative to mancozeb seed treatment for seed borne common scab control.

High common scab cover on seed lines

Increasing common scab severity, based on infected seeds with more than 5% surface cover, increases the incidence of common scab and deep scab transmitted on to daughter tubers. The mancozeb seed treatment was not as effective when used on seeds that have relatively severe scab (5% or greater scab cover). This indicates that the use of a chemical seed treatment is only beneficial when used on infected seed lines that have low scab coverage.

4. The efficacy of fludioxinil (Maxim 100FS®) compared to mancozeb in seed treatments for common scab control

Abstract

A pot trial was conducted to compare the efficacy of fludioxinil (Maxim 100FS®) and mancozeb (Tato dust®) seed treatments, as well as Maxim® seed + gypsum soil treatment, for the control of common scab. Maxim was applied as a spray application, mancozeb was applied as fir bark + Tato dust in a dust application on to freshly cut seed pieces, and gypsum (Turf-Gyp®) was mixed thoroughly into the potting mix. Maxim and mancozeb were shown to be highly effective in controlling common scab due to severely infected seeds, reducing common scab incidence on daughter tubers by 66% and 47% and deep scab incidence by 92% and 73%, respectively, in comparison to the untreated control. There was no phytotoxic effect due to the Maxim seed treatment, even when applied immediately onto seed pieces after cutting. Maxim seed + gysum soil treatments gave the highest level of common scab control, reducing common scab incidence by 83% and deep scab incidence by 88% in comparison to the untreated control. No *Rhizoctonia* infected seeds were recorded on tubers produced from Maxim treated seeds. This study demonstrates that the Maxim seed treatment used for seed borne *Rhizoctonia* control is also effective for seed borne common scab control.

Introduction

In recent years, mancozeb has been increasingly used to treat seeds for seed borne common scab control. Mancozeb can be applied onto whole seeds or onto cut seed pieces; however, a high concentration of mancozeb is phytotoxic to tissues on the freshly cut surface of seed pieces. Therefore, in Tasmania, mancozeb is usually applied by diluting Tato dust (40% mancozeb) with Douglas fir bark to reduce its concentration to approximately 6% mancozeb. The resulting fir bark + mancozeb mix is then dusted onto freshly cut seed pieces. This dusting treatment is usually carried out either in a seed store after the cutting process or when seed pieces are being loaded into a truck. The seed dusting treatment is often carried out in proximity to operators and/or in a confined space, and the inhalation of chemical dust poses a serious occupational hazard. The modifications required to separate the seed treatment process from operational areas is costly and is not considered to be feasible by the seed store operators. A shift away from the use of chemical dusting to spray application in a treatment box is an option that could help minimise chemical exposure to seed handlers. The use of mancozeb spray applications onto freshly cut seed pieces has been shown to be highly toxic to the cut surface in a previous project.

Fludioxinil (Maxim 100FS®), which is sprayed onto freshly cut seed pieces, is increasingly being used for seed borne *Rhizoctonia* control. In initial studies carried out 1998/99, Maxim seed treatment was also effective in controlling seed borne common scab (Pung et al 2000). Therefore, this study aimed to establish whether Maxim seed treatment for *Rhizoctonia* control is also effective against seed borne common scab, and could be a suitable alternative to mancozeb dust treatment.

Summary of trial

Table 4.1: Pot trial planted in 2004

POT TRIAL	
Variety	Ranger Russet
Location	Bellfield, Tasmania
Soil Type	Pasteurised potting mix
Total No. Treatments	4
Trial Design	Randomised complete block
Replicates	10
Pot size	280 mm x 270 mm pot (14 litres soil mix)
Planting Density	1 sett/pot
Seed Treatment Date	15/12/04
Planting Date	15/12/04
Harvest Date	13/04/05

Materials & Methods

Seed-pieces with common scab lesions and approximately 20% scab cover from an infected Ranger Russet commercial seed line were used in the pot trial. Seed treatments were applied on seed pieces as described in Table 4.2.

Table 4.2: Application methods used in seed and soil treatment

Treatment	Application method
Fir bark seed	Freshly cut seed pieces coated with Douglas fir bark (Nubark) at 4 kg/tonne seed by mixing in a plastic bag.
Fir bark + mancozeb seed	Freshly cut seed-pieces coated with fir bark + 6% mancozeb (Nubark + Tato Dust mixture) at 4 kg/tonne seed.
Maxim seed	Freshly cut seed-pieces sprayed with a diluted spray mix containing 0.625% Maxim 100FS® until well covered. Maxim concentration based on 25 mL/4 L water).
Gypsum soil	Granular gypsum (Turf-Gyp®) mixed at 1 L into 14 L potting mix for approximately 7% gypsum in soil

A summary of the trial is presented in Table 4.1. Plants in the pot trial were watered with overhead sprinklers on alternate days, and soil moisture ranged from field capacity (after irrigation or rainfall) to close to wilting point.

For disease assessment, all tubers were harvested, washed and assessed for the numbers of tubers with common scab lesions, deep pitted scab lesions and black scurf (*Rhizoctonia*). The common scab incidence and deep pitted scab (severity) were then tabulated as percentages of total tubers assessed. The weights of all tubers in each pot were recorded and the average tuber weights were calculated. Analysis of variance was conducted using StatGraphics Plus 2.0, and comparisons were made of mean values using Fisher's Least Significant Difference (LSD) Test.

Maxim treated seed pieces

Results & Discussion

In the pots, plants were subjected to extremely dry conditions before watering at regular intervals. Only common scab lesions, and no powdery scab, were found on the daughter tubers (Photograph 4.1). Deep pitted scab lesions carried forward from mother tubers to the daughter tubers as a severe expression of the disease. As only pasteurized soil was used in the trial, all expressions of common scab are considered to have originated from the inoculum on infected seeds. Maxim and mancozeb seed treatments were highly effective in controlling common scab from these severely infected seeds, reducing common scab incidence on daughter tubers by 66% and 47%, and deep scab incidence by 92% and 73%, respectively, in comparison to the untreated control (Table 4.3, Figures 4.1-4.2). Maxim seed + gysum soil treatment gave the highest level of common scab control, reducing common scab incidence by 83%, and deep scab incidence by 88%, in comparison to untreated control. This indicates that the gypsum soil application may have altered soil conditions, making it less favourable for the common scab pathogen.

There was no significant difference in the levels of common scab control between the mancozeb and maxim seed treatments. There was, however, a trend of lower scab incidence on tubers produced from Maxim treated seeds compared to those from mancozeb treated seeds. This finding confirms that Maxim seed treatment is a suitable alternative to mancozeb seed treatment for common scab control. As a result of research findings in an earlier project (Pung et al 2000) and in this project, Maxim was registered in 2005 for use as seed treatment on potatoes for suppression of common scab in Australia. This is a unique development, as fludioxinil, the active ingredient in Maxim, is a fungicide and it has activity against *Streptomyces scabies*, a bacterial pathogen.

An analysis of the average tuber weight of all tubers produced in each plant or pot showed significant differences between treatments (P = 0.006). There was a significant increase in the average tuber weight or size of tubers produced from the combined Maxim seed + gypsum soil treatment compared to other treatments (Table 4.3, Figure 4.1). This indicates that in addition to reduced scab disease, Maxim seed + gypsum soil treatment also improved tuber growth. There are a number of possible explanations for this effect, including a nutritional response from either calcium or sulphur, a higher water holding capacity in the gypsum treated soil, or improved aeration of the gypsum treated soil.

Although some tubers were affected by black scurf (*Rhizoctonia*), only four out of forty plants in the pots had infected tubers, which was too low for comparison. However, there was no black scurf on any of the daughter tubers produced from Maxim seed or Maxim seed + gypsum soil treatments. Maxim is registered for use to control seed borne *Rhizoctonia*.

Table 4.3: Initial scab and seed treatment effects on scab levels on daughter tubers in the pot trial

Code	Treatment	Common scab (% tubers affected)		*Rhizoctonia* (% tubers with black scurf)	Average weight (g/tuber) *
		Incidence *	Deep pitted scab *		
1	Nil	62 c	26 b	10	62 a
2	Mancozeb seed	33 b	7 a	17	81 a
3	Maxim seed	21 ab	2 a	0	77 a
4	Maxim seed + gypsum soil	10 a	3 a	0	99 b
	P-value	***0.0004***	***0.002***	***0.170***	***0.006***

All seed-pieces were from common scab infected seeds with approximately 20% scab coverage
* Within each column, means followed by same letter are not significantly different (P = 0.05) according to Fisher's LSD test

