PT022
Improving cosmetic quality of ware potatoes

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Know-how for Horticulture™

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Improving Cosmetic Quality of Ware Potatoes

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HORTICULTURAL SCIENCE GROUP, SCHOOL OF AGRICULTURE
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Table of Contents

Index to figures/tables

Figures:

Tables:

1. Executive Summary

Project aims:

To define and document the cosmetic quality problems causing significant downgrading of potatoes produced in the Manjimup/Pemberton region of Western Australia. The project has been divided into two phases; problem definition using stored and collected data, and investigation of the causal agents of the identified problems. Problem definition was given priority due to the limited time available. This task was achieved by analysis of stored quality data and by on-site sampling of the 91/92 Manjimup/Pemberton production period. A limitation of the stored quality data was that only incidence within consignments (qualitative data) was available. Some preliminary statistical analysis of the data carried out.

Stored Data Analysis:

Background: Quality data recorded on consignment pack-out slips held at the WA Potato Marketing Authority was assessed for the 1988/89, 89/90, 90/91 seasons. Comparisons of Delaware production between the Manjimup and Pemberton localities, and between the four major potato producing regions of WA were made. Additionally, two other white varieties (Sebago and Coliban) produced within the Manjimup /Pemberton region were compared to Delaware in terms of indicated quality problems.

Results: *Greening, injuries, malformation, insect damage, skin blemish, staining, lenticel problems, second-growth, growth cracks and scabs were found to be the most frequently reported quality problems* in Delaware tubers from the Manjimup/Pemberton region. Minor differences in reported malformation, lenticel problems and staining exist between the Manjimup and Pemberton localities. However, when compared to the rest of the state both localities were found to have relatively high levels of these problems.

Reported frequencies of malformation, skin blemishes, lenticel problems and periderm staining show an increasing trend over recent years. A comparison of the major potato producing regions of WA showed that malformation, skin blemish, periderm staining and second-growth occurred mainly in the Manjimup /Pemberton area. It is most likely that these problems are related to the soil type within the region (heavy red karri loam).

Recommendations: The analysis highlighted inefficiencies in the recording of quality data and it was recommended that the indicated quality section of the consignment pack-out slip be re-designed to allow estimation of the proportion of consignment affected by the problem. A new design was implemented in 1991 and the pack-out slip is now a more refined feed-back tool for the industry, as well as a more efficient vehicle for future historical surveys of reported cosmetic quality. Additionally, a cosmetic quality problem identification poster to complement the new pack-out slip design was recommended.

1991/92 On-site Production Sampling

Background: An on-site sampling programme was used to assess the 1991/92 potato crop from the Manjimup/Pemberton region. Samples of Delaware tubers were removed from production areas chosen at random from the Manjimup/Pemberton region. Tubers were taken at harvest for both spring (August, September) and summer (December, January) planted crops, and at five weeks prior to harvest for the spring crop. A comparison of the response of differing seed 'types' of Delaware was also made.

Results: Most cosmetic quality problems occurring in 1991/92 produced Delawares could be related to irrigation practices and soil compaction. *The cosmetic quality problems that occurred above 5% of the sample were minor periderm russeting, lenticel rotting, physical malformation, peridermal staining, pre-harvest soil abrasion, netted growth cracking, silver scurf/black dot, second-growth, periderm suberisation, pre-harvest greening, insect damage, scabs and rhizoctonia sclerotia.*

The majority of the physical malformation present was in the form of minor tuber denting and angular growth, such as may be expected from compacted soils. Second-growth occurred mainly as knobs, with some pointed end and elongation also being present. *Minor russeting, staining and suberisation of the periderm were highlighted as affecting the overall appearance of the tuber.*

Lenticel rotting, physical malformation, pre-harvest soil abrasion, peridermal staining and periderm suberisation were discovered at high levels mid-way through tuber development, while netted growth cracks, second growth, pre-harvest greening and pests/disease categories became prominent in the final weeks before harvest. *Physiological tuber shape problems and netted growth cracking were found to be more prevalent in summer produced tubers.*

The high levels of physical malformation, pre-harvest greening and tuber russeting point to soil compaction in the region. Inter-tuber compaction may have inhibited tuber growth as well as affected periderm quality (russeting) through inadequate aeration and ethylene build-up. The high levels of pre-harvest greening may be linked to restricted rooting and subsequent shallow tuber set caused by hard pans under the ridge. A preliminary penetrometer survey of two production areas within the region shows *soil strengths of up to 20 bars at 30 cm depth from the ridge top.*

This problem would have been further compounded by wash-out due to heavy rainfall experienced early in the 1991/92 production period. *The shallower rooting would also make the plants more susceptible to water deficit stress, thus increasing the levels of second growth and netted growth cracking.*

A variation in the response of plants from differing seed sources to stress was found.

Recommendations: Production sites known to have high aggregate levels and compaction/drainage problems should be avoided wherever possible. Use of tensiometers to monitor soil moisture levels is recommended to allow accurate timing of irrigation, thus circumventing waterlogging problems such as lenticel rots. Irrigation regimes should be modelled on those supplied by the WA Department of Agriculture for the soils in the area. Where applicable, increased irrigation frequency to avoid stress related problems such as second-growth and netted growth cracking is advisable. Regular random sampling by growers across the tuber development period will enable prompt identification and action to rectify problems of known origin and treatment (eg. pests/disease, irrigation related problems). The use of wider ridges is recommended for production areas producing high levels of preharvest greening.

A soil compaction survey should be conducted across production sites in the Manjimup/Pemberton area. Determination of the existence of hard pans and their distribution within production areas could be correlated with a detailed cultural practices survey. Mapping of the distribution of soils susceptible to compaction within the region would also be beneficial. An extension programme covering compaction avoidance techniques on susceptible soils can be coupled to this work. Crop scale field trials with treatments designed to alleviate soil compaction (ie precision tillage, general deep ripping, gypsum application) can be conducted. Assessment of the variation between seed potatoes based on clonal source and pre-planting treatment in response to timing and severity of stress is needed. The results of an investigation of the effects of varying storage time and temperature within and between cultivars could be used to advise seed growers.

Postharvest quality

Background: Samples of Delaware tubers were randomly taken at the merchant level from bulk ungraded consignments. The tubers were assessed for postharvest mechanical damage and greening.

Results: *Approximately 47% (retransformed data) of tubers sampled were found to have some form of postharvest damage.* The majority of this damage was minor impact splits/cracks and bruising. Digger damage (gouges, cuts etc) occurred in approximately 2% (retransformed data) of tubers. Misshapenness of tubers was found to not affect levels of impact splits/cracks. *However, poorly shaped tubers were found to be significantly (P<0.05) more susceptible to bruising..*

Both impact splitting and bruising were found to bear a positive correlation to tuber mass. Greening levels in the postharvest sample were found to not differ significantly (P<0.05) from levels present pre-harvest.

Recommendations: The relatively high levels of mechanical damage present in Delaware may be extrapolated to other varieties. Clearly, a further detailed survey to define points of occurrence of postharvest damage in the production chain is necessary. Aspects of handling such as drop heights during bulk tuber transferral and machinery settings should be investigated. An extension programme covering damage avoidance techniques (both pre-harvest and postharvest) is needed. Additionally, cultural practices that reduce pre-harvest greening should be encouraged.

ii. Acknowledgments

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♣

" The greatest tragedy of science
is the destruction
of a beautiful hypothesis
by an ugly fact!"
T.H. Huxley

1.0. Introduction

The Problem

Poor cosmetic quality of ware potatoes produced in the Manjimup/Pemberton area of Western Australia has been reducing grower returns in recent years. The major problems were reported to be shape and periderm discolouration, or 'staining', in white varieties. In recent years, there has been a trend for increased superficial cosmetic quality of tubers at the point of sale, particularly since tuber washing became commonplace. Tuber periderm condition, while rarely affecting internal quality, does affect consumer choice in a very competitive local market.

Historical factors

Quality of potatoes originating from the Manjimup/Pemberton region has been assessed previously. In 1967 the Western Australian Department of Agriculture conducted a survey of the factors affecting the percentage of grade I potatoes (Fallon 1967). The regions surveyed were Perth, Bunbury, Albany and Manjimup, with both spring and summer crops from Manjimup sampled. The survey defined second growth greening, mechanical injury and insect damage as the main reasons for downgrading No distinction was made concerning the relative quality of tubers sampled from spring or summer crops within the Manjimup/Pemberton area.

The project

The major aim of this project was to define and document the cosmetic quality problems causing significant downgrading of potatoes produced in the Manjimup /Pemberton region of Western Australia. The project was divided into two aspects problem definition, and causal agent investigation. Under the constraints of the project the problem definition stage was given priority. Problem definition was further divided into two stages. Stage 1 involved the assessment of stored pack-out data for the region over time, with the intention of pinpointing those quality problems increasing in significance in recent years. An equal number of growers were surveyed from both th Manjimup and Pemberton areas. Indicated quality information contained on pack-ou statements held by the WA PMA for these growers was analysed for the previous thre seasons. Stage 2 entailed on-site sampling at various levels of production for th 1991/92 Manjimup/Pemberton season. Sampling of tubers during development, a harvest for extremes of season, and across the delivery period at the merchant packe level was used to gain an accurate picture of the predominant cosmetic quality problem for the 91/92 season. Such data would enable priority areas for on-going research to b pin-pointed, and as such ensure efficient use of time and available resources. Due to i dominance in the region, and restricted time and resources, the variety Delaware wa chosen for close examination under the terms of the survey.

The results of the surveys presented in this report are an over-view (Manjimup/Pemberton Delaware production in recent years. The results do n represent any individual or property within the region.

Literature cited

Fallon, J.P. (1967). Factors affecting the percentage of grade 1 Delaware potatoes in Western Australia. *Proceedings of the Australian Potato Agronomy Conference, Victoria* pp 10(b) 1-3.

2.0. Stored Data Analysis.

2.1. Abstract

Quality data recorded on consignment pack-out slips held at the WA Potato Marketing Authority was assessed for the 1988/89, 89/90, 90/91 seasons. Comparisons of Delaware production between the Manjimup and Pemberton localities, and between the four major potato producing regions of WA were made. Additionally, two other white varieties (Sebago and Coliban) produced within the Manjimup /Pemberton region were compared to Delaware in terms of indicated quality problems.

Greening, injuries, malformation, insect damage, skin blemish, staining, lenticel problems, second-growth, growth cracks and scabs were found to be the most frequently reported quality problems in Delaware tubers from the Manjimup/Pemberton region. Minor differences in reported malformation, lenticel problems and staining exist between the Manjimup and Pemberton localities. However, when compared to the rest of the state both areas were found to have relatively high levels of these problems. Trends in cosmetic quality problem occurrence in consignments over time were highlighted. Reported frequencies of malformation, skin blemishes, lenticel problems and periderm staining show an increasing trend over recent years. Malformation, skin blemish, periderm staining and second-growth were shown to be a particular problem in the Manjimup/Pemberton area when the major potato producing regions of WA were compared. It is most likely that these problems are related to the soil type within the region.

Sebago and Coliban showed a significantly higher incidence of lenticel problems and significantly lower incidence of reported malformation and second growth compared to Delaware. A large decrease in lenticel related down-grading, coupled with the decreased susceptibility to malformation and second growth, may well lead to significantly higher premium and class I yields for Sebago and Coliban compared to Delaware. The high levels of greening and injury across the varieties suggest a problem in harvest and postharvest handling.

The analysis highlighted inefficiencies in the recording of quality data by Quality Inspectors. The indicated quality section of the consignment pack-out slip was re-designed to allow estimation of the proportion of consignment affected by the problem, thus refining the slip as a feed-back tool for improvement of quality delivered.

2.2. Background information

Quality problems within a potato consignment are recorded by Quality Inspectors on the Western Australian Potato Marketing Authority (WA PMA) consignment pack-out slip. As these slips are filled out for every consignment passing through the system, they are excellent resource for the analysis of recent cosmetic quality trends. Up to November 1991 the quality problems were recorded on a present/absent basis. For this reason, the results do not in any way indicate the extent to which each load is affected. For example, greening may be recorded as being present in 20% of loads delivered, but proportions within each consignment may only be 1% on average.

An historical analysis (1988/89, 89/90 and 90/91 seasons) of the pack-out slips held at the PMA will show new or continuing cosmetic quality problems, and narrow the scope for continued investigation. Broadly, soil types differ slightly between the Manjimup and Pemberton localities (McArthur and Clifton, 1975). In an attempt to further localise cosmetic quality problems, Delaware tubers delivered from properties within the localities were compared.

Regional relationships may exist with cosmetic quality. A comparison of broad potato producing areas of Western Australia should highlight such relationships. To further investigate the nature of cosmetic quality afflictions inherent within the Manjimup/Pemberton region, white skinned varieties other than Delaware were assessed. Determination of the relationship between variety and cosmetic quality problems would provide evidence towards identifying which of these problems were either site related or a product of varietal susceptibility to latent site conditions. Sebago and Coliban are two white skinned varieties grown in the Manjimup /Pemberton area, and represent a reasonably large proportion of white tuber production other than Delaware from that region.

The results presented here are an indicator of the major quality problems occurring in the Manjimup/Pemberton region that are coming to the notice of the WA PMA Quality Inspectors.

2.3. Materials and Methods

Recorded details of consignments of Delaware tubers originating from 20 growers within the Manjimup/Pemberton were sampled for three seasons (1988/89, 89/90, 90/91), and the quality data entered into a database. Half of these growers produced within the Pemberton locality, and half within the Manjimup locality. Although consignment number differed between growers, an approximate average of 20 consignments were delivered by each grower for each season. Additionally, 10 growers of Coliban tubers and 10 growers of Sebago tubers were sampled from within the Manjimup/Pemberton region and their consignment quality data collected from stored records.

The State was divided into four broad potato producing regions based on geographic location. These were Metropolitan, Bunbury/Harvey/Myalup, Busselton /Marybrook and Manjimup/Pemberton. A random sample of 10 large producers of Delaware tubers was selected from within each of these regions, and consignment quality data for three seasons (1988/89, 89/90, and 90/91) was analysed.

For details on statistics and transformation of the data please refer to Appendix 3.0. Miscellaneous Formulas/Analysis. The databases used were constructed using Microsoft Excel™ and the data was presented graphically using Cricket Graph™ on the Macintosh computer.

2.4. Results

Overall indicated cosmetic quality of Delaware tubers

The major reported reasons for downgrading of tubers were greening, injuries, malformation, insect damage, skin blemish, staining, lenticel problems, second-growth, growth cracks and scabs (Fig 2.1).

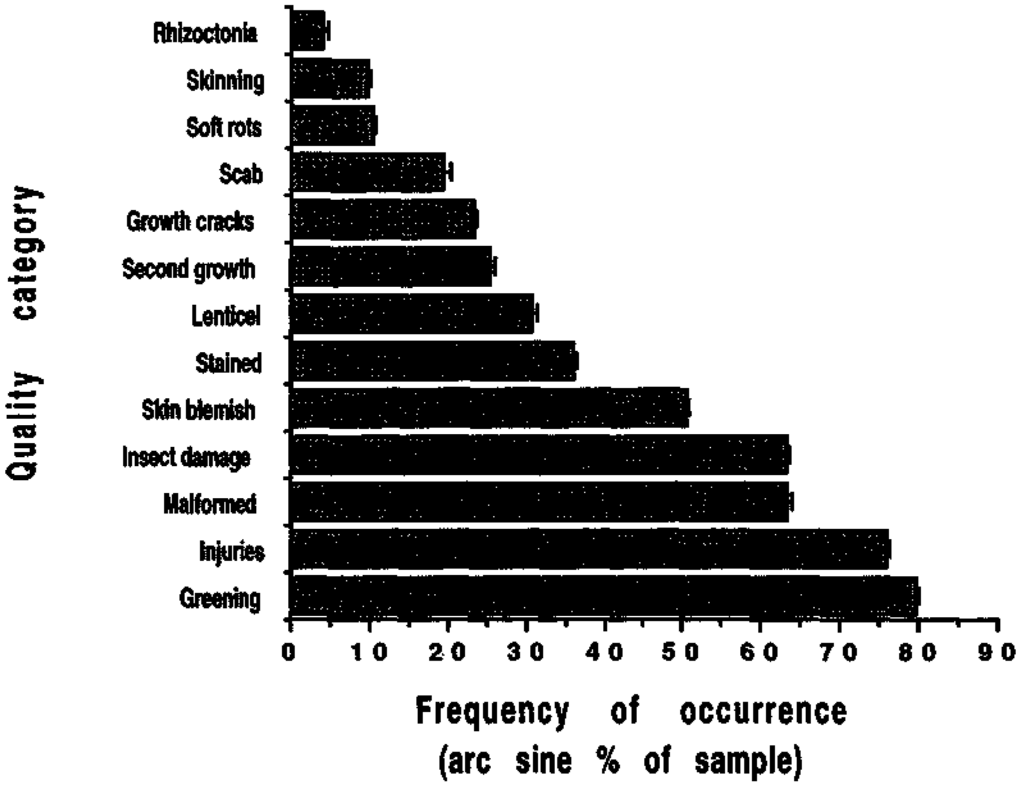


Fig 2.1. Mean reported frequency levels for cosmetic quality problems occurring in Delaware grown in the Manjimup/Pemberton region over the 88/89, 89/90, 90/91 production periods. Lines extending from the bars represent standard errors of the means.

Comparison of indicated tuber quality between Manjimup and Pemberton localities

Minor increases in the reported frequency of malformation, lenticel and second-growth were found in the Pemberton locality (Fig 2.2). No differences were found in the reported frequency of all other major quality problems.

Trends in reported quality over time

Reported greening and injury frequencies are variable but still relatively high over the three seasons (Fig 2.3). Insect damage, lenticel problems, malformation, skin blemish and periderm staining appear to be increasing in reported frequency over time.

Comparison of indicated cosmetic quality of some white skinned varieties grown in the Manjimup/Pemberton region

Sebago and Coliban had less reported malformation, but higher frequencies of insect damage, lenticel problems and soft rots (Fig 2.4). Greening, injury and periderm staining levels were equally high for all three varieties.

Comparison of the major potato production regions within Western Australia

Reported greening and injury frequencies were equally high across the major potato producing regions (Fig 2.5). Malformation, skin blemish, periderm staining and second-growth occurred at relatively higher frequencies in the Manjimup/Pemberton region. Scabs and skinning appear to be particular problems in production areas on the coastal sands.

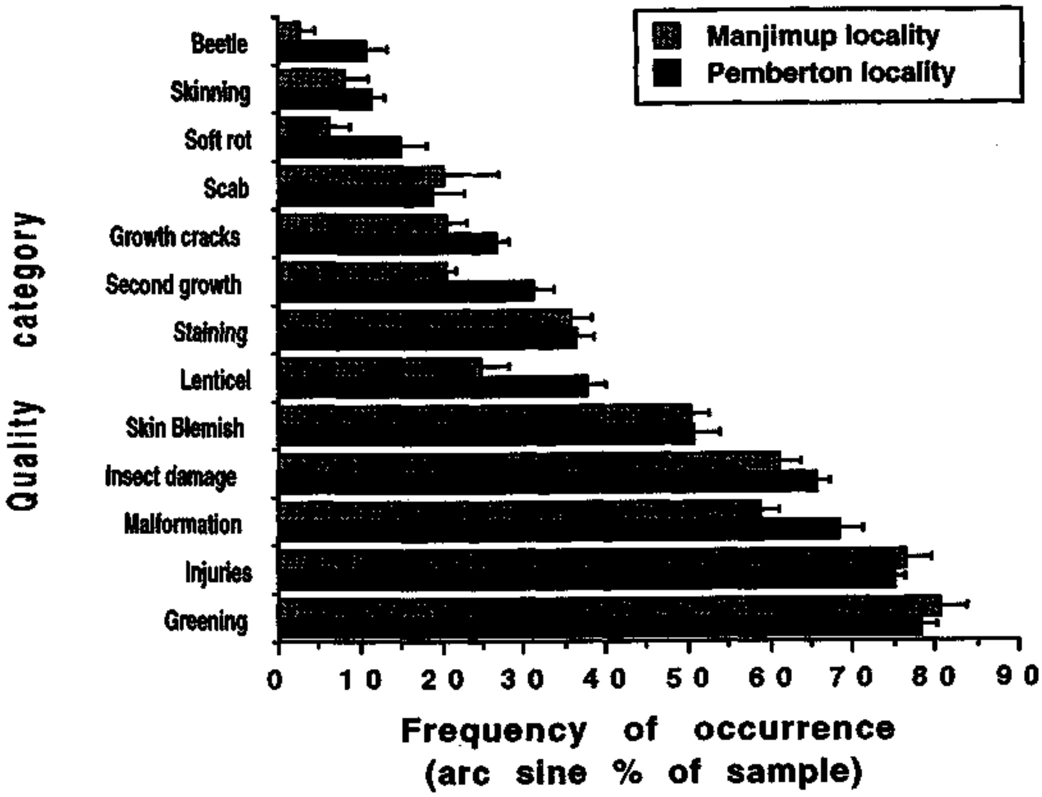


Fig 2.2. Locality effects on reported cosmetic quality for Delaware over a three seasons period (88/89,89/90,90/91). Lines extending from the bars represent standard errors of the means.

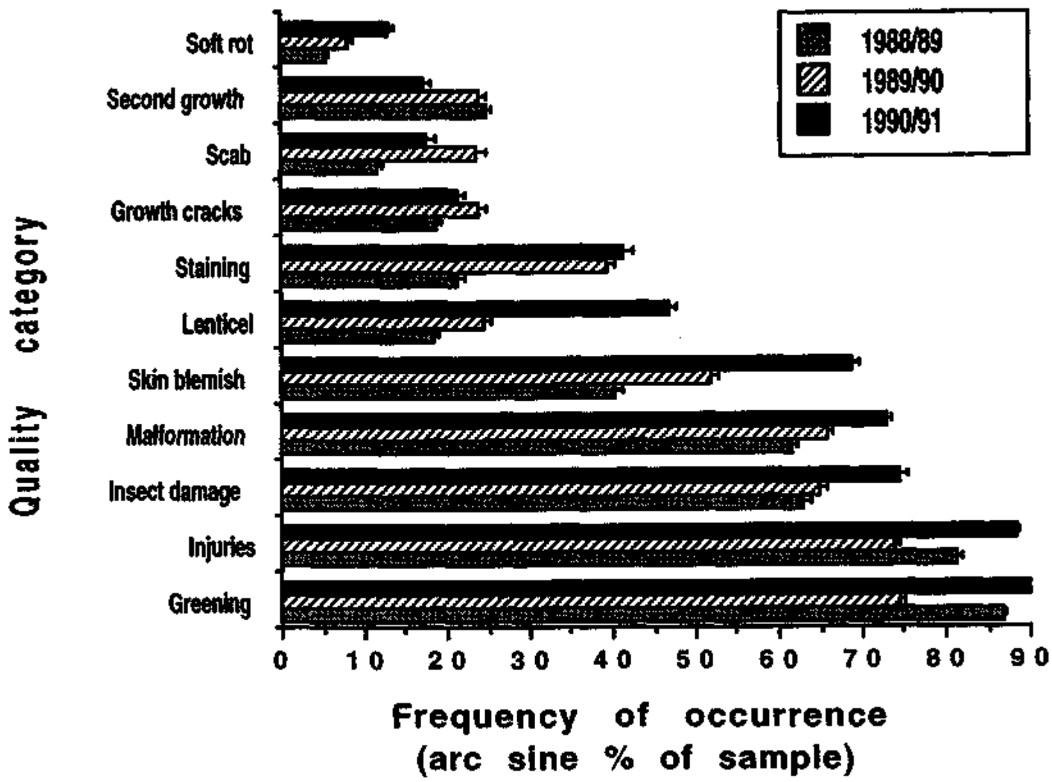


Fig 2.3. Trends in reported quality of Delaware tubers from the Manjimup /Pemberton region over three seasons (88/89,89/90, 90/91). Vertical lines extending from the bars represent standard errors of the means.

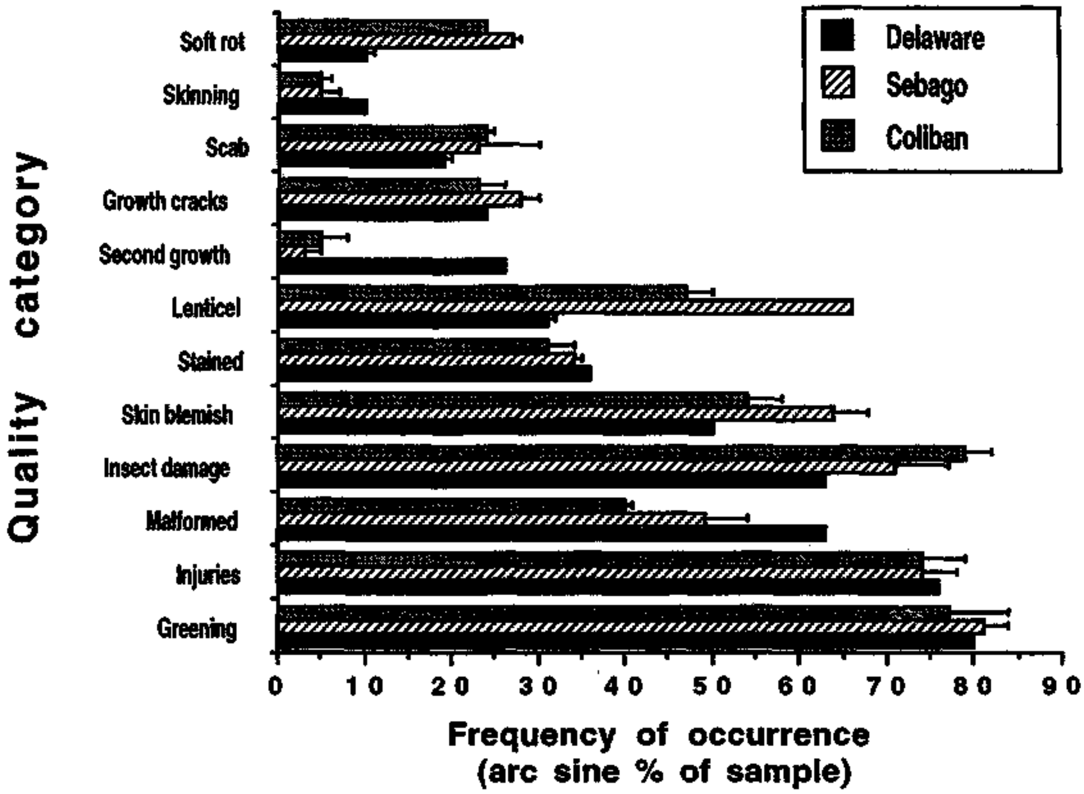


Fig 2.4. A comparison of three white periderm potato varieties produced in the Manjimup/Pemberton region in terms of reported cosmetic quality. Lines extending from the bars represent standard errors of the means.

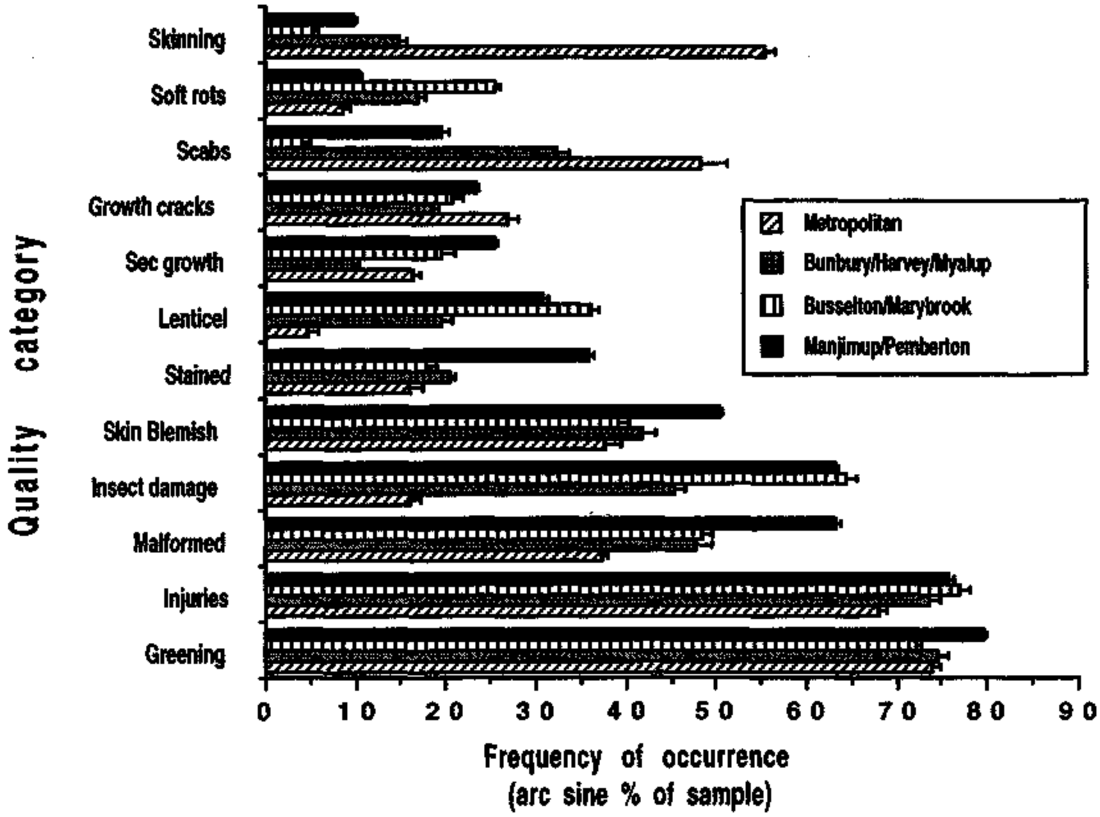


Fig 2.5. A comparison of the major potato producing regions of Western Australia in terms of reported cosmetic quality over a three season period (88/89,89/90,90/91). Lines extending from the bars represent standard errors of the means.

Quality of Potatoes Marred by: [Tick if Applicable]

1	2	3	
[ ]	[ ]	[ ]	Greening
[ ]	[ ]	[ ]	Malformation
[ ]	[ ]	[ ]	Growth cracks
[ ]	[ ]	[ ]	Second growth
[ ]	[ ]	[ ]	Soft rot
[ ]	[ ]	[ ]	Hollow heart
[ ]	[ ]	[ ]	Injuries-[ ]Split [ ]Bruised [ ]Harvest
[ ]	[ ]	[ ]	Lenticel-[ ]Enlarged [ ]Rotted
[ ]	[ ]	[ ]	Scab-[ ]Powdery [ ]Common
[ ]	[ ]	[ ]	Staining
[ ]	[ ]	[ ]	Skinning
[ ]	[ ]	[ ]	Internal Fleck
[ ]	[ ]	[ ]	Rhizoctonia
[ ]	[ ]	[ ]	Scurf
[ ]	[ ]	[ ]	Beetle
[ ]	[ ]	[ ]	Moth
[ ]	[ ]	[ ]	Weevil
[ ]	[ ]	[ ]	Eelworm
[ ]	[ ]	[ ]	________
[ ]	[ ]	[ ]	________

1 = 5% of load
2 = 5% - 25%
3 = >25%

DESCRIPTION OF WASTE COMPONENTS	%
Total	100

Fig 2.6. The redesigned indicated quality section of the WA Potato Marketing Authority's consignment pack-out slip.