Figure 4.1: Treatment effects on common scab incidence on daughter tubers

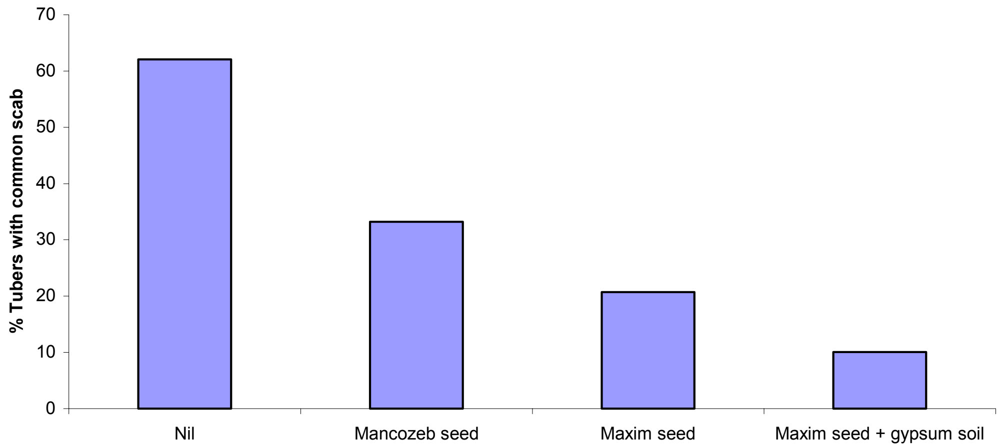
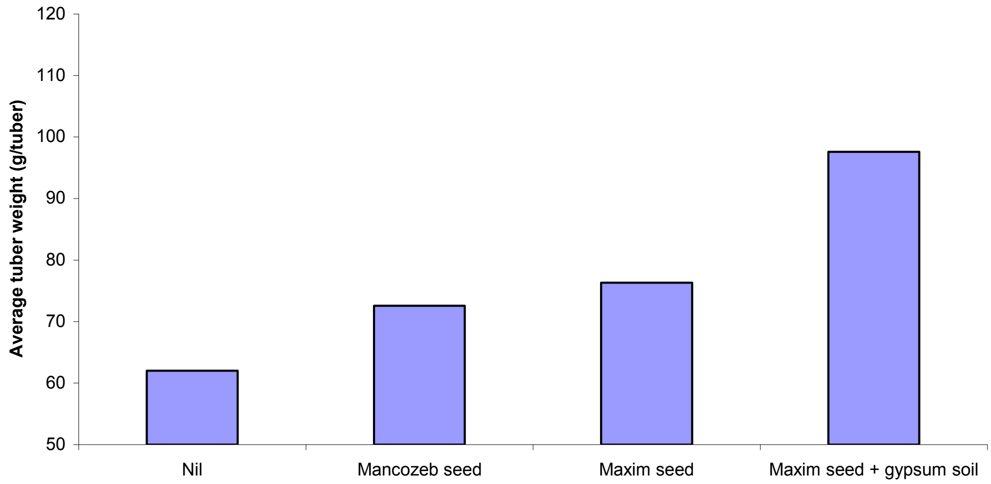


Figure 4.2: Treatment effects on the average tuber weights of daughter tubers



Photograph 4.1: Treatment effects on common scab on daughter tubers

5. Influence of seed lines and treatments on powdery scab

Abstract

Seven trials were conducted within commercial crops in Tasmania in 2003-2005, to examine the impact of scab incidence, coverage and severity, particularly of common scab, on seed lines, on scab levels on their daughter tubers. Over this period, substantial improvements in cultural practices adopted by growers have led to powdery scab becoming the prevalent scab disease in all of these trials. Regular soil moisture monitoring has led to increased frequency of irrigation, hence creating conditions that favour powdery scab instead of common scab. These changes have also resulted in the increased prevalence of powdery scab on seed lines, and reduced the importance of common scab on seed lines. Studies in this section demonstrate that relatively low powdery scab incidence on seed lines, at less than 10%, did not result in increased powdery scab incidence or deep scab incidence. Only a seed line with 21% powdery scab incidence and 32% deep-pitted scab caused an increase in the deep scab incidence. Seeds with a high proportion of severe common scab infected seeds were also shown to increase the incidence of powdery scab and deep scab. This appeared to be due to delayed plant emergence and growth, which increased the daughter tubers' susceptibility to powdery scab. Chemical seed treatments with mancozeb or Maxim 100FS® were shown to be effective in reducing the risk of powdery scab transmission onto daughter tubers.

Aims

As new ground that has never been sown with potatoes become very scarce, potato seed crops are increasingly being grown in rotations with other crops. As a consequence, some tuber diseases, such as common scab and powdery scab, are common. In Tasmania, depending on seasonal weather conditions and crop management systems, one of the two scab diseases, common scab or powdery scab, will be more prevalent. In recent years, changes in cultural and management practices have resulted in a shift to more prevalent powdery scab instead of common scab. The changes in cultural practices include later planting of seed crops in warmer soils, and improved irrigation with regular soil moisture monitoring. Before these changes, many seed crops were planted early and grown without irrigation. In Russet Burbank seeds produced in 2002/03, powdery scab was more common than common scab in the scab infected seed lines. The acceptable maximum limit for scab on seed lines is 4%, irrespective of whether it is common scab or powdery scab. Since 2003, seed lines are more likely to be rejected due to greater than the maximum limit of powdery scab. Following earlier trial studies, reported in Section 2, a total of five field trials were conducted in 2003/04 and 2004/05 within commercial crops in Tasmania, in order to further examine the relationship of scab incidence and coverage on its transmission. As the resulting daughter tubers produced in these trials were predominantly infected by powdery scab, this section essentially examined the influence of seed lines, initial powdery scab and seed treatment effects on powdery scab incidence and severity.

Summary of trials

Trials conducted in 2003/04

	TRIAL 5.1	TRIAL 5.2	TRIAL 5.3	TRIAL 5.4
Variety	Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank
Location	Sunnyside, Tasmania	Moriarty, Tasmania	Sunnyside, Tasmania	Moriarty, Tasmania
Soil Type	Ferrosol	Ferrosol	Ferrosol	Ferrosol
Total No. Treatments	12	12	16	16
Trial Design	Randomised complete block	Randomised complete block	Randomised complete block	Randomised complete block
Replicates	6	6	6	6
Plot Size	1.6 m x 2 rows	1.6 m x 2 rows	1.6 m x 2 rows	1.6 m x 2 rows
Row Spacing	80 cm	80 cm	80 cm	80 cm
Plant Spacing	32 cm	32 cm	32 cm	32 cm
Planting Density	10 setts/plot	10 setts/plot	10 setts/plot	10 setts/plot
Total No. Plots	72	72	96	96
Seed Treatment Date	17/11/03	17/11/03	17/11/03	17/11/03
Planting Date	20/11/03	24/11/03	20-21/11/03	24/11/03
Harvest Date	25/05/04	17/05/04	25-26/05/04	16-17/06/04

Trials conducted in 2004/05

	TRIAL 5.5	TRIAL 5.6	TRIAL 5.7
Variety	Ranger Russet	Ranger Russet	Russet Burbank
Location	Abbotsham, Tasmania	Barrington, Tasmania	Barrington, Tasmania
Soil Type	Ferrosol	Ferrosol	Ferrosol
Total No. Treatments	10	10	10
Trial Design	Randomised complete block	Randomised complete block	Randomised complete block
Replicates	6	6	6
Plot Size	1.6 m x 2 rows	1.6 m x 2 rows	1.6 m x 2 rows
Row Spacing	80 cm	80 cm	80 cm
Plant Spacing	32 cm	32 cm	32 cm
Planting Density	10 setts/plot	10 setts/plot	10 setts/plot
Total No. Plots	60	60	60
Seed Treatment Date	26/10/04	26/10/04	08/11/04
Planting Date	03/11/04	18/11/04	22/11/04
Harvest Date	22-23/03/05	21/04/05	11-12/05/05

Materials & Methods

A total of seven trials were conducted over two seasons in 2003/04 and 2004/05 within commercial Russet Burbank crops in Tasmania. Summaries of all the trials are presented in Tables 5.1-5.2. The seed lines and treatments for the trials are listed in Tables 5.4-5.5. Seed treatments were applied as described in Table 5.3:

Table 5.3: Seed treatment application methodology

Seed treatment	Application method
Fir bark only	Freshly cut seed pieces coated with Douglas fir bark (Nubark) at 4 kg/tonne seed by mixing in a plastic bag.
Fir bark + mancozeb	Freshly cut seed-pieces coated with fir bark + 6% mancozeb (Nubark + Tato Dust mixture) at 4 kg/tonne seed.
Formaledhyde	Formalin containing 40% formaldehyde was applied at a rate of 25 mL/L water for 1% formaldehyde. Whole seeds were dipped into formaldehyde solution for 5 minutes, air-dried and then cut into seed-pieces.
Maxim	Freshly cut seed-pieces sprayed with a spray mix containing 0.625% Maxim 100FS® until well covered. Maxim concentration based on 25 mL/tonne seed applied in 4 L water.

The two main processing potato cultivars Russet Burbank and Ranger Russet were used in the trials. In Trials 5.1, 5.2, 5.3, and 5.4, Shepody seeds treated with formaldehyde were included in the trials as an indicator for soil borne scab. In Trials 5.1 and 5.2, seeds taken from five commercial seed lines, X, A, B, C and D were closely examined for their precise common and powdery scab incidence and coverage (Table 5.5). In Trials 5.3 and 5.4, Russet Burbank seeds used in the trials came from a commercial seed line that was free of scab (seed line X), tubers from a 2002/03 trial at Don that had less than 5 common scab lesions and only shallow scab lesions (seed line L), and severe common scab infected ware potato crop that had 30% or more coverage and deep scab lesions (seed line W). For different scab incidence and severity, the percentage of tubers from seed lines L (scab infected and non-infected tubers) and W were blended accordingly for the desired levels as shown in Table 5.6.

In Trials 5.5-5.7, seeds from a scab infected seed line were sorted into different common scab incidence, coverage or treated as shown in Table 5.7. Ranger Russet was used in Trials 5.5-5.6, and Russet Burbank was used in Trial 5.7.

Table 5.5: Treatment lists for Trials 1 & 2

No.	Variety	Seed line	Precise scab incidence on seeds	Precise powdery scab incidence on seeds	Seed origin (all unwashed tuber seeds)	Seed treatment
1	Shepody	S1	0	-	Seeds	1% formaldehyde
2		S2	0	-	Seeds	
3	Russet Burbank	X	0	0	Certified	Fir bark only (untreated control)
4		A	1.9	8.8	Approved	
5		B	2.0	4.6	Approved	
6		C	6.0	8.2	Certified	
7		D	60.9	20.7	Approved	
8	Russet Burbank	X	0	0	Certified	Fir bark + 6% Mancozeb
9		A	1.9	8.8	Approved	
10		B	2.0	4.6	Approved	
11		C	6.0	8.2	Certified	
12		D	60.9	20.7	Approved	

All Russet Burbank seeds were from commercial seed lines; certified seed lines have 4% or less scab, and approved seed lines have > 4% scab.

Table 5.6: Treatment list for Trials 3-4

No.	Variety	Seed line	Scab coverage*	% Common scab incidence	% High & severe common scab incidence	Seed treatment
1	Shepody	S1	-	0	0	1% formaldehyde
2		S2	-	0	0	
3	Russet Burbank	X	0	0	0	Fir bark only (control)
4		L	Low	5	0	
5		L	Low	10	0	
6		L	Low	20	0	
7		L	Low	40	0	
8		L + W	Low + High	100	10	
9		L + W	Low + High	100	20	
10		L + W	Low + High	100	40	
11		L + W	Low + High	100	10	Fir bark + 6% mancozeb
12		L + W	Low + High	100	20	
13		L + W	Low + High	100	40	
14		L + W	Low + High	100	10	Maxim (Maxim@ 25 mL/4 L water)
15		L + W	Low + High	100	20	
16		L + W	Low + High	100	40	

* Low = 1 - 2% scab coverage; High = 20 - 30% scab coverage plus deep scab

Table 5.7: Initial scab incidence, coverage and chemical seed treatment for Trials 5-7

Treatment No.	Scab incidence	Scab coverage (%)	Seed treatment
1	0	0	Nil
2	10	1	Nil
4	10	20	Nil
6	10	40	Nil
3	20	1	Nil
5	20	20	Nil
7	0	0	Maxim
8	10	1	Maxim
9	10	20	Maxim
10	10	40	Maxim

Cultivars used: Ranger Russet in Trials 5-6, and Russet Burbank in Trial 5.7

At harvest, all tubers were harvested, washed and assessed for incidence of tubers with common scab, powdery scab and deep scab lesions. The incidence of common scab or powdery scab was recorded as presence or absence of scab lesions on tubers and expressed as a percentage of total tubers assessed. In the assessment for deep scab, scab lesions that were obviously deep or that could only be removed with 2 or more scrapes of a vegetable peeler were rated as deep scab. Although the weights of scab infected and non-infected tubers were also measured, their mean values followed a similar pattern to those based on tuber numbers, although subject to greater variabilities between plots. Therefore, the data values based on tuber weights were not presented or analysed.

Results from each trial were collated and analysis of variance was conducted on data values using StatGraphics Plus 2.0, and comparisons were made of mean values using Least Significant Difference (LSD) Test.

Results

Trials conducted in 2003/04

Trials 5.1 and 5.2

An assessment of the Russet Burbank seeds to be planted in these trials for precise scab levels showed that, except for seed line X, both common and powdery scab were present on the same seed lines. The common scab incidence ranged from 0% to 61% (Table 5.8), and the powdery scab ranged from 0% to 21% (Table 5.9). The highest levels of common scab and powdery scab were recorded in seed line D, which also had 32% tubers with deep pitted scab lesions.

Table 5.8: The precise common scab incidence and coverage on seed lines used in Trials 5.1 - 5.2

Cultivar	Seed line	Certification	Total no. of tubers assessed	Precise common scab on seeds*				
				Incidence (%)	Scab coverage (% tubers)			% Deep pitted scab
					Low	Moderate	High	
Russet Burbank	X	Certified	183	0	0	0	0	0
	A	Approved	160	2	2	0	0	0
	B	Approved	153	2	1	1	0	0
	C	Certified	184	6	4	2	0	0
	D	Approved	179	61	34	27	4	32

* scab coverage: low < 5 lesions and shallow scab, moderate = 5 or more lesions and shallow scab, high = 5 - 10% scab lesion coverage
deep pitted scab = deep lesions due to both common scab and powdery scab

Table 5.9: The precise powdery scab incidence and coverage on seed lines used in Trials 5.1 - 5.2

Cultivar	Seed line	Certification	Total no. of tubers assessed	Precise powdery scab on seeds*		
				Incidence (%)	Scab coverage (% tubers)	
					Low	Moderate
Russet Burbank	X	Certified	183	0	0	0
	A	Approved	160	9	9	0
	B	Approved	153	5	5	0
	C	Certified	184	8	7	1
	D	Approved	179	21	11	9

* scab coverage: low < 5 lesions and shallow scab, moderate = 5 or more lesions and shallow scab, high = 5 - 10% scab lesion coverage

Almost all of the scab infections on harvested tubers in Trial 5.1 and Trial 5.2 were powdery scab. This included the deep scab lesions, which could not be removed with two passes of a potato peeler. In Trial 5.1, *Sclerotinia* disease was widespread in the paddock, infecting approximately 50% of plants in the trial area and approximately 80% of plants in the commercial crop outside the trial area, causing plants to senesce early, and affecting tuber size and yield. Both powdery scab and *Sclerotinia* diseases are favoured by wet soil conditions, which are in contrast to the dry field conditions that are conducive to common scab. In 2003/04, Simplot introduced a crop monitoring system in potato crops in Tasmania, where many paddocks were regularly monitored for soil moisture in order to improve irrigation and increase potato yields. This system tends to result in increased frequency of irrigation, possibly creating conditions that favour powdery scab instead of common scab.

Shepody tubers were highly susceptible to powdery scab (Photograph 5.1), with approximately 98% infected tubers in Trial 5.1 (Table 5.10) and 85% infected tubers in Trial 5.2 (Table 5.11). Russet Burbank tubers are comparatively tolerant to powdery scab, but the incidence in Russet Burbank seed lines still ranged from 63% to 74% infected tubers in Trial 5.1 and 3% to 18% infected tubers in Trial 5.2. Most powdery scab lesions on Russet Burbank were relatively small in size and were shallow lesions (Photograph 5.1). In Trial 5.1, some infected tubers had high surface coverage due to the presence of many powdery scab lesions that merged to cause deep scab, which ranged from 3% to 18%.

Table 5.10: Scab levels on seed lines and daughter tubers in Trial 5.1 at Sunnyside

	Seed lines – scab incidence and seed treatments					Daughter tubers				
							Powdery scab coverage			
Treat-ment Code	Variety	Seed line *	% Common scab	% Powdery scab	Seed Treatment	% Powdery scab incidence	% Mild	% Moderate	% Severe	% Deep scab
1	Shepody	S1	0	0	1% formaldehyde	99	45	48	6	74
2		S2	0	0		97	27	54	16	83
3	Russet Burbank	X	0	0	Fir bark (control)	70	70	0	0	3
4		A	2	9		70	70	0	0	4
5		B	2	5		72	72	0	0	12
6		C	6	8		74	74	0	0	8
7		D	61	21		77	76	1	0	18
8		X	0	0	Fir bark + mancozeb (Mz)	64	63	0	0	4
9		A	2	9		63	62	0	0	6
10		B	2	5		66	65	1	0	4
11		C	6	8		72	72	0	0	6
12		D	61	21		64	64	0	0	5

Powdery scab coverage: mild < 5% cover, moderate = 5-10% cover, severe >10% cover

Figure 5.1: Treatment codes and powdery scab incidence and deep scab incidence on daughter tubers in Trial 5.1 (means and 90.0 percent LSD intervals)

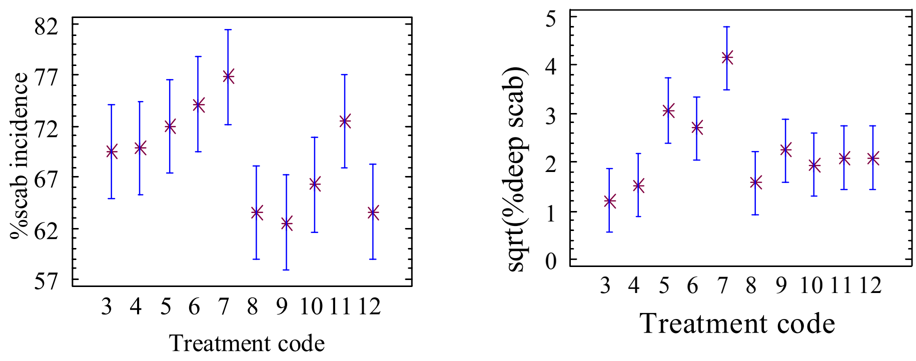
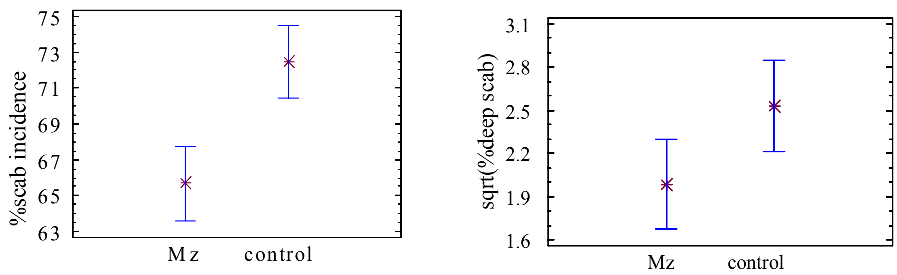


Figure 5.2: Seed treatment effects on powdery scab incidence and deep scab incidence on daughter tubers in Trial 5.1 (means and 90.0 percent LSD intervals)

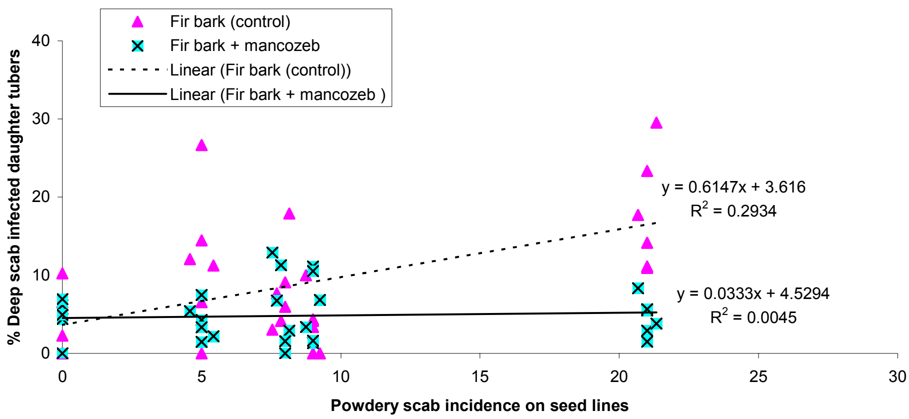


Photograph 5.1: Powdery scab lesions on Russet Burbank tuber (left) and Shepody tuber (right)

The high powdery scab incidence in treatments planted with formaldehyde treated Shepody seed indicates that powdery scab inoculum was very high and widespread in the soils of the two trial sites. Due to their vast differences in susceptibility, only the data for the Russet Burbank seed lines were analysed.