2.5. Discussion

Overall indicated cosmetic quality of Delaware tubers

Reported levels of second-growth are high considering the data was collected at the Merchant wash/packer level of production. Second-growth affected tubers are highly noticeable and should have been removed from consignments at harvest. No indication was given as to the nature of injuries occurring within consignments, but it was assumed that the category was mechanical damage arising from harvest and postharvest transport. Greening in consignments can arise from both pre-harvest and postharvest exposure to light (Sinden 1987). Unfortunately, no distinction between the two forms can be made at the wash/packer level of production. The malformation category is basically a repository for all shape problems, and may or may not also include second-growth which can manifest itself in forms other than knobs.

Comparison of tuber quality between Manjimup and Pemberton localities

No major differences were found in reported cosmetic quality between the Manjimup and Pemberton localities (Fig 2.2). The frequencies of malformation, lenticel problems and second-growth were slightly greater for Pemberton, but both localities had relatively high levels of these problems compared to other potato growing regions in the state (Fig 2.5). The region can therefore be looked at in future work as a whole.

Trends over time

Greening and injury frequencies have remained at high levels over recent seasons (Fig 2.3). There is obviously a need for investigation into harvest and postharvest handling procedures at points on the production chain leading up to the wash/packer level. The apparent increase in frequency of insect damage, lenticel problems, malformation, skin blemish and periderm staining over the last three seasons is a cause for concern. These problems must be further defined and solved if quality of tubers from the Manjimup/Pemberton regions is to be improved.

Comparison of white skinned varieties

The same quality categories appeared as the major reasons for down-grading in all three of the varieties assessed. The greatest reasons for down-grading in both Coliban and Sebago were insect damage, greening, injury, skin blemish, lenticel problems, malformation, and staining (Fig 2.4). The major differences in the reasons for down-grading between these varieties and Delaware from the same region are lenticel problems, malformation, and soft rots. Both Sebago and Coliban showed a significantly higher incidence of lenticel problems and significantly lower incidence of reported malformation and second growth compared to Delaware. Lenticel problems arise from high moisture levels in the soil adjacent to the tuber, mainly due to over-irrigation (Rich 1983). A large decrease in lenticel related down-grading, coupled with the decreased susceptibility to malformation and second growth, may well lead to significantly higher premium and class I yields for Sebago and Coliban compared to Delaware. The difference in incidence of staining between the varieties appears to be not significant. This suggests that the phenomenon may not be a product of varietal susceptibility, and is evidence towards soil/cultural factors as the causal agent. The high levels of greening and injury across the varieties suggest a problem in harvest and postharvest handling.

Comparison between major potato production regions within Western Australia

Greening and injuries were reported at high levels for all the regions surveyed. The Manjimup/Pemberton region appears to have several inherent problems, these being malformation, skin blemish, staining and second-growth. Some cosmetic problems appear to follow a geographic trend. Reported malformation levels tend to increase as production moves from sandy coastal soils to heavier inland southern soils.

Improvement of pack-out slip format

A non-linear scale for the estimation of proportion was introduced to the indicated quality section of the consignment pack-out slip (Fig 2.6). Additionally, the categories listed on the slip were streamlined. The new system allows the Quality Inspector to indicate whether less than 5%, 5 - 25% or greater than 25% of the consignment is affected by any particular problem. The section allowing waste components to be estimated was re-introduced from an older pack-out slip design. The implementation of this system refines the indicated quality section as a useful tool for concurrent industry feedback and for future historical quality surveys.

2.6. Literature cited

McArthur, W.M., and Clifton, A.L. (1975). *Forestry and Agriculture in Relation to Soils in the Pemberton Area of Western Australia* CSIRO Soils and Landuse series no. 54.

Rich, A.E. (1983). *Potato Diseases* Academic Press, New York.

Sinden, S.L. (1987). Potato glycoalkaloids *Act. Hort.* **207:** 41-47.

3.0. 1991/92 On-site Production Sampling

3.1. Abstract.

An on-site sampling programme was used to assess the 1991/92 potato crop from the Manjimup/Pemberton region. Samples of Delaware tubers were removed from production areas chosen at random from the Manjimup/Pemberton region. Tubers were taken at harvest for both spring (August, September) and summer (December, January) planted crops, and at five weeks prior to harvest for the spring crop. A comparison of the response of differing seed 'types' of Delaware was also made.

The cosmetic quality problems that occurred above 5% of the sample for the whole of Delaware production were minor periderm russeting, lenticel rotting, physical malformation, peridermal staining, pre-harvest soil abrasion, netted growth cracking, silver scurf/black dot, second-growth, periderm suberisation, pre-harvest greening, insect damage, scabs and rhizoctonia sclerotia. The majority of the physical malformation present was in the form of minor tuber denting and angular growth, such as would be expected from compacted soils. Second-growth occurred mainly as knobs, with some pointed end and elongation present. Minor russeting, staining and suberisation of the periderm were highlighted as affecting the overall appearance of the tuber. Lenticel rotting, physical malformation, pre-harvest soil abrasion, peridermal staining and periderm suberisation were discovered at high levels mid-way through tuber development, while netted growth cracks, second growth, pre-harvest greening and pests/disease categories became prominent in the final weeks before harvest.

Physiological tuber shape problems and netted growth cracking were found to be more prevalent in summer produced tubers. The greater range of second-growth forms in the summer-grown tubers is thought to be the result of increased stresses experienced throughout the development period, mainly higher temperatures and wider soil moisture fluctuations. Soil and air temperature data recorded over tuber development support this argument. The corresponding high levels of netted growth cracking, a disorder that occurs in response to high soil moisture deficits, is added evidence for wide soil moisture fluctuations.

The high levels of physical malformation, pre-harvest greening and tuber russeting are evidence pointing to the presence of compaction in production soils in the region. Inter-tuber compaction may be inhibiting tuber growth as well as affecting the periderm quality through inadequate aeration and ethylene build-up. The high levels of pre-harvest greening may be linked to restricted rooting and subsequent shallow tuber set caused by hard pans under the ridge. A preliminary penetrometer survey of two production areas within the region shows soil strengths of up to 20 bars at 30 cm depth from the ridge top. This problem would have been further compounded by wash-out due to heavy rainfall experienced early in the 1991/92 production period. The shallower rooting would also make the plants more susceptible to water deficit stress, thus increasing the levels of second growth and netted growth cracking. A variation in the response of plants from differing seed sources to stress was found.

3.2. Background information.

On-site sampling was necessary to accurately define the types and levels of cosmetic quality problems in the Manjimup/Pemberton region. Sampling of the 1991/92 production period was carried out to achieve a number of objectives. Firstly, the frequency of occurrence of cosmetic quality problems immediately prior to harvest was defined. The timing of cosmetic quality problem occurrence was also desirable. Knowledge of problem frequency at a point during the growth period would be beneficial to understanding individual quality problems.

Liaison with growers in the region led to reports that cosmetic quality, particularly tuber shape, differed between 'early' and 'late' season production (spring and summer crops). Sampling to compare spring and summer produced tubers was carried out to assess these reports. Liaison with growers also produced the possibility of variation within seed type and source in terms of cosmetic quality. To this end, a limited comparison between two seed types of Delaware, and Crystal grown under similar conditions was undertaken.

3.3. Methods.

The data presented are for Delaware tuber samples taken from crops grown and lifted in the 1991/92 Manjimup/Pemberton production/harvest period (August 1991 to May 1992). A random selection of 12 major (classified according to quota data held at the Potato Marketing Authority) production areas were sampled from both early (January/February lifted) and late (April/May lifted) in the production period. Sampling of both early and late crops was carried out just prior to harvest, with an additional sample from the early crops at week 11 from planting. Sampling was conducted at 10 random points approximately 20 m apart in a zigzag fashion across the production area. Ten tubers were sampled at random from each point and bulked. Tubers used in the comparison of seed type were grown in the same field at the same time of year with uniform cultural treatments. The two seed types within the variety Delaware were September 1990 lifted, cool stored and November 1990 lifted, shed stored. The other variety assessed was Crystal.

All tubers were handled with care between sampling and assessment to avoid confounding damage and further greening. Prior to quality assessment, the samples were washed in tap water and soil carefully removed using a soft brush. Assessment of cosmetic quality was carried out within 48 hours of sample harvest. Ambient soil and air temperatures were measured at two locations using 64K UNIDATA datalogging equipment. The soil thermistor probes were placed in the tuber zone in the centre of the ridge (approximately 20cm from the ridge top). Ambient air temperature was measured within a PVC Stevenson screen at 1.2 m above ground level. Soil mechanical strength was determined using a field digital penetrometer (30° cone). Readings were taken in the centre of the ridge using 20 replicate sites across the production area.

For information on transformation of data (arc sine) please refer to Appendix A.3 Miscellaneous Formulas/Analysis. Statistical analysis on selected data was carried out at the 5% level of significance using the Chi-squared method for assessment of proportional data.

3.4. Results.

Overall reasons for tuber rejection

The horizontal dotted lines appearing on some graphs (eg. Fig 3.1) represent 5% and 25% of the sample respectively, and are arbitrary cut-off levels set for use by Quality Inspectors when reporting consignment quality on pack-out statements (ref section 2.0. *Improvement of Packout Slip Format*). The major cosmetic quality problems (*viz* those at 5% of sample or above) occurring in the 91/92 production period were (ranked from most pre-dominant down) russeted periderm, lenticel problems, physical malformation, peridermal staining, pre-harvest soil abrasion, netted growth cracking, Scurf/Black dot, second-growth, suberisation, pre-harvest greening, insect damage, scabs and rhizoctonia sclerotia (Fig 3.1).

Physical malformation forms

The majority of tubers placed in the malformation category were those with minor 'dents' in the tuber surface (Fig 3.2). The more severe forms of malformation such as stunted, bent and folded tubers occurred at relatively low levels.

Second growth forms

A wide range of physiological shape problems were found (Fig 3.3). The majority of second growth was in the form of knobs, but relatively high levels of internodal swelling (ripple) and pointed end were discovered.

Severity of occurrence of cosmetic quality problems

Russeted periderm, lenticel problems, malformation, pre-harvest abrasion and growth-cracks were mainly minor problems when present on tubers (Fig 3.4). A high proportion of staining, silver scurf/black dot, pre-harvest greening and second growth affected tubers were designated severe. Because tubers were either suberised or not, all tubers displaying suberisation were designated severely affected.

Comparison of mid-growth stage to harvest for spring crop

Several quality problems were found to occur at unacceptably high frequencies at a point midway through tuber development. These were lenticel rotting, russeting of the periderm, malformation, periderm abrasion, suberised periderm and staining (Fig 3.5). These problems continued to be the major source of downgraded quality at harvest of the sampled crops. Growth-cracking, second-growth, pre-harvest greening and the various pests and disease problems were found to occur at relatively low levels midway through tuber development, but most became problems at harvest.

Comparison of Spring and Summer crops

Growth cracking and second-growth occurred at significantly greater ($P<0.05$) frequencies in summer produced tubers compared to spring (Fig 3.6). All other problem levels did not differ significantly between the two periods. The majority of growth cracking discovered was the netted type (Table 3.1). A breakdown of second-growth forms for the two periods (spring and summer) shows that knobs formed the majority of second-growth problems for spring crop tubers, with some pointed stolon end (Fig 3.8). Mean maximum and minimum soil and ambient air temperatures were gathered from two locations (Fig 3.7). The developmental period for summer grown crops show many days, both continuously and as peaks, where the air temperature was above 27°C. Soil temperatures were highest from late January to early March, and after that began to decline. Soil temperature ranged from 23.5 °C (February and March) to 10.5°C (May). The average max-min range over summer crop development was approximately 21 - 18°C.

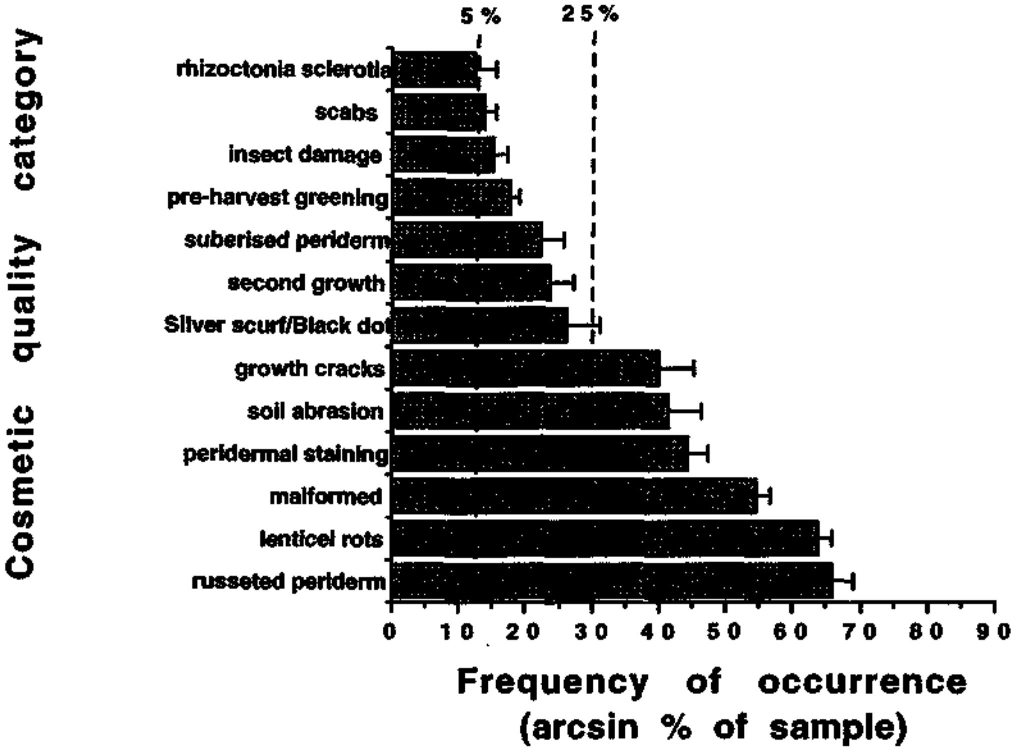


Fig 3.1. Overall significant cosmetic quality problems for Delaware tubers across the 1991/92 Manjimup /Pemberton production period. Lines extending from the bars represent standard errors of the means.

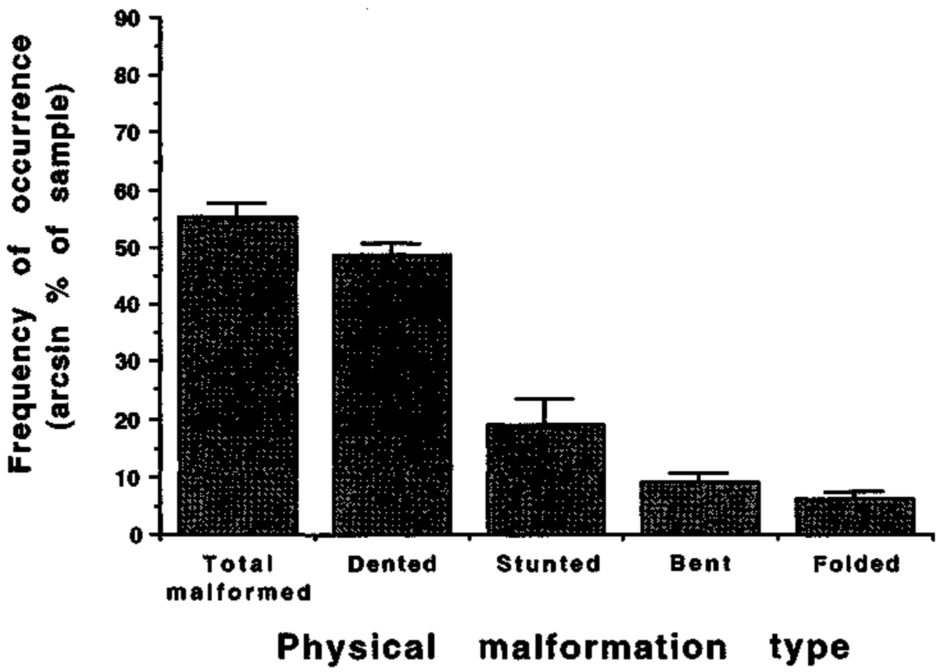


Fig 3.2. A breakdown of the components of physical malformation for Delaware tubers sampled from the 1991/92 Manjimup/Pemberton production period. Vertical lines extending from the columns represent standard errors of the means.