Despite the apparently high powdery scab disease due to soil borne inoculum in Trial 5.1, mancozeb as a seed treatment collectively gave significant reduction of approximately 8% in the incidence of powdery scab on daughter tubers across the different seed lines (P = 0.002, Figure 5.2), with the most marked effect on seed line D. Seed line D was the only seed line with more than 10% incidence of powdery scab on the mother tubers. There was also a reduction in deep scab as an effect of mancozeb treatment, with seed line D again being significant.

Figure 5.3: The linear relationship between the powdery scab incidence on seed lines and the deep scab incidence on their daughter tubers



High disease pressure from soil borne inoculum in Trial 5.1 meant that seed borne inoculum of less than 10% powdery scab (seed lines A, B and C) did not contribute in any substantial way to the powdery scab levels on daughter tubers.

Table 5.11: Scab levels on seed lines and daughter tubers in Trial 5.2 at Moriarty

	Seed lines – scab incidence and seed treatments					Daughter tubers				
						% Powdery scab incidence	Powdery scab coverage			
Code	Variety	Seed line *	% Common scab	% Powdery scab	Seed Treatment		% Mild	% Moderate	% Severe	% Deep scab
1	Shepody	S1	0	0	1% formaldehyde	85	78	7	1	27
3	Russet Burbank	X	0	0	Untreated	27	27	0	0	0
4		A	1.9	9		31	31	0	0	1
5		B	2	5		25	25	0	0	2
6		C	6	8		32	32	0	0	0
7		D	60.9	21		34	34	0	0	3
8		X	0	0	6% Mz in Nubark	32	32	0	0	1
9		A	1.9	9		29	29	0	0	0
10		B	2	5		33	33	0	0	2
11		C	6	8		33	33	0	0	1
12		D	60.9	21		34	34	0	0	2

In Trial 5.2, almost all of the scab lesions found on Russet Burbank tubers were also powdery scab, ranging from 25% to 34% (Table 5.11). There were no significant differences in the scab incidence between all the treatment codes (p = 0.987) or seed treatments (p = 0.564) in Trial 5.2. There was no apparent relationship between the powdery scab incidence on the seed lines and the powdery scab levels on daughter tubers. Only low incidences of deep scab infected tubers, as a result of deep powdery scab lesions, were recorded on Russet Burbank tubers in the trial. No potato crop had been grown in this paddock for the previous 40 years, although the farm as a whole has a powdery scab problem. With no treatment effects, it seems likely that all disease inoculum was introduced from other than infected seeds, such as irrigation water. This trial has established that variation in powdery scab incidence between seed lines of 5% to 21% has no effect on the disease incidence or severity in daughter tubers.

Trial 5.3 and Trial 5.4

In Trials 5.3 and 5.4, almost all scab infections on tubers were powdery scab. Plant emergence and initial growth tended to be slower in plots that had higher percentages of severe common scab infected seeds from seed line W. The slower plant growth from the seed line W in comparison to the other seed lines was only evident in the first 8 weeks after planting, and became less evident as the plants matures. No conclusions can be made from the sorting and blending treatments of the seed lines prior to planting, as the combinations were oriented to developing treatments with different levels of seed borne common scab, while the disease expression in daughter tubers was powdery scab. Although there appeared to be differences in the powdery scab incidence between seed lines, they may be related to unmeasured differences in seed borne powdery scab, but could also be due to differences in time of tuber set and one seed line setting the bulk of its tubers in conditions highly favourable for the powdery scab fungus. The slower initial plant emergence and growth by the severe scab infected seed tubers from seed line W may have predisposed their daughter tubers to increased powdery scab incidence.

Some of the treatments in Trials 5.3 and 5.4 were directed at determining the effects of treating seed with mancozeb and Maxim prior to planting. While soil borne or other sources of inoculum were responsible for the powdery scab recorded in these trials, there was a significant reduction in the powdery scab incidence due to mancozeb and Maxim application to the seed in Trial 5.3 (P = 0.0003, Figure 5.4). Although not significantly different in Trial 5.4, the chemical seed treatments tended to result in lower powdery scab incidence (P = 0.110, Figure 5.4).

Table 5.12: Scab levels on seed lines and daughter tubers in Trials 5.3 and 5.4

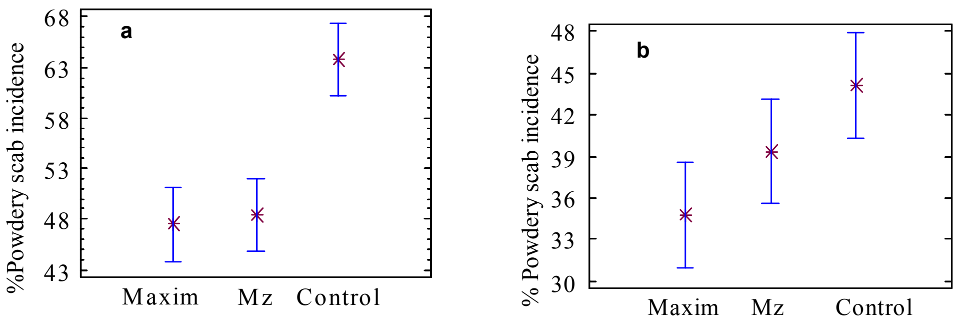
Treat ment No.	Seed line common scab coverage & severity & treatment					TRIAL 5.3		TRIAL 5.4	
	Variety *	Seed line	% Scab incidence	% Severe scab	Seed Treatment	% Powdery Scab incidence	% Deep scab	% Powdery scab incidence	% Deep scab
1	S	S1	0	0	1% formal-dehyde	91	62	93	20
2	S	S2	0	0		97	56	na	na
3	R	X	0	0	Fir bark only (control)	55	1	40	3
4	R	L	5	0		47	3	29	1
5	R	L	10	0		49	2	32	3
6	R	L	20	0		46	2	37	3
7	R	L	40	0		48	1	39	5
8	R	L+W	100	10		59	4	40	5
9	R	L+W	100	20		65	2	41	6
10	R	L+W	100	40		68	7	50	7

* Variety S = Shepody, R = Russet Burbank

Table 5.13: Seed treatment effects on scab incidence, coverage and severity on daughter tubers in Trials 5.3 and 5.4

Treatm ent No.	Seed line common scab incidence & severity & treatment				TRIAL 5.3		TRIAL 5.4	
	Seed line *	% Scab incidence	% Severe scab	Seed Treatment	% Scab incidence	% Deep scab	% Scab incidence	% Deep scab
8	L+W	100	10	Fir bark only (control)	59	4	40	5
9	L+W	100	20		65	2	41	6
10	L+W	100	40		68	7	50	7
11	L+W	100	10	Fir bark + mancozeb (Mz)	46	0	45	6
12	L+W	100	20		55	4	38	3
13	L+W	100	40		44	2	36	5
14	L+W	100	10	Maxim	42	1	29	2
15	L+W	100	20		55	2	37	3
16	L+W	100	40		48	1	39	3

Figure 5.4: Seed treatment effects on powdery scab incidence on daughter tubers in Trial 5.3 (a) and Trial 5.4 (b) (means and 90.0 percent LSD intervals)

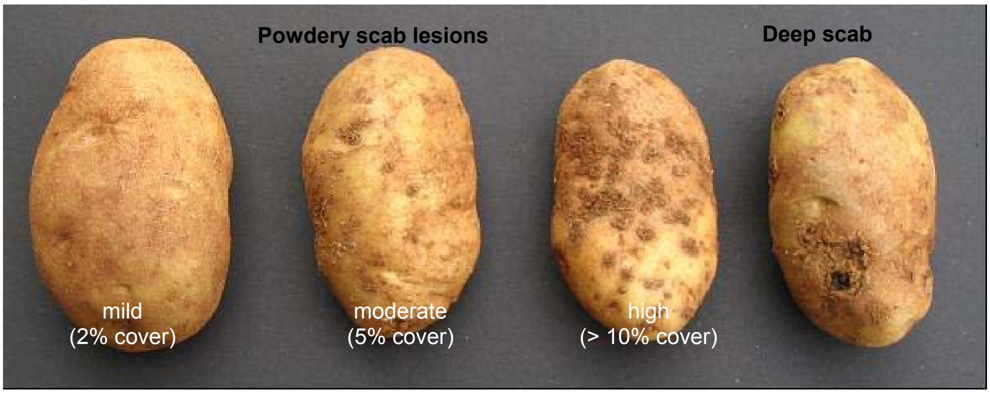


Trials conducted in 2004/05

Trials 5.5, 5.6 and 5.7

In the 2004/05 growing season in Tasmania, powdery scab was again common in many potato crops, but the disease was generally mild for coverage on Ranger Russet and Russet Burbank, the two main processing potato varieties. As in 2003/04, regular monitoring of soil moisture and more frequent irrigation appeared to favour powdery scab development in northern Tasmania.

Photograph 5.2: Russet Burbank tubers with superficial powdery scab and a tuber with deep scab



The trials were conducted within commercial potato crops and maintained in the same manner as the commercial crops. Powdery scab was the main disease found on the daughter tubers (Photograph 5.2). The percentage of daughter tubers affected by common scab was negligible in all the field trials, with less than one percent tubers affected. No relationships could be determined between the initial levels of common scab incidence and coverage and its transmission onto daughter tubers, as the common scab organism was not present to any extent at harvest, and the treatments and measurements of the seed lines were designed around common scab, rather than powdery scab. The powdery scab levels in the harvested treatments were assessed and are presented in Tables 5.13, 5.14 and 5.15.

With deep scab, there were trends of lower percentages of deep scab tubers in daughter tubers produced from Maxim treated seeds in Trial 5.6 (P = 0.006) and Trial 5.7 (P = 0.081) when compared to untreated seed-pieces (Figure 5.5). There were no deep scab tubers in Trial 5.5.

Table 5.13: Initial scab and seed treatment effects on scab levels on daughter tubers in Trial 5.5

	Initial common scab			Powdery scab on daughter tubers				
					Coverage			
Treatment No.	Scab incidence	Coverage (%)	Seed treatment	Incidence (%Infected tubers)	% Mild	% Moderate	% Deep scab	% Marketable tubers (weight)
1	0	0	Nil	12	12	0	0	96
2	10	1	Nil	17	17	0	0	92
4	10	20	Nil	18	18	0	0	94
6	10	40	Nil	16	16	0	0	92
3	20	1	Nil	13	13	0	0	94
5	20	20	Nil	17	17	0	0	90
7	0 + Mx	0	Maxim	18	18	0	0	91
8	10 + Mx	1	Maxim	13	13	0	0	92
9	10 + Mx	20	Maxim	12	12	0	0	92
10	10 + Mx	40	Maxim	14	14	0	0	95

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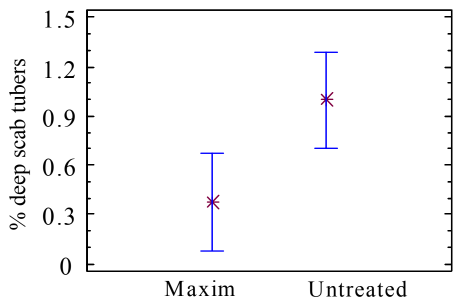


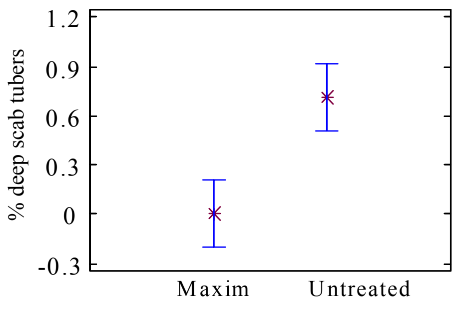


Table 5.14: Initial scab and seed treatment effects on scab levels on daughter tubers in Trial 5.6

	Initial common scab			Powdery scab on daughter tubers				
					Coverage			
Treatment No.	Scab incidence	Coverage (%)	Seed treatment	Incidence (%Infected tubers)	% Mild	% Moderate	% Deep scab	% Marketable tubers (weight)
1	0	0	Nil	36	35	0.3	0.3	92
2	10	1	Nil	53	51	1.4	0.5	93
4	10	20	Nil	54	53	0.9	0.7	92
6	10	40	Nil	49	47	1.0	1.2	91
3	20	1	Nil	42	42	0.0	0.6	91
5	20	20	Nil	50	50	0.0	1.2	92
7	0	0	Maxim	35	35	0.3	0.0	88
8	10	1	Maxim	46	45	0.7	0.0	94
9	10	20	Maxim	52	52	0.0	0.0	92
10	10	40	Maxim	49	49	0.2	0.0	92

Table 5.15: Initial scab and seed treatment effects on scab levels on daughter tubers in Trial 5.7

	Initial common scab			Powdery scab on daughter tubers				
					Coverage			
Treatment No.	Scab incidence	Coverage (%)	Seed treatment	Incidence (%Infected tubers)	% Mild	% Moderate	% Deep scab	% Marketable tubers (weight)
1	0	0	Nil	55	55	0.0	0.9	82
2	10	1	Nil	33	33	0.0	0.2	83
4	10	20	Nil	32	31	0.2	1.7	84
6	10	40	Nil	26	26	0.0	1.2	80
3	20	1	Nil	37	36	0.3	0.4	83
5	20	20	Nil	32	32	0.0	2.0	79
7	0 + Mx	0	Maxim	35	35	0.0	0.6	83
8	10 + Mx	1	Maxim	31	31	0.0	0.0	77
9	10 + Mx	20	Maxim	34	34	0.1	0.0	85
10	10 + Mx	40	Maxim	35	35	0.0	0.7	81

Discussions

Powdery scab is often associated with poorly drained fields. Powdery scab was far more prevalent than common scab in trials conducted within commercial crops in 2003/04 and 2004/05, reflecting changes in cultural practices of improved crop and soil moisture monitoring. These changes included increased frequency of irrigation, possibly creating conditions that favour powdery scab instead of common scab. These changes may also have resulted in the increased prevalence of powdery scab on seed lines, and reduced the importance of common scab on seed lines. Lapwood et al. (1973) showed that irrigation management during the critical initial stages of growth gave good control of powdery scab.

Studies in this section demonstrated that relatively low powdery scab incidence on seed lines of less than 10% did not resulted in increased powdery scab incidence or deep scab incidence (due to powdery scab). Only a seed line with 21% powdery scab incidence and 32% deep pitted scab caused an increase in the deep scab incidence in daughter tubers.

Seeds with a high proportion of severe common scab infected seeds were shown to be associated with an increased incidence of powdery scab and deep scab. One possible explanation is that the common scab may delay plant emergence and growth, leading to tuber set occurring during a period more favourable for the powdery scab fungus. Seed tubers with severe common scab (71% cover) had been shown by Adams & Hide (1981) to reduce the total number of stems produced, delay sprouting and reduce plant growth.

Chemical seed treatments with mancozeb or Maxim were shown to be effective in reducing powdery scab transmission onto daughter tubers. Falloon et al (1996) showed that mancozeb gave good control of powdery scab due to seed borne infection. However, effective chemical seed treatment will only form part of an integrated management strategy for this disease.

General Discussion

Common scab and certification standard

Most certification schemes among the major potato producing countries imply that certification standards for common scab have evolved to what is practical and achievable for seed producers. Moreover, in many parts of Europe, USA and Canada that have long traditions of potato growing, where common scab and powdery scab pathogens are already common in soils, it is unrealistic to produce scab free seeds. In Australia, seed production initially tends to occur on land with little or sometimes no history of potato production, so a much higher certification standard may be achievable. But in recent years, as new land has become increasingly difficult to find or is too costly, the majority of seed crops are planted in lands that have a tradition of potato growing in rotation with other crops. Seeds are also often sold to traditional potato growers and planted in areas that have a history of potato production. Therefore, seed production and ware potato production in Australia is becoming similar to conditions in North American and European countries. With these changes, it may be time to review the strict and demanding standards within Australia that are increasingly impractical and costly to seed growers.

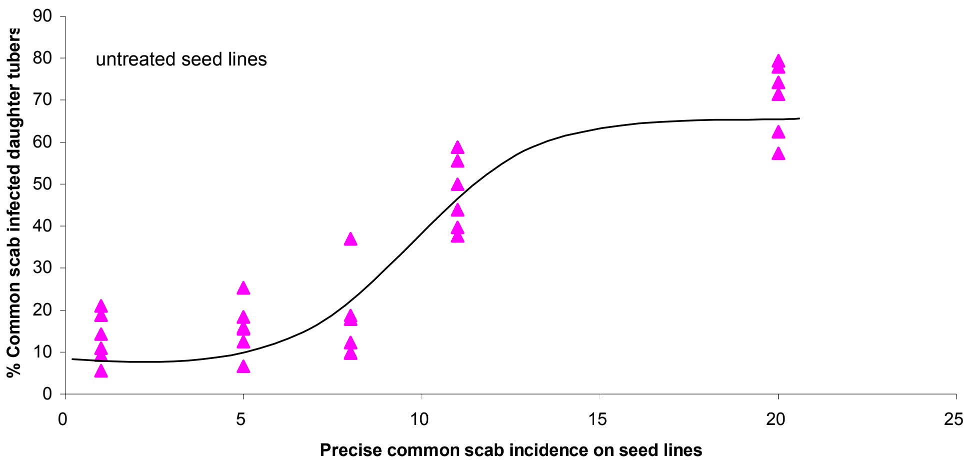
Trial studies in this project demonstrated that common scab infected seed was an important source of transmission onto daughter tubers only in new ground that is relatively free of soil borne inoculum. In old ground, where potatoes had been planted in crop rotations, most common scab on daughter tubers was caused by soil borne inoculum. Common scab caused by the soil borne inoculum often masks any effects due to common scab infected seeds or seed treatments. Potatoes are typically grown in paddocks that already have a history of potato cropping. As a result, many soil borne potato pathogens, including *Streptomyces scabies* (common scab) and *Spongospora subterranae* (powdery scab), occur in most paddocks. Soil borne scab levels are generally present in old potato paddocks and appeared to be a more important source of disease inoculum than seed borne source. Most field trials in this project were located in paddocks that have a history of potato growing over a long period, but did not have a history of major scab problems.