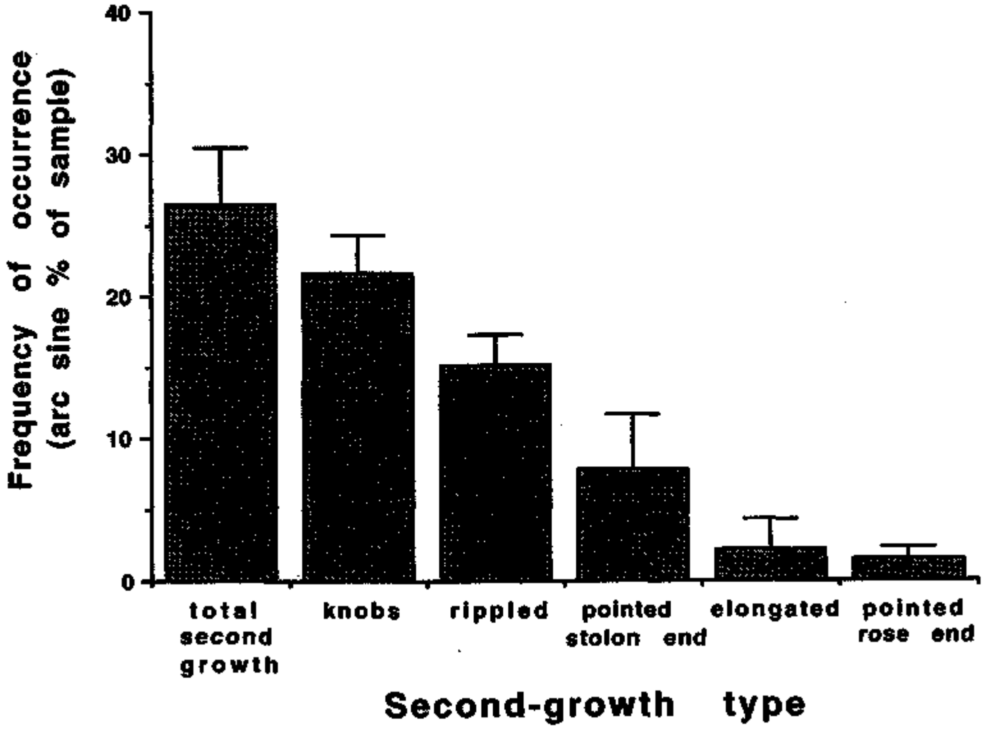


Fig 3.3. A breakdown of second-growth forms occurring in Delaware tubers sampled from the 1991/92 Manjimup/Pemberton production period. Vertical lines extending from the columns represent standard errors of the means.

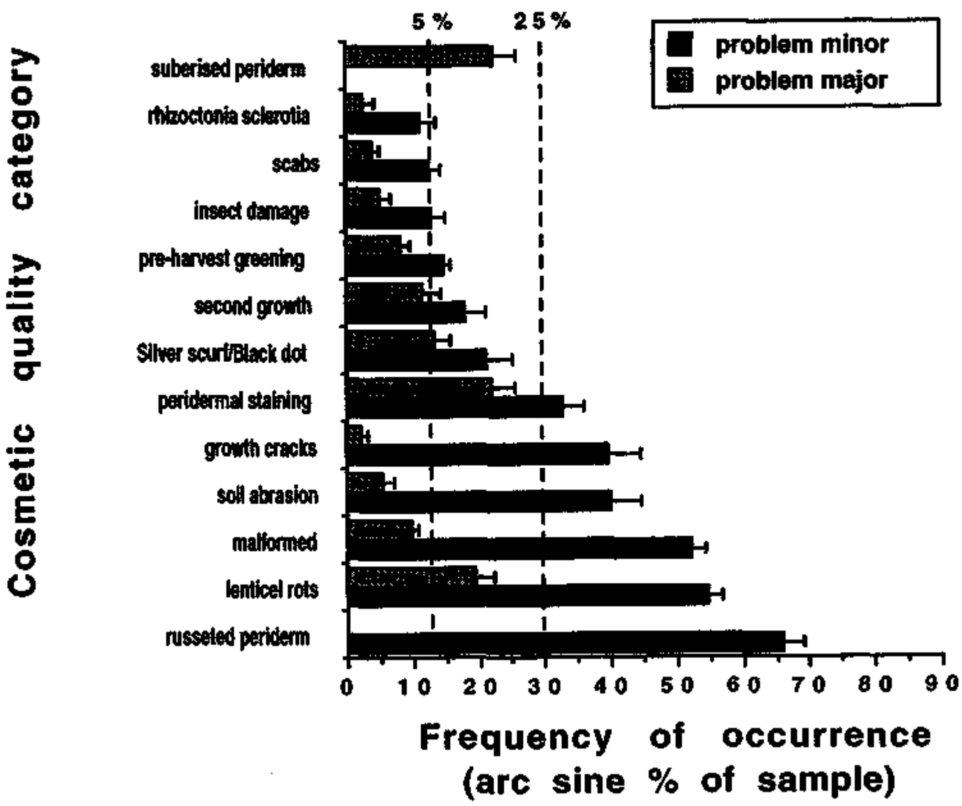


Fig 3.4. Severity of cosmetic quality problems for Delaware tubers across the 1991/92 Manjimup /Pemberton production period. Lines extending from the bars represent standard errors of the means.

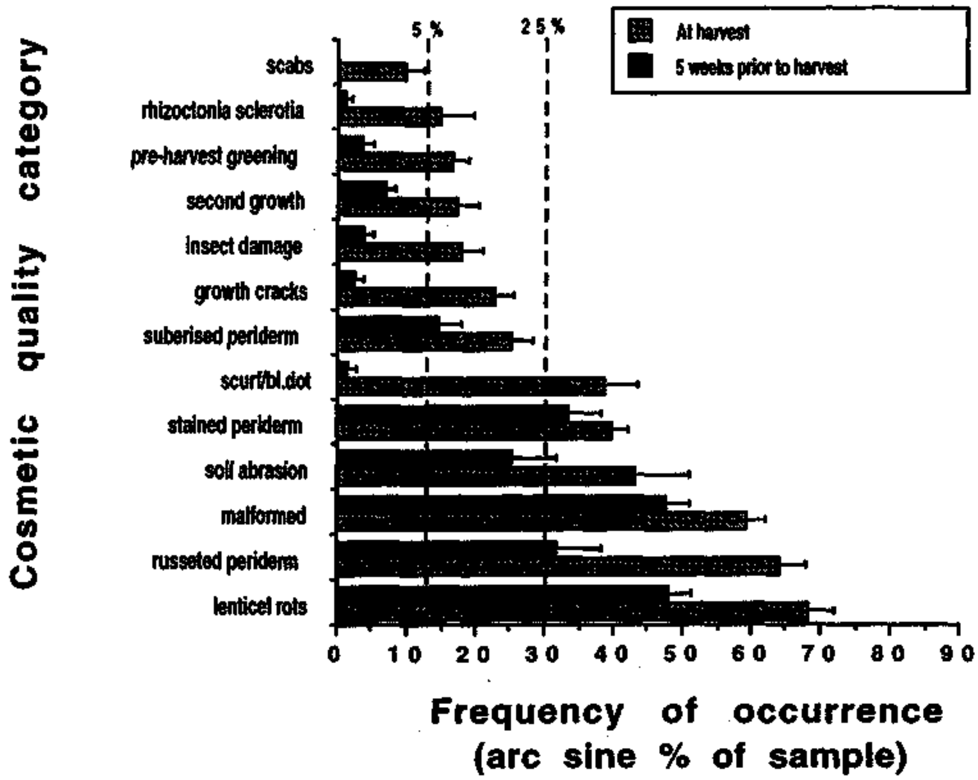


Fig 3.5. A comparison of cosmetic quality problem frequency between two stages of development for Delaware tubers across the 1991/92 Manjimup production period. Lines extending from the bars represent standard errors of the means.

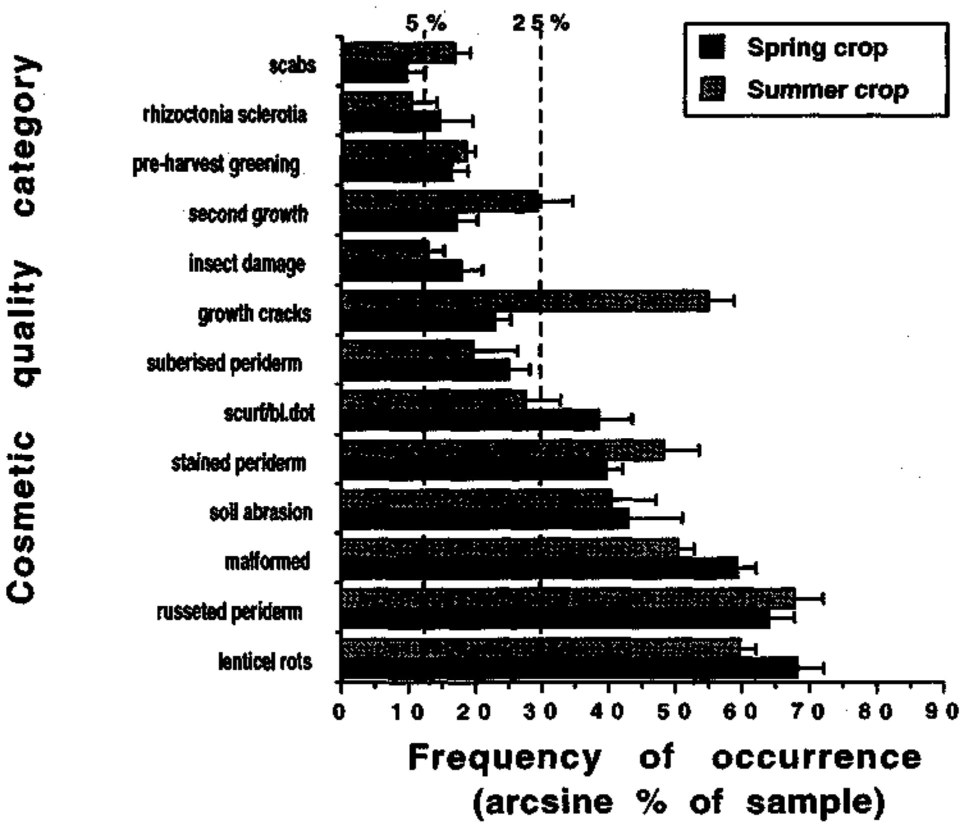


Fig 3.6. A comparison of cosmetic quality problem frequency between spring and summer production f Delaware tubers across the 1991/92 Manjimup/Pemberton production period. Lines extending from the bars represent standard errors of the means.

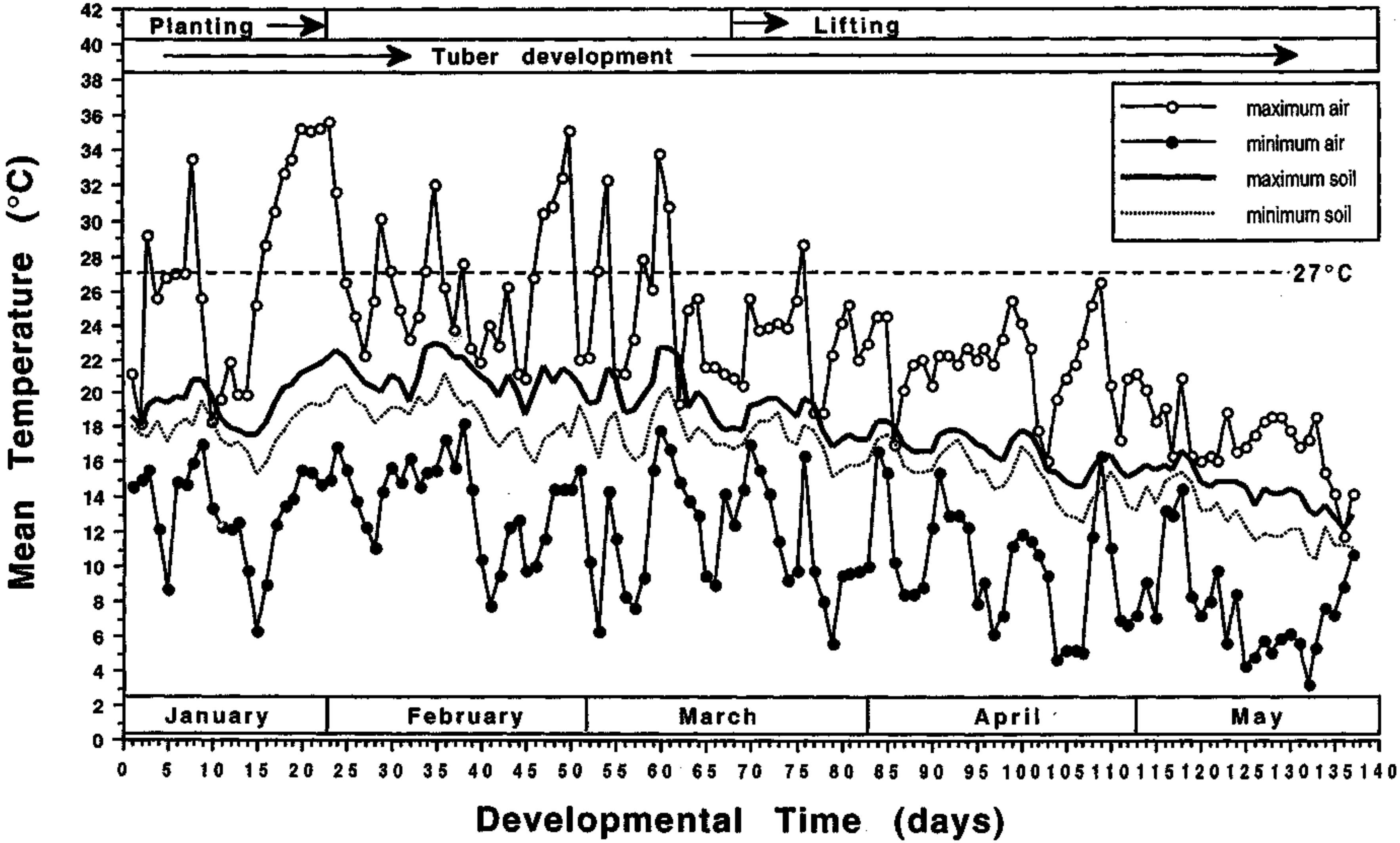


Fig 3.7. Maximum and minimum soil and air temperatures throughout the developmental period of late season (summer crop) Delaware tubers in the Manjimup/Pemberton region.