This project showed that in new ground that is relatively free of scab inoculum, there were no obvious common scab transmissions due to infected seed lines with 2%, 4% and 8% visible scabs. Substantial increases in the incidence of common scab on daughter tubers were only noted at 10% or higher in the scab incidence on seed lines, indicating that this may be the meaningful threshold incidence for common scab on seed lines. There was a strong correlation between seed lines' common scab incidence and scab transmission. This correlation, however, was dependent on the exact or precise common scab incidence of the seed lines. With the less precise common scab incidence of the seed lines that were determined by small sub-samples of a whole seed crop for the seed certification process, there was no obvious correlation. These findings question whether the maximum limits and seed sampling for seed certification are meaningful to seed buyers and fair to seed growers. In the former question, the maximum limits of 1% to 4% infected seeds did not appear to be meaningful, and we could not detect any obvious differences between them. In the latter question, seed sampling places a very high risk of wrongfully rejecting a seed line that meets the maximum limits. When examining a sample of 100 seeds per seed line, there is a 32% chance of rejecting a seed line with 2% infected seeds at a maximum limit of 2%. Similarly, there is a 37% chance of rejecting a seed line with 4% infected seeds at a maximum limit of 4%. By increasing the maximum limit to 10%, there is a 0% and 0.2% chance of rejecting a seed line with 2% and 4% infected seeds, respectively. In sampling statistics, the increase in the number of seeds examined for seed certification did not substantially reduce the probability of wrongfully rejecting a seed line. Therefore, an increase in seed sampling numbers is likely to increase the cost of assessments, yet brings little or no benefit in improving sampling accuracy. An increase in common scab threshold, however, from 4% to 10%, has a much greater impact in improving sampling accuracy and preventing wrongful rejections of seed lines.

A worldwide review of seed certification schemes for potato scab shows that it is common for most schemes to accept a certain level of common scab on tubers and places greater importance on scab coverage. In the general standards of European Union countries, more than one third of the tuber surface needs to be covered (either common scab or powdery scab) for the tuber to be counted as *scabby*. In Scotland, the level of surface cover needs to extend to 25% before the tuber is regarded as *scabby*. The various United States of America (USA) certification schemes all differ, but most deem that seeds with less than 5% of the tuber surface covered by scab lesions are not important and hence not counted in scab assessment, but any presence of pitted scab on a tuber is regarded as being *scabby*. Among eight national certification schemes examined, other than Australia, only South Africa consider and count the presence of common scab lesions on a tuber as being *scabby* for the purpose of assessment. In South Africa, the maximum tolerance level for any common scab on seed lines is 10%. In Australia, the maximum limit of acceptable common scab is 1% in New South Wales, 2% in Victoria and Western Australia, and 4% in South Australia and Tasmania. These limits mean that, compared with other certification schemes around the world, the Australian thresholds for maximum levels are unusually harsh and also set very low. There has been no previous study in Australia to support the low maximum tolerance levels of 1% to 4%, and in this project, there was no supporting evidence for these limits.

In this project, soil samples were collected from field trial areas and sent to Dr. Nigel Crump of DPI Victoria, in order to test for soil borne common scab inoculum, to assist in determining the relevance of seed borne vs soil borne inoculum. Unfortunately, the PCR tests for common scab were still at the early stages of development, and no test results could be provided for interpretation in this project.

Figure 1: The relationships between common scab incidence on untreated seed lines and the common scab incidence on daughter tubers



Common scab coverage in certification standard

This project also demonstrates a strong correlation between seed lines' common scab coverage and their transmission on to daughter tubers. Substantial increases in the incidence of common scab on daughter tubers were only noted when 4% or more tubers have greater than 5 lesions or with greater than 2% surface cover. This suggests that 4% tubers with more than 2% surface cover could be a useful benchmark. With more than 2% surface cover, infected tubers are easier to detect and assess with greater accurately compared to those tubers with less than 2% surface cover. Sometimes, soil on seed tubers can obscure a few common scab lesions. In Canada, U.S.A. and Europe, scab severity based on the percentages of tubers with high surface covered by common scab or deep scab are typically used as benchmark levels instead of the presence of any scab lesions. When considering a new standard for common scab on seeds, the Canadian certification scheme, which gives consideration to both scab coverage and incidence, may be a suitable compromise. The Canadian certification scheme accepts up to 10% of light scab (less than 5% surface cover) and up to 5% moderate scab (5% to 10% surface cover) in a seed lot. Most of the infected seeds in Australian seed lines have light scab cover of less than 5% surface cover.

Seed sorting and washing

Seed sorting to remove and reduce the scab level in infected seed lines is a practice that is regularly used by seed growers in Victoria to achieve the acceptable limit for seed certification. Harvested seeds, with obvious and high scab coverage of 20% or more, can be easily spotted and are often removed. Seed lines that have different levels of common scab at harvest, therefore, can have little or no scab after careful sorting and look similar. In this project, the sorting of seeds that had relatively high common scab incidence ranging from 20% to 75% infected tubers to 0%, 2% 25% or 50% infected tubers were shown to give no beneficial effects in reducing seed borne common scab transmission. Seed lines with 20% or more infected tubers before sorting, consistently caused substantial increases in common scab transmissions compared to control seeds that had no visible common scab lesions.

These findings, therefore, seriously challenge the current practice of systematically sorting and removing disease infected seed after harvest. There has been no previous scientific study to support its use, and this project demonstrated that there is little or no benefit in such sorting on common scab. Instead, it can be counter-productive, as careful sorting can disguise the inherent levels of *Streptomyces scabies* inoculum within a seed line. This may give the false impression that the seed line has 0% common scab and will not be potentially infective to new ground. Moreover, the practice of sorting seed is very labour intensive and adds significantly to the overall cost of seed production. In addition to common scab, this project also raised questions as to the cost benefits of sorting for other tuber diseases such as black scurf and powdery scab. The methodology used in this project to study the effects of sorting on common scab, could also be used to provide quantitative data, and to examine the cost benefits of sorting for other tuber diseases.

Some seed growers also use seed washing as a commercial practice in preparing their early generation seed for planting. There is a view that washing helps to remove some of the scab inoculum as well as other pathogens from the seed surface, thus reducing the risk of transferring the disease to the next generation. In this project, washing of common scab infected seed lines did not reduce common scab transmission.

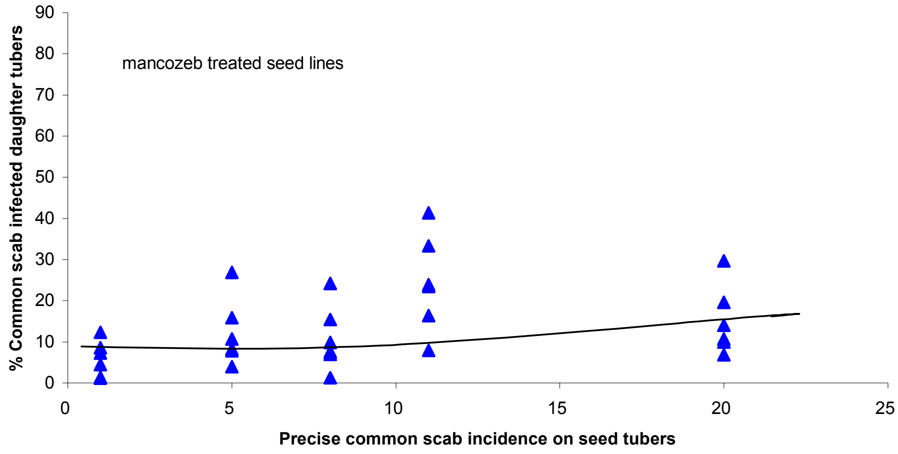
Seed management

The lack of beneficial effects due to seed sorting and seed washing on common scab transmission suggests that the seed industry may need to review such practices. The additional cost, especially in seed sorting to reduce common scab incidence to acceptable thresholds, gives misleading expectations by seed buyers. Chemical seed treatments could be used instead of the labour intensive and costly method of sorting and grading seeds to meet the maximum tolerance limits. Chemical seed treatments to control seed borne common scab were shown to be more effective over many field trials. Mancozeb and fludioxinil (Maxim 100FS®) seed treatments were shown to be effective and consistent in Tasmanian and Victorian field trials in controlling common scab from infected seeds that have low scab coverage of less than 5%. In a Tasmanian field trial conducted on new ground, the mancozeb treated infected seeds resulted in a similar scab levels as control seeds that had no visible common scab. There were no obvious differences in the levels of disease control between Maxim® treated seeds in comparison to mancozeb treated seeds. This indicates that where mancozeb dusting treatment poses an occupational hazard to seed operators, Maxim® liquid spray application may used as an alternative. Maxim® spray application is also regularly used for seed borne *Rhizoctonia* control.

In one Tasmanian field trial conducted on new ground and two Victorian field trials on soils that appear to have low levels of inoculum, the mancozeb treated infected seeds resulted in similar scab levels as control seeds that had no visible common scab. These results have important considerations for seed growers in managing seed crops for minimal common scab. They show that while the disease remains at low levels and as surface cover only, chemical treatment is as effective as planting clean seed. Sorting to remove infected seed is not effective. Therefore, seed growers should not attempt to sort and remove scab infected seed on early generation seed lines, but should ensure that these seed lines are chemically treated before planting. Chemical treatment probably should not be delayed until the generation prior to certification or certified seed itself, as the scab levels may be increasing in successive generations and treating G4 or G5 seed may not be effective if high scab incidence and coverage, or deep scab develops in the later seed generations.