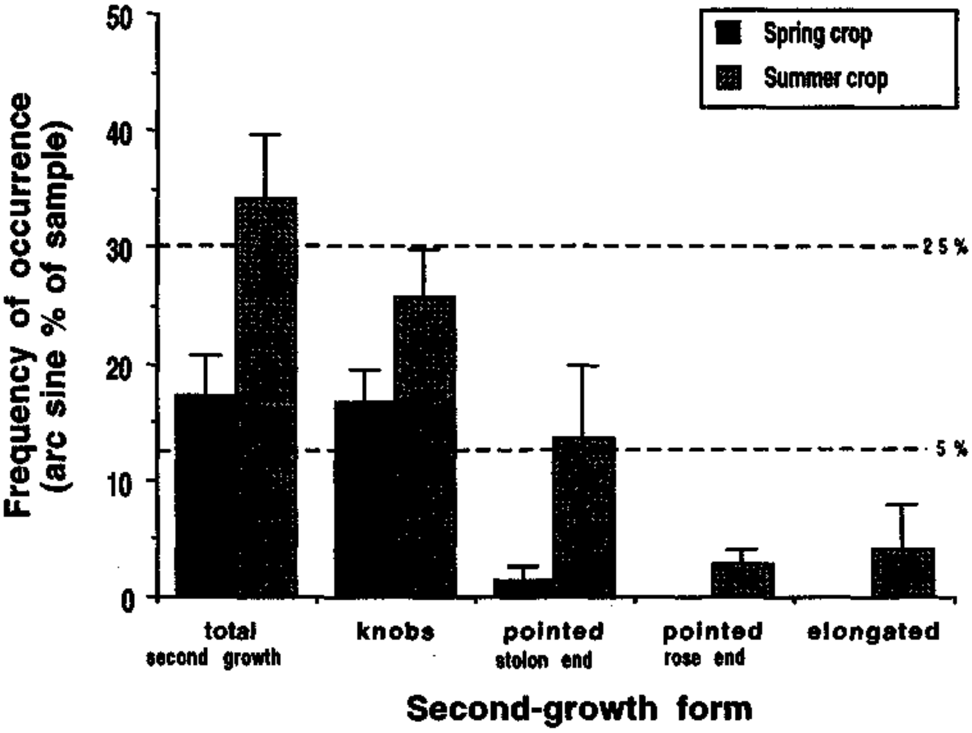


Fig 3.8. Frequency of second-growth forms between spring and summer produced Delaware tubers across the1991/92 Manjimup/Pemberton production period. Vertical lines extending from the columns represent standard errors of the means.

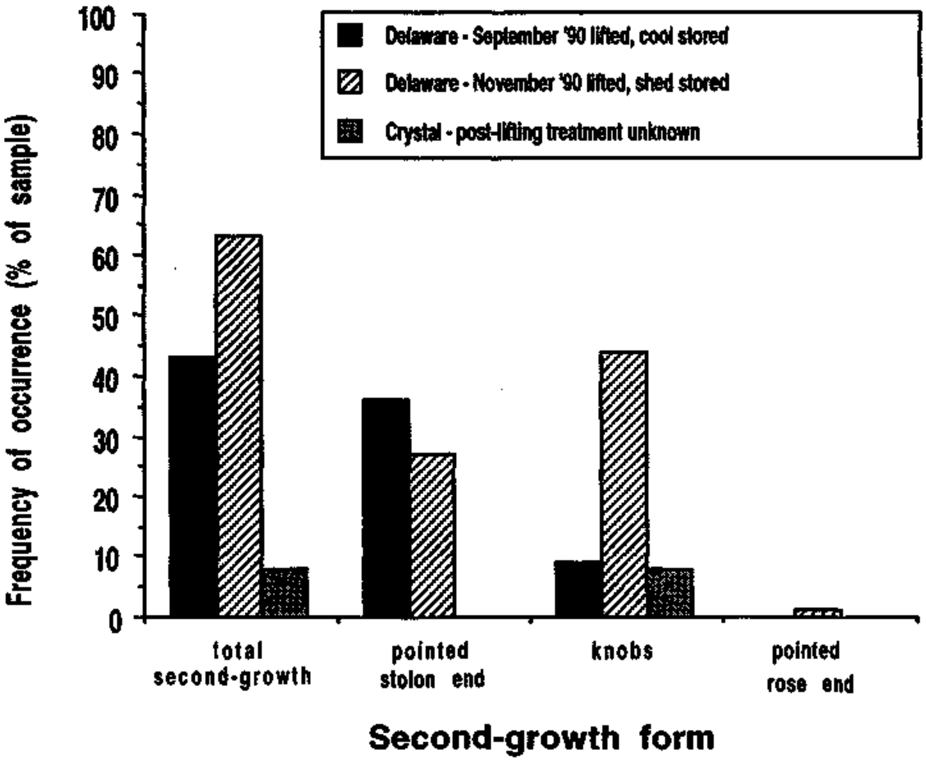


Fig 3.9. Comparison of second-growth forms occurring between Crystal and two differing seed types of Delaware grown under similar conditions.

Comparison of seed types

There were major differences between the seed sources in the second-growth category (Fig 3.9). Overall, Delaware had a higher level and broader range of second-growth forms than Crystal. Within Delaware, the late lifted, shed stored Delaware seed displayed more second growth variety than the early lifted, cool stored seed.

Table 3.1. Growth crack types occurring in Delaware tubers across the 91/92 Manjimup/Pemberton production period.

	arcsin % of sample	
	Spring crop	Summer crop
Netted type growth cracks	22.6 ± 2.8*	54.9 ± 3.7
Cleavage type growth cracks	6.8 ± 3.7	3.4 ± 1.7

* standard errors of the means

Preliminary survey of soil strength

The two production areas sampled in the survey had similar soil strength profiles (Fig 3.10). Average soil strength exceeded 10 bars at the base of the ridge, and climbed to approximately 20 bars at 30 cm from the ridge top.

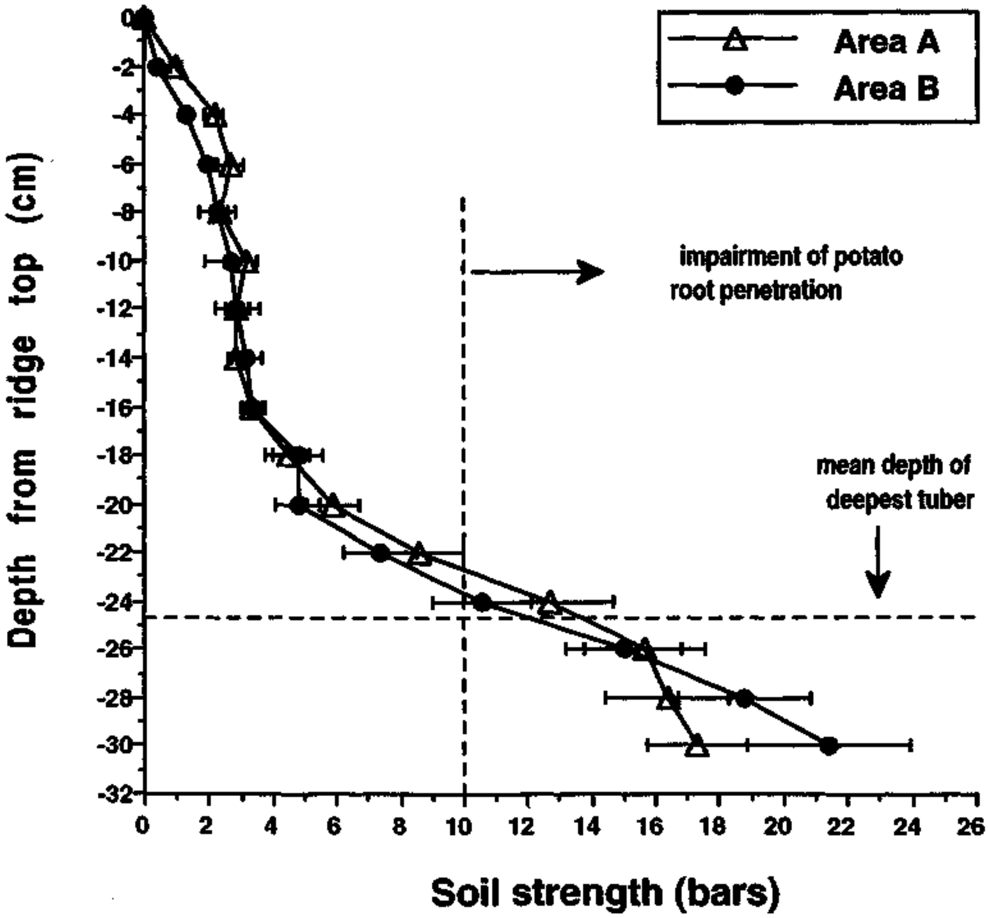


Fig 3.10. Penetrometer survey of soil strengths in two 1991/92 Delaware production areas within the Manjimup/Pemberton region. Horizontal lines extending from each point represent standard errors of the means (n = 20).

3.5. Discussion

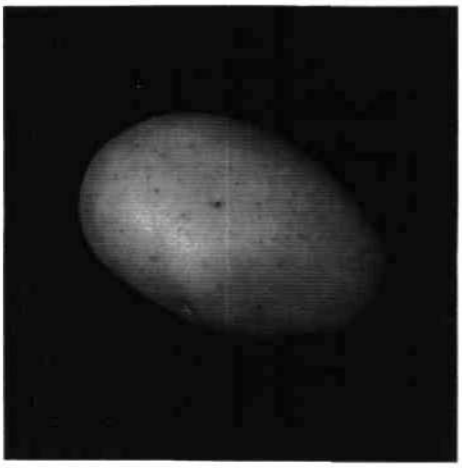
Overall reasons for tuber rejection

The major cosmetic quality problems occurring in the 91/92 production period were russeted periderm, lenticel problems, malformation, staining, pre-harvest abrasion, netted growth cracking, silver scurf/black dot, second-growth, pre-harvest greening, insect damage, scabs and rhizoctonia sclerotia (Fig 3.1). Minor russeting (Plate 2 A) in white tubers has previously not been considered as a relevant cosmetic quality problem. While russeting is a feature of some varieties (*viz* Russet Burbank) the presence of a russeted periderm in smooth skinned white varieties can degrade appearance, especially in washed lines. The problem has been linked previously to pH of the soil (Blodgett 1946), soil temperature (Ruf 1963, Yamaguchi *et al.* 1964), moisture levels (Ruf 1963) and ethylene (C_2H_4) build-up in the soil due to compaction (Campbell and Moreau 1979). Tubers exhibiting some degree of russeting of the periderm occurred at a relatively high frequency for the 91/92 season (Fig 3.4).

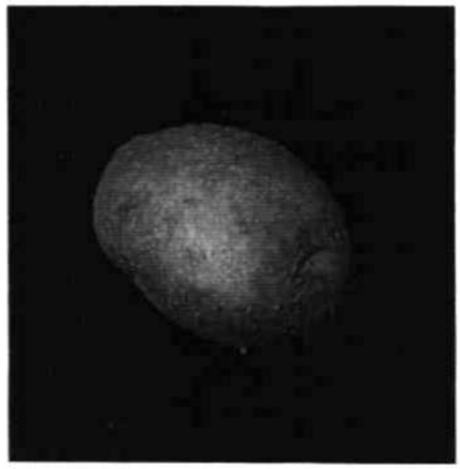
Smooth stain describes a tan/brown periderm appearance, which has a reflective sheen when washed (Plate 1 A). The cause of the problem has yet to be determined, although preliminary analysis has highlighted a link to iron (Fe) levels in the periderm (ref section 5.0. Preliminary Data Analysis, this report). Suberisation describes a response of the periderm to stresses such as high temperature or pathogenic infection. The periderm becomes very thick and corky, with a dark brown colour (Plate 1 B). The high levels of suberised tubers found mid-way through development may be attributed to stresses other than those caused by pests and disease, as these categories were all at very low levels at that time. The periderm problems discussed all vary in their effect on quality during grading. However, according to Government grading standards (Anon. 1987) tubers displaying these superficial problems cannot be graded as premium class, and thus can be considered as valid reasons for downgrading between classes, depending on severity.

Pre-harvest soil abrasion, a previously undescribed cosmetic quality problem, is a pinkish to brown blemish on the tuber surface, usually associated with upraised or exposed portions of the tuber (Plate 2 B). The markings may appear corky due to wound periderm formation, and are most likely caused by an interaction between tuber expansion and the physical properties of the soil surrounding the tuber. High levels of this problem within a consignment would detrimentally affect the pack-out, as the tuber surface appears blemished. This periderm defect would most probably be recorded by Quality Inspectors as blemishes on the pack-out slip, and could serve to explain the reported high frequency of incidence of blemished tubers found in the initial survey of stored data (see Section 2.0. Stored Data Analysis, this report).

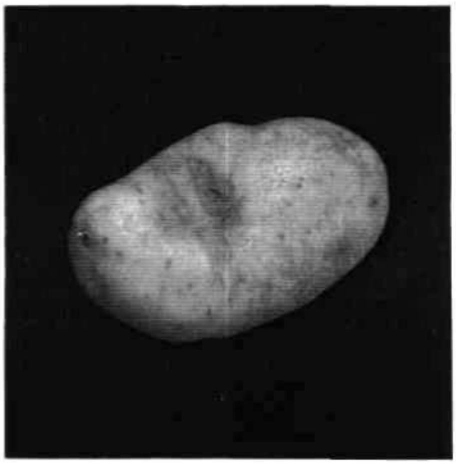
The tuber symptoms for Silver scurf and Black dot are very similar, but arise from different causal organisms (*Helminthosporium solani* and *Colletotrichum atramentarum* respectively; Hunger and McIntyre 1979). When distinguishing between these diseases one must identify structures microscopically (Anon. 1981). As a result, it was initially deemed too time consuming to separate them when subjectively analysing tuber samples. However, it soon became apparent that Black dot was occurring at a high enough frequency to be detrimentally affecting cosmetic quality. Some indication of the ratio between these diseases was needed to work out the relative importance of each. Accordingly, a number of samples were assessed distinguishing between these two diseases. Overall, the ratio of Silver scurf to Black dot was found to be approximately 25/75 respectively per 100 tubers infected. A large percentage of tubers placed in this category were severely affected



A. Peridermal Staining

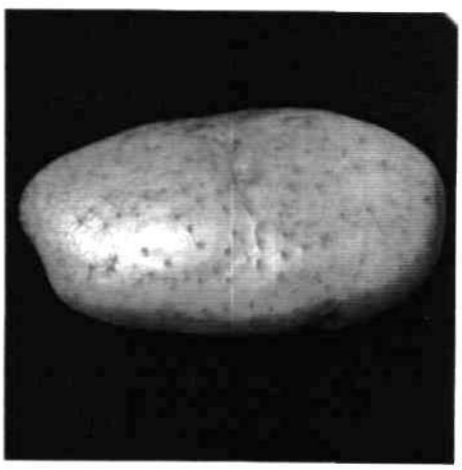


B. Suberized Periderm



C. Dented Tuber

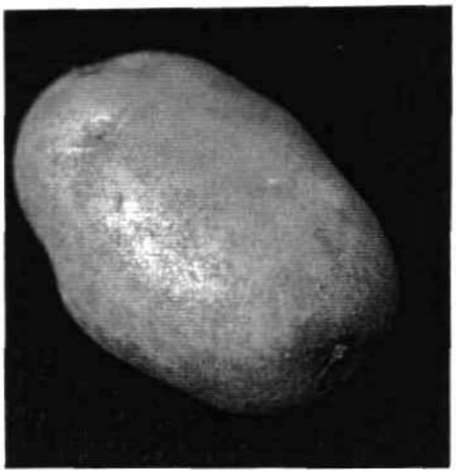
D. Stunted Tuber



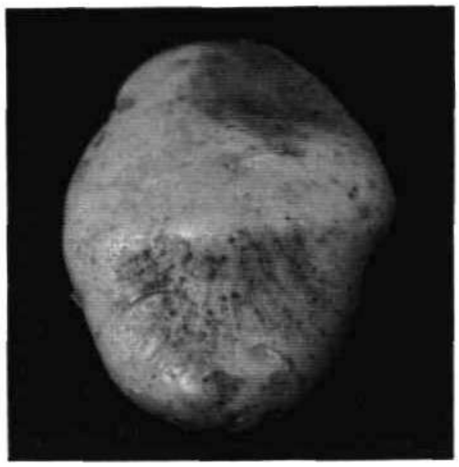
E. Lenticel Rots

F. Rippled Tuber

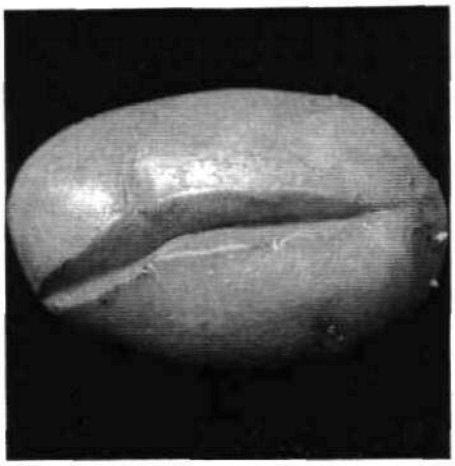
PLATE 1.



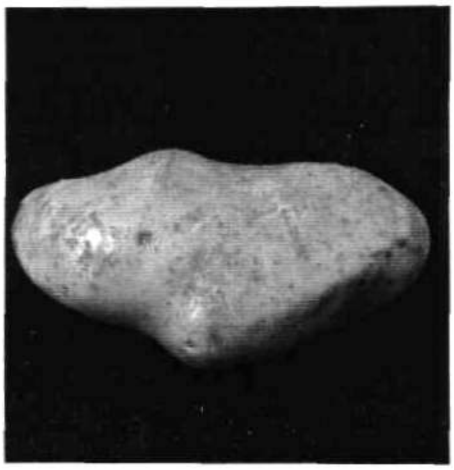
A. Russeted Periderm



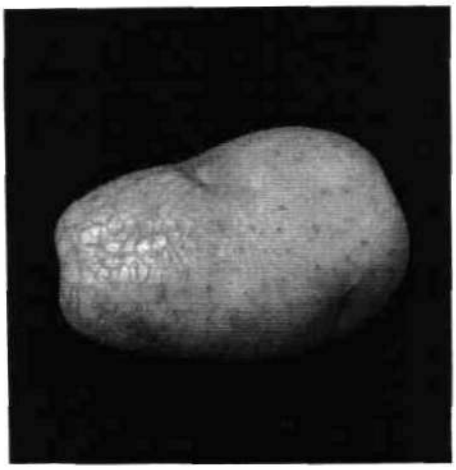
B. Pre-harvest Abrasion



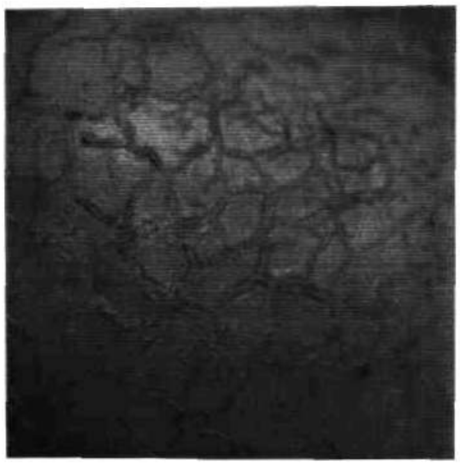
C. Cleavage Growth Cracks



D. Swollen Nodes (eyes)



E. Netted Growth Cracks



F. Netted Cracks (zoom)

PLATE 2.

by the diseases, and these would have been down-graded to waste (Anon. 1987).

Contrary to high frequencies of occurrence in consignments recorded by Quality Inspectors over previous years (see Section 2.0. Stored Data Analysis, this report), actual insect damage found in Delaware tubers over 91/92 production was relatively low. This may be due to over-estimation of the problem by Quality Inspectors due to the highly noticeable nature of the problem. Alternately, it may be a product of the pest management research and extension programmes conducted by the WA Department of Agriculture over recent years. However, further surveys will be required to determine whether this is a real decrease and not just the product of abnormal climatic conditions.

Shape problems - components

Deviations in tuber shape can be of physical or physiological origin. To clarify the shape situation, deformed tubers encountered during sampling were segregated into two groups. The **second-growth** category contained all tubers whose shape aberration was of known or assumed physiological origin (eg. knobs, pointed end, elongation). The **malformation** category contained all other deformed tubers. When the tubers were subjectively assessed, a record of the particular form of tuber malformation or second-growth was kept (Figs 3.2 and 3.3). For definitions of these shape deformities refer to the Glossary (Appendix A.1). The majority of malformation in the samples was found to be due to minor indentations in the tuber surface, termed 'dents' (Plate 1 C). It is theorised that the indentations result from a combination of soil type, inter-tuber compaction level and tuber density in the hill. Work carried out in California has shown that soil bulk density (a measure of compaction) at 20 cm depth was positively correlated to tuber deformation (Grimes and Bishop 1971). The level of stunted (radially and longitudinally) tubers present in the samples also indicate a soil compaction problem (Plate 1 D).

Most of the second-growth category was minor knobs, and much of this was only marked swelling of the nodes that would, if development continued, eventually form knobs (Plate 2 D). This second-growth form is a highly visible, and highly undesirable growth defect, as well formed knobs sustain damage and can break off during handling. The resulting wound serves as an entry point for pathogens and as an exit for water, thus affecting tuber turgor and so saleable weight. Consequently, knobby tubers are downgraded to waste, usually in the field. Nodal swelling can dramatically alter the shape of the tuber, making it appear angular. Levels of pointed stolon end were also relatively high. Second-growth occurs due to stress (eg. water, temperature) experienced by the plant during tuber development (Sparks 1958, Bodlaender *et al.* 1964, Lugt *et al.* 1964, Anon. 1986). The tuber ceases growth and, when conditions normalise, continues growth. However, growth can be restarted in a different direction, usually switching from the longitudinal axis to the radial axes. Pointed stolon or stem end results from stress early in the tuber developmental period, while pointed rose or bud end results from stresses late in development (Iritani 1963, Anon. 1981). The high levels of second-growth (knobs) and pointed stolon end indicates that the crops sampled were most likely subjected to stress at a point mid to late in tuber development.

Rippled tubers are those that exhibit cortical swelling in an internodal phyllotaxy, ie bulges in the tuber not related to the eyes that give the tuber a rippled appearance (Plate 1 F). This previously undescribed form of tuber deformity is thought to arise from differences in growth rate between the radial axes (eyes) and general cortical expansion. Thus rippling may be a form of physiological malformation. It appears to bear a minor relationship with other forms of physiological shape problems (eg. knobs, pointed end) (ref. Section 5.0. Preliminary Data Analysis, this report).

Severity of occurrence of quality problems

The greatest percentage of tubers placed in the russeting, lenticel rots, malformation, pre-harvest abrasion, and growth cracking categories were only slightly affected (Fig 3.5). However, under Government gazetted regulations governing the grading of ware potatoes, these minor problems would down-grade a tuber from premium to class I or II (provided grading was rigorous) (Anon. 1987). Lenticels are not readily seen on normal Delaware periderm, so the minor lenticel problem category includes darkened to slightly rotted lenticels (Plate 1 E), not overly detracting from tuber appearance. Major lenticel problems include those corky, upraised or heavily rotted and severely detracting from tuber appearance. Staining, second-growth, pre-harvest greening, suberised periderm and the various pests and diseases categories contained large percentages of tubers with major inflictions (Fig 3.5). Severely affected tubers would have been graded to waste (Anon. 1987), as all are highly noticeable quality disorders,

Comparison of spring and summer produced tubers

Reports of shape differences between spring and summer produced tubers were found to have some substance. However, the shape problems were confined to those of stress related physiological origin ie second-growth and netted growth cracking (Fig 3.6). Summer or late season tubers had a broader range of second-growth forms, with high levels of pointed stolon end, some pointed rose end and elongation (Fig 3.8). The greater range of second-growth forms in the summer tubers are clearly the result of increased stresses experienced throughout the development period, mainly higher temperatures and wider fluctuations in soil moisture. Formation of secondary growth can be caused by high soil or air temperatures, or a combination of both (Lugt *et al.* 1964). The duration of the heat period also influences the degree of second-growth (Bodlaender *et al.* 1964). Records of soil and air temperature from January to May 1992 (covering the summer crop growth period) show many days when the ambient air temperature was above 27°C (Fig 3.7), the critical temperature for second-growth induction (Anon. 1981).

The majority of growth cracking recorded was the netted type (Table 3.1), which is reported to be a product of irregular irrigation (Jefferies and Mackerron 1987, Bailey 1990). Netted growth cracks are easily distinguishable from the more common cleavage type cracks (Plate 2 C, E & F). As the soil moisture deficit (SMD) increases the tuber experiences moisture stress and cracking in a netted pattern occurs upon re-wetting (Robins and Domingo 1956, Jefferies and Mackerron 1987). Differences in sensitivity to crack-inducing stress have also been recorded between potato varieties (Bailey 1990, Storey and Davies 1992). The great increase in the incidence of netted growth cracks in the summer produced tubers is most likely related to the increased dependence on irrigation, and thus the increased likelihood of severe temporary soil moisture deficits. Minor differences in the incidence of pest/disease related quality problems between the spring and summer crops (Fig 3.6) are most likely related to edaphic factors (soil temperature and moisture levels).

Comparison of seed types within Delaware

The varied response of the two differing seed types indicates that seed treatment can affect susceptibility of potato plants to stress related cosmetic quality disorders. The effect on second-growth (Fig 3.9) cannot be readily attributed to time of seed lifting or storage conditions due to the limited nature of the sample. However, the exercise does highlight the need for some intensive research into the effects of seed treatment on cosmetic quality under local conditions.

Soil compaction

Potato roots, depending on variety, usually penetrate past 50cm, but never exceed 100cm (Gregory and Simmonds 1992). Potato root density and penetration is severely reduced by soil strengths exceeding 10 bars (Bishop and Grimes 1978). The preliminary survey of two Delaware production areas showed soil strengths exceeding 10 bars (average) after approximately 22 cm depth from the ridge top (Fig 3.10). Impairment of root penetration in potatoes has several effects. Firstly, tuber set is usually shallower in shallow rooted potato plants, which can increase levels of pre-harvest greening due to tubers 'pushing' out of the soil. Additionally, shallower rooting increases the susceptibility of the plant to water stress between irrigations (Miller and Martin 1987). Such an increased susceptibility to water deficit would account for the high levels of netted growth cracking and second growth found in the 1991/92 production period, especially in summer grown tubers.

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4.0. Postharvest Quality

4.1. Abstract.

Samples of Delaware tubers were randomly taken at the merchant level from bulk ungraded consignments. The tubers were assessed for postharvest mechanical damage and greening. Approximately 47% (retransformed data) of tubers sampled were found to have some form of postharvest damage. The majority of this damage was minor impact splits/cracks and bruising. Digger damage (gouges, cuts etc) occurred in approximately 2% (retransformed data) of tubers. Misshapenness of tubers was found to not affect levels of impact splits/cracks. However, poorly shaped tubers were found to be significantly ($P<0.05$) more susceptible to bruising. Both impact splitting and bruising were found to bear a positive correlation to tuber mass. Greening levels in the postharvest sample were found to not differ significantly ($P<0.05$) from levels present pre-harvest.

The relatively high levels of mechanical damage present in Delaware may be extrapolated to other varieties. Clearly, a further detailed survey to define points of occurrence of postharvest damage in the production chain is necessary. Aspects of handling such as drop heights during bulk tuber transferral and machinery settings should be investigated. An extension programme covering damage avoidance techniques (both pre-harvest and postharvest) is needed. The lack of significant increase in greening after lifting suggests that the major determinant of greening in Manjimup/Pemberton produced tubers is exposure to light before harvest. Cultural practices that reduce pre-harvest greening should therefore be encouraged.

4.2. Background Information.

Postharvest injury has been a cause of concern for the potato industry worldwide (Bailey, 1990). The causes of postharvest tuber damage can be broadly divided into (a) injuries that occur at harvest (eg digger damage), (b) injuries that occur during transport (eg weight bruising, vibration abrasion) and (c) injuries that can occur at all stages of the postharvest chain (eg impact splits/cracks/bruises) (Anon. 1980). Any damage to the tuber surface leads to loss of impermeability and, as a consequence, the tuber loses turgor and so saleable weight and quality. Another postharvest problem of great importance is greening. Exposure of the tuber to light triggers chlorophyll formation in the periderm and associated with this is the production of toxic glycoalkaloids. The amount of glycoalkaloid synthesis is controlled by light intensity, wavelength, and cultivar. Due to the high intensity, exposure to sunlight causes much greater synthesis of glycoalkaloids than exposure to artificial light (Sinden 1987). Green tubers are graded to waste because of the possibility of toxic levels of glycoalkaloid production. Greening and postharvest injuries were found to occur at unacceptably high frequencies when pack-out slips were examined for consignments delivered from the Manjimup/Pemberton region (ref section 2.0. Stored Data Analysis, this report). Greening can be a pre-harvest or a postharvest problem, and it is difficult to indicate the origin of this problem at the wash/packer level. Production samples (ref section 3.0. 1991/92 On-site Production Sampling, this report) were carefully removed from the ground just prior to harvest to avoid handling damage. Therefore, a series of merchant level samples were taken in order to determine the real levels of postharvest handling injuries present in potatoes from the Manjimup/Pemberton region.

4.3. Methods

Ten samples of 100 tubers were taken at random from bulk ungraded consignments delivered to the WA PMA Coogee shed. The samples were a composite of smaller samples taken from under the top layer of tubers from bins randomly chosen across the consignment. The tubers were handled with extreme care between sampling and assessment to avoid confounding mechanical damage and further greening. Assessment of greening and damage was carried out within 24 hours of sampling. Consignments were randomly chosen over the entire 1991/92 Manjimup/Pemberton delivery period (January to May) to ensure a representative sample of production. Greening was assessed as minor (<10 estimated tuber surface area affected) or major (>10 estimated tuber surface area affected).

For information about data transformation please refer to Appendix A.3 Miscellaneous Formulas/Analysis. Statistical analysis was carried out at the 5% level of significance using the Chi-squared method for assessment of proportional data.

4.4. Results

Postharvest injury levels

Some level of damage was found to occur in approximately 47% (retransformed data) of tubers assessed (Fig 4.1). Most of this damage was in the form of minor bruising/abrading and splits/impact cracks, which were only noticeable upon close inspection of the tuber. About 2% (retransformed) of tubers showed major damage inflicted during lifting (ie half tubers, crushed or gouged tubers). Postharvest injuries in the form of impact splits/cracks and bruising/abrasion were found to be closely correlated to tuber mass (Fig 4.2).

Greening

Levels of greening recorded for the pre-harvest and postharvest samples (Table 4.1) were found to be not significantly different at the 5 % level using the Chi-squared distribution.

Table 4.1. Frequency of occurrence of tubers with various degrees of greening from pre-harvest and postharvest samples.