Streptomyces had been shown to multiply rapidly in rhizosphere and spread through growth of roots and tubers (Curl & Truelove 1986, Keineth & Loria 1989, Wang 2005). Therefore, seed growers need to manage scab control in early generations, and chemically treat early generations to remove scab.

Figure 2.14: The relationships between common scab incidence on mancozeb treated seed lines and the common scab incidence on daughter tubers



Powdery scab

Field trials conducted within commercial crops to examine the impact of scab incidence, coverage and severity on seed lines in Tasmania in 2003-2005, resulted in high levels of powdery scab on their daughter tubers. Over this period, substantial improvements in cultural practices adopted by growers led to powdery scab becoming the prevalent scab disease in all these trials. Regular soil moisture monitoring led to increased frequency of irrigation, hence creating conditions that favour powdery scab rather than common scab. These changes resulted in the increased prevalence of powdery scab on seed lines, and reduced the importance of common scab on seed lines. In Victoria, powdery scab also appeared to be more widespread in seed production areas. Studies demonstrated that relatively low powdery scab incidence on seed lines at approximately 10% did not resulted in increased powdery scab incidence or deep scab incidence. Only a seed line with 25% powdery scab incidence and 32% deep pitted scab caused an increase in the deep scab incidence. Chemical seed treatments with mancozeb or Maxim 100FS® were shown to help reduce powdery scab levels on daughter tubers.

Maximum scab threshold limits for common scab may also applies to powdery scab. *S. subterranae*, the powdery scab pathogen, produces large quantities of spore balls that can become soil borne and airborne. In recent test studies, spore balls were frequently detected in soil dust that accumulates in seeds and seed stores. Therefore, powdery scab could still be carried on seeds that have no visible powdery scab lesions. Certification standards for common scab are similar to those used for powdery scab in Australia. Similarly, these limits for powdery scab are also very low and unusually harsh in comparison to standards used by North American and European Union countries, where only infected tubers with high scab coverage are counted in scab assessments for seed certifications.

Technology Transfer

- A one-page summary on the project's background, aims and methods was distributed to the project focus group at the first group meeting.

- A meeting was held at Devonport on 1st August 2003 with potato industry representatives, to review and discuss project outcomes for the first year's study. Copies of a PowerPoint presentation of trial findings from the above meeting were made available to those industry representatives who requested it.

- Project outcomes were also presented at a Tasmanian vegetable extension day held at Devonport on 5th September 2003. This was well attended by Tasmanian growers, industry representatives and researchers.

- A summary of the project's proposal and aims was published in Potato Australia, in September 2002, Volume 13. Updates on project findings were published in Potato Australia in 2003, 2004 and 2005.

- Project studies were presented at the Common Scab workshops in Melbourne on 8th December 2003, and in Devonport on 10th December 2003, by Tony Pitt and Hoong Pung, respectively. Dr. Calum Wilson organized the workshops as part of project PT02013, to enable overseas researchers on common scab to meet and present overseas studies to Australian researchers, growers and representatives from the potato industry.

- Project updates were presented to the Tasmanian representatives of the potato industry on 15th October 2004 in Devonport.

- Presentation of project findings by Tony Pitt to seed growers in Victoria at the 12 April 2006 committee meeting.

- Presentation of project findings by Tony Pitt to the Australian Seed Potato Advisory Group annual meeting in 20 July 2006 in South Australia.

- .An overview of project findings and their implications will be discussed with the Australian Seed Advisory Committee in their next meeting in Adelaide in 2006.

- A paper on common scab and prevention through seed management to be presented to the McCain Growers at their annual workshop at Ballarat Demonstration Farm by Tony Pitt in August 2006.

- Paper on common scab prevention in certified seed to be presented at the ViCSPA annual general meeting in Victoria and Tasmania.

- Presentation of project findings by Hoong Pung and Tony Pitt to the Tasmanian potato industry in May 2006.

- Project findings and their implications will be published in Potato Australia in September 2006.

References

Adams, M.J. , Hide, G.A.,1981. Effects of common scab (*Streptomyces scabies*) on potatoes. Annal of Applied Biology 98: 211-216.

Bahme, J.B., M.N. Schroth, 1987. Spatial-temporal colonization patterns of a rhizobacterium on underground organs of poato. Pythopathology 77: 1093-1100.

Curl, E.A., B. Truelove, 1986. The rhizosphere. Srpiger-Verlag, Berlin.

Falloon, R.E., A. R. Wallace, M. Braithwaite, R.A. Genet, H.M. Nott, J.D. Fletcher, W.F. Braam, 1996. Asessment of seed tuber, in-furrow, and foliar chemical treatments for control of powdery scab (*Spongospora subterranea f. sp. subterranea*) of potato. New Zealand Journal of Crop and Horticultural Science, 24: 341-353.

Keinath, A.P., R. Loria, 1989. Population dynamics of Streptomyces scabies and other actinomyces as related to common scab of potato. Phytopathology 79: 681-687.

Loria, L, 2001 Common scab. In “Compendium of Potato Disease”. Second Edition. American Phytopatholigcal Scoiety, St. Paul, MN. pp14-15.

Pung, H. & Cross, S., 2000a. Investigation on common scab diseases of potatoes and development of control methods. HRDC Project PT96010. Final Report

Pung, H. & Cross, S., 2000b. Common scab – incidence on seed potatoes and seed-borne disease control. Proceeding of Australian Potato Research, Development and Technology Transfer Conference, Adelaide, South Australia, p81-84.

Ryan, A.D., L.L. Kinkel, 1997. Inoculum density and population dynamics of suppressive and pathogenic Streptomyces strains and their relationship to biological control of potato scab. Bioloical Copntrol 10: 180-186.

Wang, Aixia, 2005. Role of Seed Tubers in the Spread of Plant Pathogenic Streptomyces and Initiating Potato Common Scab Disease. American Jounral of Potato Research. May/June issue.

Wilson, C. 1995. Integrated management of potato common scab. HRDC Final report PT205.

Wilson, C.R., Ransom, L.M., and Pemberton, B.M. 1999. The relative importance of seed-borne inoculum to common scab disease of potato and the efficacy of seed tuber and soil treatments for disease control. Journal of Phytopathology 147: 13-18.

Information on seed certification schemes compiled from the following reference sources:

SOAEFD (2000)	The Seed Potatoes (Scotland) Regulations 2000, Scottish Statutory Instrument 2000 No 201, Queens Printer of Acts of Parliament.
CFIA (2002)	Consolidated Statutes and Regulations, Seeds Act, Seeds Regulations Part II Seed Potatoes, Department of Justice, Canada.
UNECE (2003)	Revised UNECE Standard for Seed Potatoes (S-1), Working Party on Agricultural Quality Standards, Economic Commission for Europe.
DANI (1981)	Classification of Seed Potatoes in Northern Ireland, Seed Potatoes Regulations (Northern Ireland) 1981 No 243, Department of Agriculture.(of Northern Ireland).

NAK (2003) The Inspection of Dutch Seed Potatoes: The Importance of Approval. Nederlandse Algemene Keuringsdienst voor zaaizaad en pootgoed van landbouwgewassen 2003

HAL (2002) The National Standard for Certification of Seed Potatoes. Seed Potato Advisory Group, Horticulture Australia Limited, 2002

Seed Potato Advisory Committee (1994) Rules of the New South Wales Seed Potato Certification Scheme, May 1994. NSW Seed Potato Advisory Committee.

Hegney M. and Holland M. (1998) Western Australian Certified Seed Potato Scheme Production Rules, Potato Growers of Western Australia September 1998.

Primary Industries and Resources SA (1998) Seed Potato Certification Scheme 1998, Grower Guidelines. Primary Industries of South Australia.

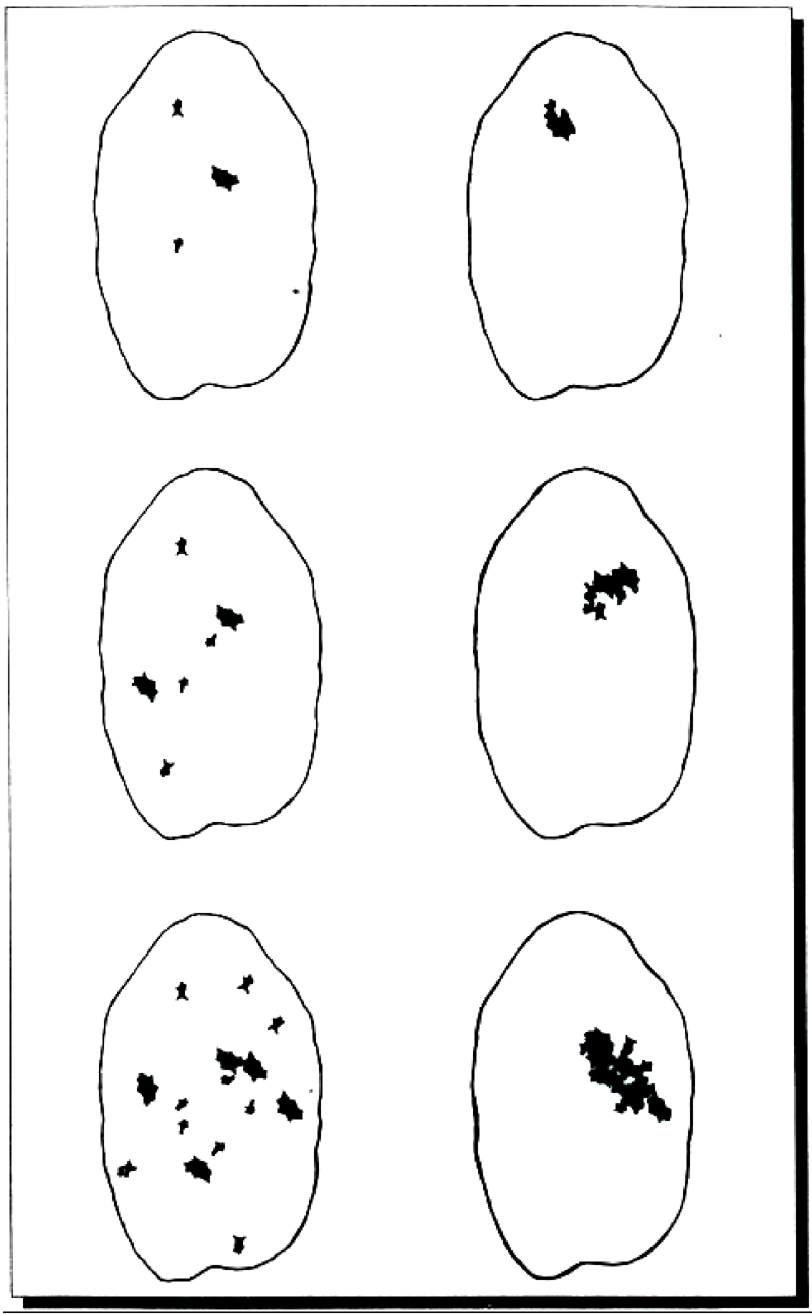
Colorado State University (1996) Colorado Rules and Regulations for Certification of Seed potatoes, May 1996. Colorado State University Cooperative Extension Service

DPIWE (1999) Tasmanian Seed Potato Certification Scheme, July 1999. Tasmanian Department of Primary Industries and Environment.

ICC (1998) Maximum Percent Insect and Pathogen Infected Seed Potatoes Permissible, Government Gazette May 15, 1998, Republic of South Africa.

Appendix i - Percent coverage of tuber surface

Scatter Cluster



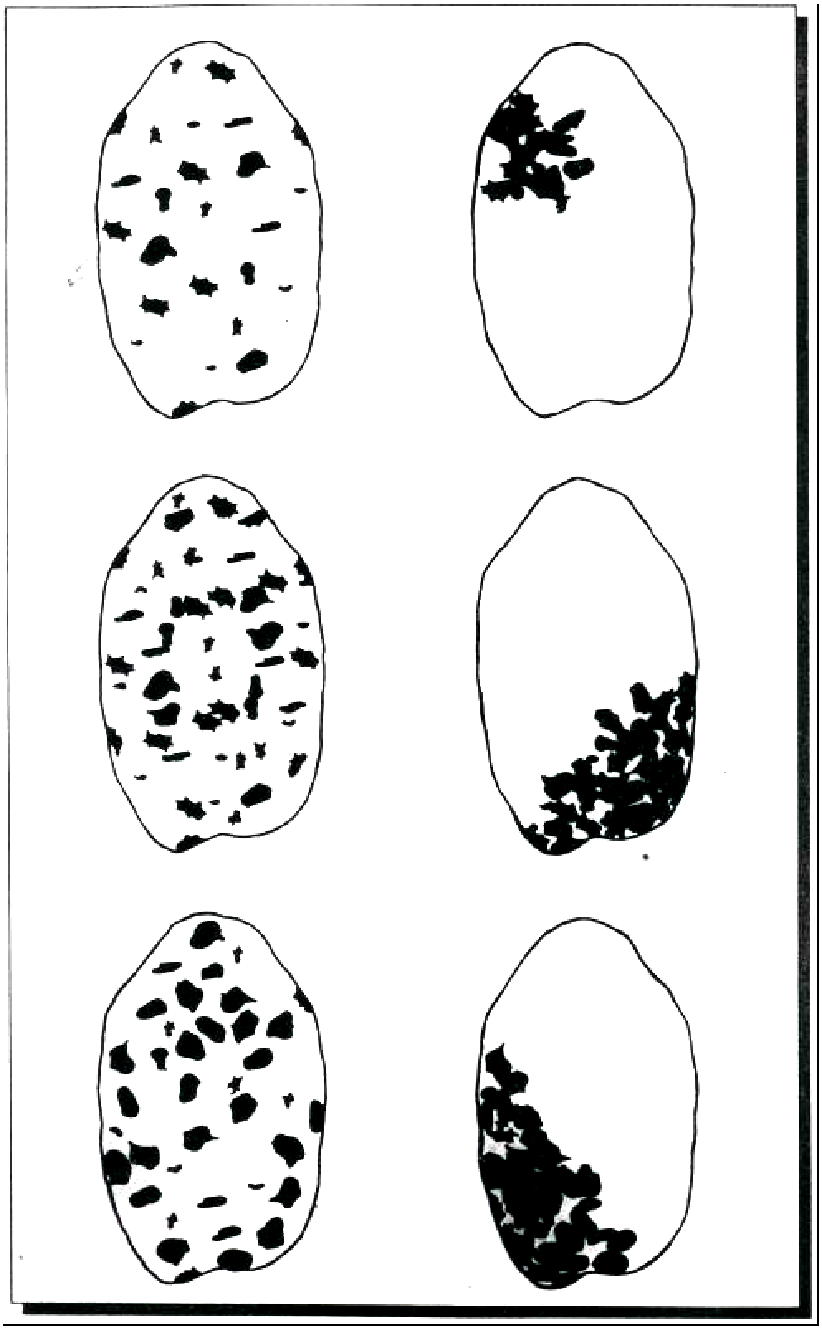
1%

2%

5%

Percent coverage of tuber surface

Scatter Cluster



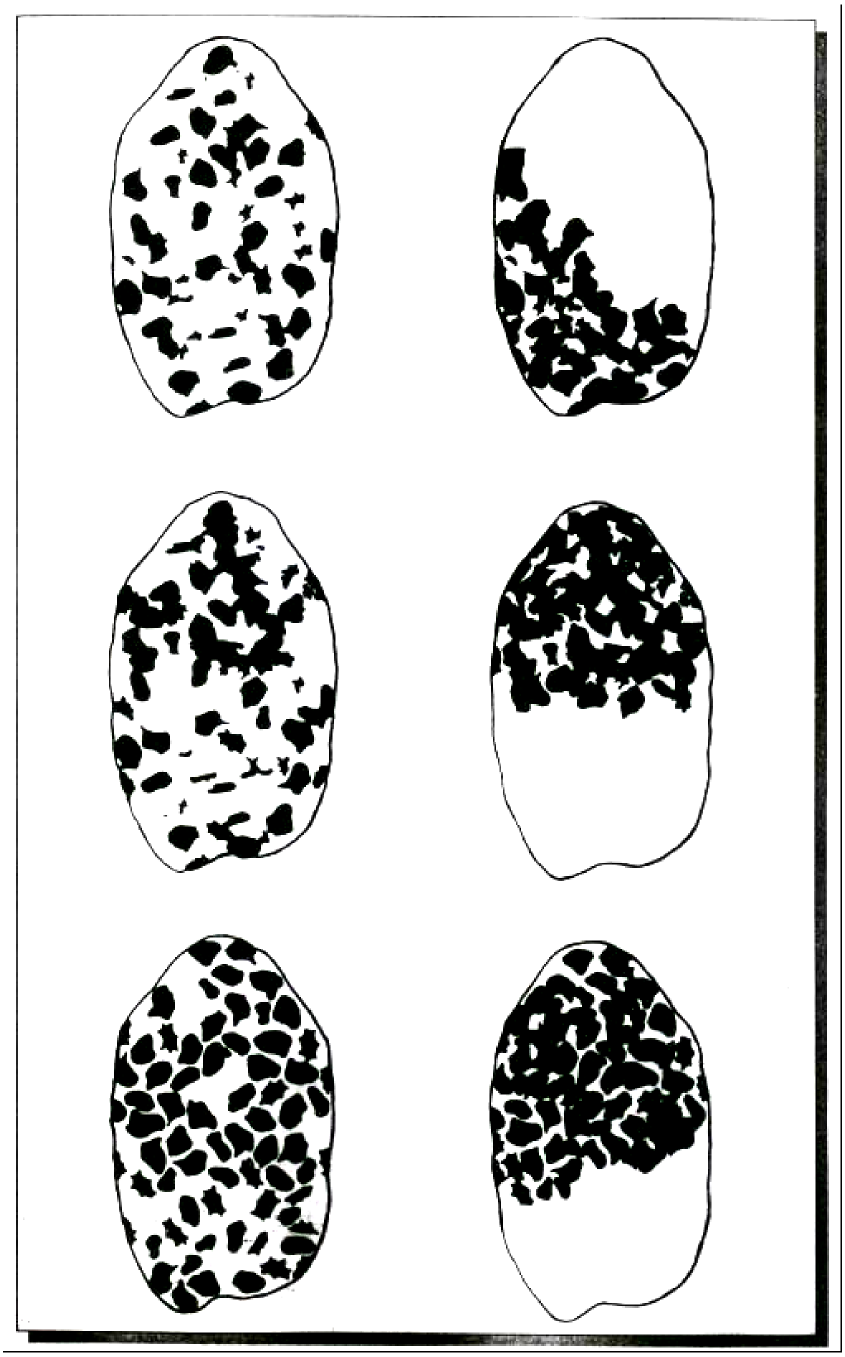
10%

20%

25%

Percent coverage of tuber surface

Scatter Cluster



30%

40%

50%