	Frequency of Occurrence (% of sample)		
	total greening	minor greening	major greening
Pre-harvest samples	9.7 ±1.3*	6.8 ±0.9	3.0 ±0.8
Postharvest samples	5.8 ±1.9	4.6 ±1.4	1.2 ±0.8
Chi-squared value	$^{a}1.1$		

a - greening not significantly different (P<0.05) between pre and postharvest samples
* - standard errors of the means

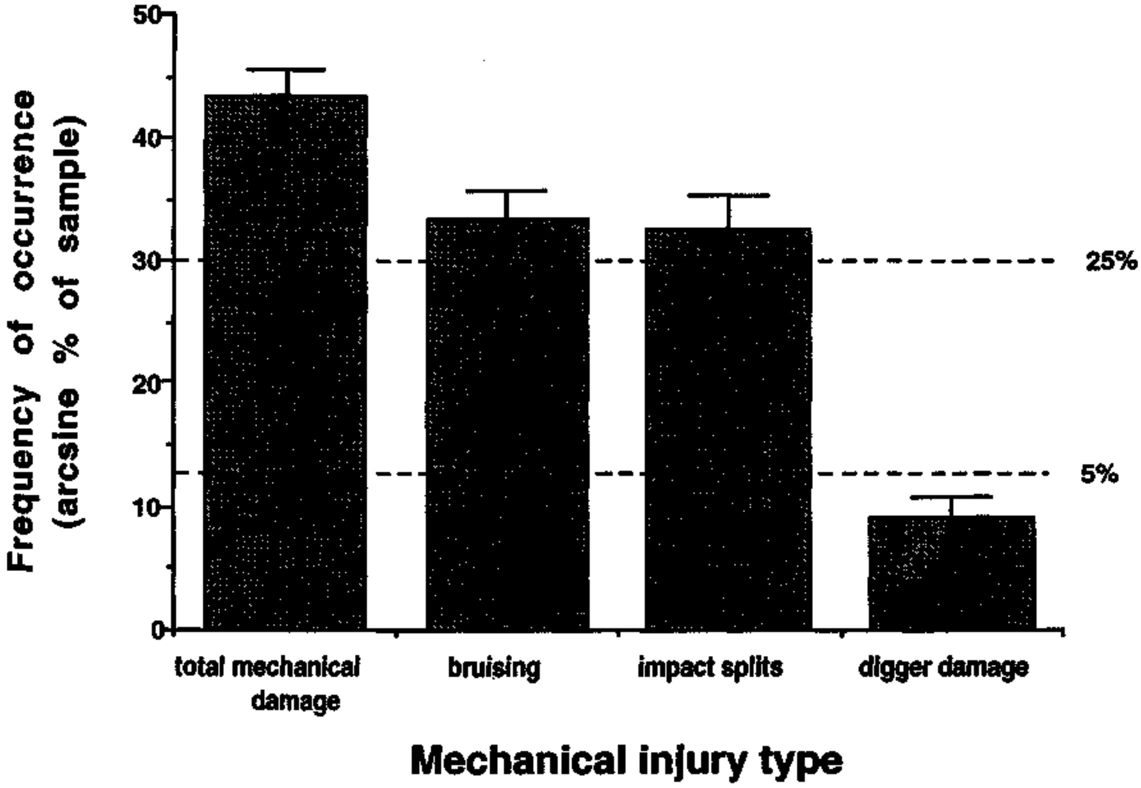

Fig 4.1. Components of mechanical injury in Delaware tubers sampled after transport from Manjimup to Coogee. The vertical lines extending from the columns represent standard errors of the transformed means.

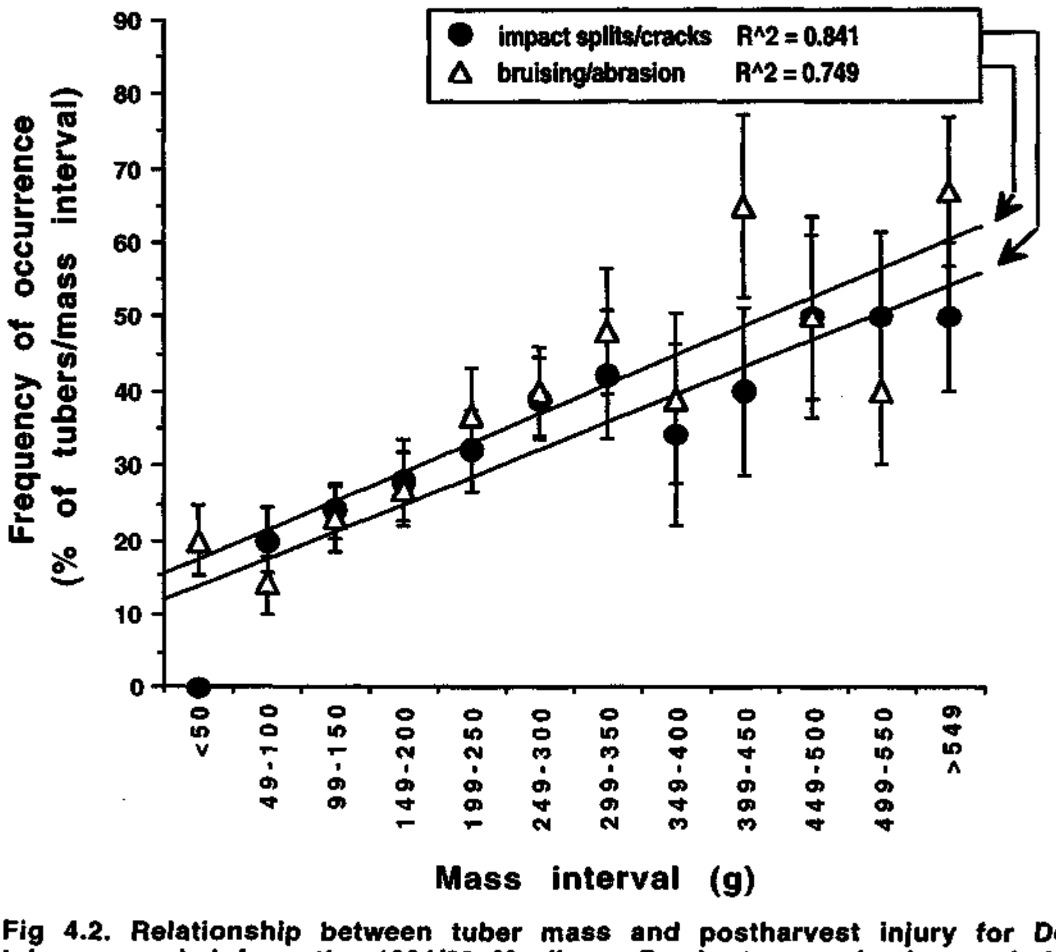

Fig 4.2. Relationship between tuber mass and postharvest injury for Delaware tubers sampled from the 1991/92 Manjimup Pemberton production period. Bars extending from the points represent standard errors of the means.

Tuber shape and levels of mechanical damage

No significant difference ($P<0.05$) was found between misshapen and well shaped tubers in terms of susceptibility to mechanical damage in the form of impact splits (Table 4.2). However, misshapen tubers were found to be significantly ($P<0.05$) more likely to have postharvest damage in the form of bruising than well shaped tubers (Table 4.3).

Table 4.2. A comparison of misshapen (malformed + second growth) to well-shaped tubers in terms of levels of tuber impact splitting.

		% of mean total per sample	
	Mean total per sample (n=10)	Impact splits	No impact splits
Misshapen tubers	64.4 ± 3.1*	32.8	67.2
Well shaped tubers	35.6 ± 3.1	25.0	75.0

* standard errors of the means

Table 4.3. A comparison of misshapen (malformed + second growth) to well-shaped tubers in terms of levels of tuber bruising.

		% of mean total per sample	
	Mean total per sample (n=10)	Bruising	No bruising
Misshapen tubers	64.4 ± 3.1*	35.9	64.1
Well shaped tubers	35.6 ± 3.1	22.2	77.8

* standard errors of the means

4.5. Discussion

Descriptions and origins of tuber damage

Most of the mechanical damage suffered by tubers in this survey was not severe, the exception being levels of lifting damage. Damage to tubers during harvest is dependant on the type and settings of the machinery used (ie depth, forward speed, primary chain speed; Anon. 1980). Additionally, high turgor status of tubers during harvest increases susceptibility to impact fractures (Bailey 1990). Apart from major cutting and crushing injuries during lifting, tubers may also sustain impact bruising and splitting while travelling through the harvest machinery and during bulk transferral to transport bins. This damage is dependant on chain speed and drop height (Anon. 1980). The mechanical damage in this study is assumed to have resulted from the passage of the tuber through the harvest machinery and from transport as the tubers were sampled prior to merchant level handling.

Implications of the damage found

The presence of fine bruises, splits and cracks does not detract from the cosmetic appearance of the tuber at the merchant grading stage of production. Research has shown, however, that these forms of damage have a large influence on the retail shelf-life of the tuber (Storey and Davies 1992). Injury to the periderm removes the natural barrier to water loss, and saleable weight is rapidly lost under adverse conditions (temperature increase, low relative humidity). As the tuber loses turgor, the freshness aspect of cosmetic quality decreases. Additionally, the damaged periderm allows entry to pathogens such as soft rot bacteria, thus further decreasing the appearance and shelf-life of the product (Burton 1989, Bailey 1990). Mechanical injury also increases levels of glycoalkaloids. Olsson (1986) showed that induced shatter cracks caused tubers to synthesise whole tuber levels of solanine and chaconine that exceeded toxic limits ($\approx$ 20mg/100g fresh mass generally).

Resistance of the periderm to damage is determined by variety (Schoorl and Holt 1983, De Maine 1986), tuber size and shape and growing conditions. The size of a tuber affects the kinetic energy which is imparted upon impact (Parke 1963); a small tuber dropped from the same height as a larger tuber generally suffers less damage (Bailey 1990). This is supported by data collected for Delaware tubers in this project, where tuber mass was correlated to impact and vibration damage (Fig 4.2).

Shape also determines the degree of damage and susceptibility is related to the radius of curvature (Bailey 1990). Tubers with smaller radii of curvature (eg elongated tubers) are more prone to mechanical damage (Carruthers 1982). Research dealing with shape and damage has concentrated on varietal aspects and while it is conceivable that misshapen tubers may have a bearing on the problem, this study has shown that well-shaped Delaware tubers were just as likely to suffer impact splitting as misshapen tubers. In general terms, the major determinant of susceptibility to fracture and external cracking is growing conditions that alter tuber turgor and periderm strength (Bailey 1990). Skin strength is associated with tuber maturity and cultivar. Within cultivars, thinner skinned immature tubers have been shown to be more susceptible to impact splitting (Finney *et al.* 1964). This study has shown that misshapen tubers are more susceptible to bruising than well shaped tubers and are thus likely to have a shorter shelf-life and lower quality at the retail level.

Greening

The lack of significant increase in greening after lifting suggests that the major determinant of greening in Manjimup/Pemberton produced tubers is exposure to light before harvest. Possible reasons for this are inadequate hilling, soil compaction and rain wash-out (Storey and Davies 1992). Kouwenhoven (1978) showed that flattened ridges yield significantly more green tubers. Formation of a compacted layer beneath the hill (hard pan) restricts deep rooting (Miller and Martin 1987, van Loon and Bouma 1978) and so leads to shallower tuber set. Inadequate hilling and heavy rainfall can then further compound the problem. Further site studies may be warranted to clarify this issue.

4.6. Literature cited

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5.0. Preliminary data analysis

5.1. Abstract.

Correlation analysis was carried out on cosmetic quality and edaphic parameters measured for the 1991/92 Manjimup/Pemberton production period. A correlation matrix was constructed to determine possible relationships between measured parameters. Peridermal staining was assessed using EDAX analysis and fluorescent microscopy. The relationship between tuber mass and cosmetic quality was also determined.

Many relationships between measured parameters were uncovered. Of particular interest was the three way relationship existing between periderm staining, stress related shape problems and tuber zone available Fe. EDAX analysis of Delaware periderm indicates the presence of elemental Fe in stained samples, particularly in the cell walls. Soil compactibility as indicated by the calculated co-efficient of non-uniformity (Cn) was found to bear little or no relationships to cosmetic quality problems thought to arise due to compaction. However, susceptibility to compaction does not necessarily indicate that a soil is compacted. A more detailed survey of soils and compaction levels in production sites in the region is needed.

The major cosmetic quality problems occurring in the 1991/92 Manjimup /Pemberton production period, with the exception of periderm staining, were found to be positively related to increasing tuber mass.

5.2. Background information.

Correlation matrix and regression analysis

Correlation techniques are useful in the preliminary examination of large data sets to see which variables are associated (Mead and Curnow, 1986). The closeness of a relationship existing between factors is described by the sample correlation coefficient (r) (Snedecor, 1962, Mead and Curnow, 1986). The value of **r** must lie between -1 and +1 (negative and positive relationships respectively). Values closer to 0 denote decreasing correlation (Snedecor, 1962). The correlation assumes linearity, that is, a low r value (closer to 0) does not necessarily mean that there is no relationship between the two factors. The relationship may in fact be curved (Mead and Curnow, 1986). A correlation matrix of all the parameters measured for Delaware tubers throughout the 1991/92 Manjimup/Pemberton season was constructed in order to investigate whether any significant relationships existed.

Mass interval and grade potential

Tubers falling within certain mass ranges depend upon cosmetic quality as to the actual grade assigned (Anon. 1986). For example, a tuber weighing 200 grams may have regular shape and be blemish free, and is subsequently graded as premium. However, if the shape or superficial quality is substandard, the tuber may fall into class I, Class II, or waste. Thus tubers falling within a certain mass range can be said to have grade *potential*, dependant entirely on their cosmetic quality. Whilst actual mass grading is not used in the wash/packing operation, an estimate of the approximate tuber mass is made based on tuber size. Consequently, the mass ranges are not strictly adhered to because of the subjective nature of the grading. In this study, however, the mass grading was rigorous to 0.1g.

The purpose of this exercise was to highlight the relative importance of factors in the downgrading of tubers from the various grades currently in use by the system. Targeting of cosmetic quality problems in this manner would allow priority ranking for future research.

5.3. Methods.

Cosmetic quality data

Raw (untransformed) proportional cosmetic quality data for each sample production area was used.

Mass interval data

Tubers were categorised by individual mass in 50 gram intervals. Within each mass interval, a proportion of total tubers with each particular cosmetic quality problem category was calculated using formula (1).

$$\frac{\text{proportion of cosmetic quality problem within the mass interval}}{\text{total number of tubers falling within the mass interval}} \times 100 \qquad (1)$$

The vertical dashed lines on each mass interval graph denote broadly defined mass grading ranges (Anon. 1986), which are as follows:

Premium	~ 150 - 350 grams
Class I	~ 30 - 350 grams
Class II	~ 30 - 450 grams
Waste	~ <30 grams and >450 grams

Soil analysis

Approximately 100g of soil was sampled from the tuber zone (approx 20 cm from the ridge top) at the points where tubers were sampled. These were bulked to produce a 1Kg composite sample for each production area. Before analysis the soil was thoroughly mixed, coned, and quartered. Chemical analysis of soil samples was carried by CSBP and Farmers LTD of Railway Parade, Bayswater. Samples consisted of approximately 250 g of soil with the >2mm fraction removed. The analysis report contained indicators of texture, gravel (%), colour, Phosphorus (ppm), Nitrogen (Nitrate and Ammonium forms)(ppm), Potassium (ppm) organic carbon (%), Iron (ppm), Conductivity (dS/m), pH ($CaCl_2$), and pH (1.5 water).

The >2mm fraction was calculated by weight by passing the whole 1 kg sample through a 2mm sieve.

Further particle size analysis was carried out according to the following protocol:

1. 20g duplicate samples (weighed accurately) of each soil sample were taken. The first sample was dried in an oven at 105°C for a minimum of 36 hours and re-weighed.
2. The second sample was placed in a 100 ml glass beaker. 30ml DI water and 5ml 5% hydrogen peroxide was added and the beaker heated carefully on a hotplate to oxidise the organic matter. Excessive frothing was alleviated by adding a few drops of octyl alcohol. The heating and addition of fresh peroxide was continued until the reaction ceased. The samples were then boiled for 10 minutes to destroy the peroxide.

3. The soil and liquid were transferred from the beaker to plastic shaking bottles. A jet of DI water from a wash bottle ensured that all soil was transfered.
4. 20ml of sodium polymetaphosphate solution was added and the samples placed on shaker. For each batch of samples, 20ml of solution was pipetted into a tared container, evaporated and left to dry overnight at 105°C. The samples were cooled in a desiccator and weighed.
5. Each plastic bottle was shaken for 10 minutes to disperse the clay, the contents washed into a 1 litre measuring cylinder, made up to 1 litre, and plunger mixed to completely homogenise the contents. The cylinders were placed on a level surface and allowed to settle according to standard times before sampling (Day 1965).
6. 20ml of the suspension was pipetted from 10 cm depth into a tared evaporating pan. The volume was reduced and the samples oven dried at 105°C for at least 24 hours. The container and the dry material (<53μm) were then weighed.
7. Step 6 was repeated for the <20μm and 2μm samples (after the appropriate time intervals).
8. The remaining contents of the cylinder were poured through a 53μm sieve, gently washing to ensure that the fine materials were removed. The sieve was dried for at least 24 hours at 105°C and weighed (>53μm) (Day 1965).

The coefficient of non-uniformity (Cn), or the susceptibility of the soil to compaction, was calculated by using the particle size distribution. The logarithmic particle size is plotted against proportion of particle size in the soil. The value at 75% on the plot is divided by the value at 10% for each soil sample, the resulting ratio indicating the compactibility of the soil.

Electron dispersion and x-ray analysis (EDAX)

Stained and non-stained (white) samples of Delaware periderm were qualitatively assessed using the EDAX technique on the Scanning electron Microscope (SEM). Samples were fixed in 4% paraformaldehyde (phosphate buffer at pH- 7.3). Dehydration was routinely performed by ascending concentrations of ethanol, with a final step of 100% acetone. The samples were then critical point dried using liquid CO_2, and mounted for coating. Coating was with carbon only, and was performed by Technicians at the UWA Centre for Microscopy and Microanalysis. The SEM beam settings were 0.10 KEV and 20 eV/ch.

Statistical analysis

The correlation matrix was constructed using Macintosh® version Minitab® statistical software (release 8.1). Means and standard errors of the data were calculated by formula in Microsoft® Excel™ (please refer to Appendix A.3. Miscellaneous Formulas/Analysis). Curves were fitted using Macintosh® Cricket™ graph software (version 3).

5.4. Results.

Soil analysis

Major differences in the >2mm particle size fraction were found in tuber zone samples of production soils (Fig 5.1). The fractional analysis of the <2mm fraction indicated differences in sand/silt/clay levels across the production sites (Fig 5.2).

Correlation matrix

Many of the parameters measured were found to be inter-related (Table 5.1). No relationship was found between total physical malformation and the >2mm fraction of the soil (Table 5.1). However, a weak negative correlation exists between levels of major malformation and the >2mm fraction (Fig 5.3). The coefficient of non-uniformity (Cn) was found to bear a relationship with lenticel problems and with levels of bent tubers (Table 5.1). Frequency of periderm staining bears a weak positive relationship to available iron (Fe) levels (Fig 5.4) and is negatively correlated to nitrogen (N) in ammonium (NH_4^+) form (Fig 5.5). The occurrence of netted growth cracks also bears a negative relationship to tuber zone levels of NH_4^+ (Fig 5.6). Russeting of tubers has a strong positive relationship with tuber zone soil nitrate (NO_3^-) level (Fig 5.7).

EDAX analysis of stained periderm

Preliminary analysis of Delaware periderm samples shows that Fe is present in relatively large quantities in stained periderm, and is absent in non-stained (white) periderm (Table 5.2). Point EDAX analysis of the peridermal cell junction in stained samples shows high levels of elemental Fe present (data not shown).

Table 5.2. EDAX analysis of stained and white periderm samples from Delaware tubers sampled from the 1991/92 Manjimup/Pemberton production period.

	White (clear) Delaware periderm		Stained Delaware periderm	
Element	Present	Absent	Present	Absent
Na	✔		✔	
Fe		✔	✔	
Al	✔		✔	
Si	✔		✔	
P	✔		✔	
K	✔		✔	
Ca	✔		✔	
Mg	✔		✔	
S	✔		✔	
Cl	✔		✔	

Effect of tuber mass on pre-harvest cosmetic quality

Tuber mass was found to be approximately normally distributed with a leftward skew (Fig 5.8). The majority of tubers fell within the 50 to 200 gram mass range. Strong positive logarithmic relationships exist between tuber mass and levels of russeting (Fig 5.9), lenticel problems (Fig 5.10), physical malformation (Fig 5.11) and pre-harvest abrasion (Fig 5.16). Occurrence of second growth is related exponentially to tuber mass (Fig 5.14). No apparent correlation exists between tuber mass and periderm staining (Fig 5.12). Netted growth-cracking (Fig 5.13) and rippling of tubers (Fig 5.15) also have a positive linear relationship to tuber mass.

Table 5.1. Correlation matrix constructed for all cosmetic quality and other parameters measured for the1991/92 Manjimup/Pemberton production period.

	Mean mass (g)	Annual rainfall (mm)	Soil compactibility	pH	Nitrate (ppm)	Ammonium (ppm)	Potassium (ppm)	Available iron (ppm)	Phosphorus (ppm)	% Clay fraction	% Silt fraction	% Sand fraction	% < 2mm fraction	% > 2mm fraction	Lenticel rots	Minor lenticel	Major lenticel	Soil abrasion	Minor abrasion	Major abrasion	Malformation	Minor malformation	Major malformation	Rippled tuber	Stunted tuber	Folded tuber	Bent tuber	Dented tuber	Russeted periderm	Stained periderm	Suberised periderm	Netted growth cracks	Cleavage growth cracks	Scurf/Black dot	Minor scurf/black dot	Major scurf/black dot	pre-harvest greening	Minor greening	Major greening	Rhizoctonia sclerotia	Minor rhizoctonia	Major rhizoctonia	Total second-growth	Total knobs	Swollen eyes	Major knobs	Pointed stolon end	Pointed rose end	Elongated	Scabs	Minor scabs	Major scabs	Insect damage	Minor insect damage	Major insect damage	Soft rots	Minor soft rots	Major soft rots
Mean mass (g)	1.00																																																								
Annual rainfall (mm)	0.25	1.00																																																							
Soil compactibility	0.25	0.48	1.00																																																						
pH	-0.43	-0.27	-0.11	1.00																																																					
Nitrate (ppm)	0.63	0.29	0.71	0.01	1.00																																																				
Ammonium (ppm)	-0.48	0.51	0.32	0.44	0.01	1.00																																																			
Potassium (ppm)	-0.25	0.03	0.17	0.55	0.24	0.54	1.00																																																		
Available iron (ppm)	0.53	0.01	0.43	0.27	0.79	0.01	0.14	1.00																																																	
Phosporus (ppm)	-0.02	0.45	0.43	-0.68	0.05	0.22	-0.34	-0.16	1.00																																																
% Clay fraction	0.06	-0.08	-0.56	-0.04	-0.23	-0.18	-0.19	-0.06	-0.16	1.00																																															
% Silt fraction	0.29	0.49	0.89	-0.07	0.65	0.22	0.15	0.33	0.25	-0.77	1.00																																														
% Sand fraction	-0.42	-0.61	-0.91	0.12	-0.75	-0.20	-0.10	-0.41	-0.25	0.53	-0.95	1.00																																													
% <2mm fraction	0.41	0.53	0.40	-0.28	0.36	0.13	-0.02	0.17	0.29	-0.33	0.53	-0.55	1.00																																												
% >2mm fraction	-0.41	-0.53	-0.40	0.28	-0.36	-0.13	0.02	-0.17	-0.29	0.33	-0.53	0.55	-1.00	1.00																																											
Lenticel rots	0.06	0.66	0.55	-0.20	0.19	0.57	0.05	0.05	0.54	-0.48	0.58	-0.54	0.71	-0.71	1.00																																										
Minor lenticel	0.08	-0.08	-0.07	0.23	0.07	0.07	-0.22	0.36	-0.08	-0.24	0.10	-0.01	0.31	-0.31	0.39	1.00																																									
Major lenticel	-0.03	0.65	0.56	-0.38	0.10	0.44	0.26	-0.29	0.56	-0.21	0.43	-0.47	0.34	-0.34	0.52	-0.58	1.00																																								
Soil abrasion	0.17	0.57	0.29	-0.41	0.25	0.20	0.17	-0.31	0.40	0.04	0.26	-0.37	0.27	-0.27	0.33	-0.36	0.62	1.00																																							
Minor soil abrasion	0.19	0.58	0.30	-0.41	0.26	0.22	0.20	-0.29	0.39	0.02	0.27	-0.37	0.29	-0.29	0.35	-0.34	0.63	1.00	1.00																																						
Major soil abrasion	-0.08	0.30	0.16	-0.30	0.06	0.00	-0.11	-0.43	0.32	0.23	0.10	-0.25	0.07	-0.07	0.01	-0.45	0.43	0.76	0.72	1.00																																					
Malformation	-0.21	0.39	-0.03	0.02	-0.24	0.44	-0.02	-0.36	0.14	-0.08	0.05	-0.03	-0.08	0.08	0.44	0.29	0.11	0.37	0.39	0.17	1.00																																				
Minor malformed	-0.04	0.57	0.06	-0.04	-0.05	0.52	0.15	-0.25	0.20	-0.11	0.14	-0.13	0.04	-0.04	0.48	0.15	0.27	0.53	0.56	0.15	0.92	1.00																																			
Major malformed	-0.20	-0.08	-0.41	0.02	-0.44	-0.20	-0.38	-0.47	-0.19	0.45	-0.40	0.31	-0.61	0.61	-0.46	-0.23	-0.20	0.08	0.05	0.39	0.45	0.29	1.00																																		
Rippled tuber	0.45	0.32	0.33	-0.55	0.39	-0.14	-0.45	0.36	0.61	-0.20	0.34	-0.36	0.62	-0.62	0.50	0.48	-0.01	0.05	0.05	-0.06	-0.06	-0.02	-0.43	1.00																																	
Stunted tuber	-0.14	0.63	0.22	0.04	-0.16	0.57	0.32	-0.32	0.08	-0.48	0.42	-0.32	0.40	-0.40	0.64	0.01	0.55	0.25	0.28	-0.10	0.50	0.60	-0.14	-0.10	1.00																																
Folded tuber	-0.30	-0.07	-0.32	0.21	-0.36	0.18	0.14	-0.26	-0.27	0.02	-0.19	0.24	-0.13	0.13	0.18	0.43	-0.24	-0.05	-0.04	-0.14	0.71	0.50	0.31	-0.14	0.30	1.00																															
Bent tuber	0.61	0.61	0.62	-0.05	0.71	0.20	0.06	0.41	0.08	-0.24	0.67	-0.77	0.50	-0.50	0.51	0.20	0.26	0.54	0.56	0.24	0.30	0.45	-0.15	0.25	0.28	-0.08	1.00																														
Dented tuber	-0.25	0.11	-0.16	0.15	-0.23	0.30	0.11	-0.30	-0.07	-0.13	-0.04	0.11	-0.30	0.30	0.20	0.31	-0.12	0.26	0.27	0.02	0.93	0.84	0.46	-0.19	0.35	0.76	0.18	1.00																													
Russeted periderm	0.54	0.17	0.35	-0.13	0.73	-0.04	0.36	0.57	-0.02	0.11	0.24	-0.37	0.15	-0.15	0.10	0.03	0.06	0.37	0.39	0.04	0.01	0.14	-0.30	0.27	-0.18	0.12	0.49	0.06	1.00																												
Stained periderm	0.56	-0.20	-0.12	-0.13	0.43	-0.58	-0.40	0.54	-0.20	0.33	-0.12	0.00	-0.22	0.22	-0.44	0.26	-0.63	-0.15	-0.15	-0.10	-0.18	-0.19	0.18	0.32	-0.66	-0.11	0.18	-0.03	0.45	1.00																											
Suberized periderm	-0.34	-0.42	-0.24	-0.09	-0.46	-0.14	0.21	-0.34	-0.13	-0.01	-0.30	0.41	-0.48	0.48	-0.23	-0.31	0.09	-0.22	-0.21	-0.28	-0.01	-0.14	0.05	-0.40	0.06	0.37	-0.59	0.14	0.01	-0.24	1.00																										
Netted growth cracks	0.42	-0.46	-0.21	-0.50	0.01	-0.85	-0.24	-0.03	-0.10	0.10	-0.17	0.18	0.05	-0.05	-0.45	-0.29	-0.12	-0.16	-0.17	-0.06	-0.65	-0.64	-0.15	0.14	-0.42	-0.28	-0.33	-0.54	0.12	0.26	0.33	1.00																									
Cleavage growth cracks	0.18	-0.29	-0.40	-0.33	-0.15	-0.40	0.16	-0.13	-0.15	0.29	-0.44	0.44	-0.35	0.35	-0.38	-0.28	-0.08	0.03	0.05	-0.21	-0.02	0.03	0.08	-0.12	-0.15	0.30	-0.35	0.17	0.44	0.22	0.68	0.55	1.00																								
Scurf/ Black dot	-0.39	-0.02	-0.47	0.44	-0.51	0.41	0.48	-0.25	-0.41	0.10	-0.40	0.48	-0.23	0.23	-0.05	-0.06	0.00	-0.29	-0.25	-0.50	0.24	0.29	0.05	-0.52	0.52	0.44	-0.38	0.30	-0.22	-0.46	0.43	-0.23	0.32	1.00																							
Minor Scurf/Black dot	-0.49	-0.06	-0.43	0.54	-0.54	0.50	0.49	-0.24	-0.39	0.05	-0.38	0.47	-0.21	0.21	0.00	-0.01	-0.01	-0.35	-0.32	-0.51	0.21	0.23	0.00	-0.54	0.51	0.40	-0.40	0.25	-0.32	-0.54	0.39	-0.32	0.16	0.98	1.00																						
Major Scurf/Black dot	-0.14	0.04	-0.49	0.18	-0.41	0.18	0.40	-0.25	-0.39	0.18	-0.39	0.43	-0.24	0.24	-0.13	-0.14	0.00	-0.14	-0.10	-0.42	0.29	0.38	0.16	-0.41	0.47	0.50	-0.30	0.37	0.01	-0.24	0.48	-0.03	0.60	0.91	0.81	1.00																					
Pre-harvest greening	0.16	0.10	-0.17	-0.06	0.08	0.02	-0.01	0.30	0.06	0.62	-0.38	0.20	0.01	-0.01	-0.17	-0.12	-0.04	-0.21	-0.21	-0.12	-0.23	-0.16	-0.01	0.22	-0.27	0.00	-0.25	-0.32	0.28	0.18	-0.02	0.15	0.31	0.20	0.14	0.29	1.00																				
Minor greening	0.04	0.25	-0.22	0.19	-0.07	0.16	0.14	0.19	-0.24	0.51	-0.30	0.14	0.02	-0.02	-0.15	-0.17	0.02	-0.30	-0.30	-0.24	-0.18	-0.11	0.04	-0.07	0.11	0.07	-0.23	-0.28	0.06	-0.01	0.04	0.00	0.16	0.51	0.46	0.54	0.82	1.00																			
Major greening	0.22	-0.13	-0.03	-0.32	0.22	-0.16	-0.17	0.29	0.39	0.45	-0.30	0.18	-0.01	0.01	-0.11	0.00	-0.09	0.01	0.00	0.08	-0.17	-0.15	-0.06	0.47	-0.59	-0.08	-0.16	-0.21	0.41	0.32	-0.08	0.26	0.32	-0.27	-0.31	-0.15	0.73	0.21	1.00																		
Rhizoctonia sclerotia	0.25	0.71	0.01	-0.15	0.15	0.25	-0.07	0.14	0.14	0.03	0.17	-0.25	0.40	-0.40	0.35	0.24	0.07	0.14	0.16	-0.11	0.26	0.43	-0.09	0.44	0.45	0.10	0.28	0.14	0.15	0.17	-0.38	-0.29	-0.05	0.19	0.11	0.31	0.29	0.48	-0.07	1.00																	
Minor rhizoctonia	0.19	0.76	-0.10	-0.08	-0.04	0.36	0.02	-0.06	0.02	0.16	0.04	-0.14	0.29	-0.29	0.36	0.11	0.20	0.26	0.29	-0.05	0.47	0.63	0.11	0.13	0.62	0.26	0.33	0.32	0.09	-0.02	-0.25	-0.40	0.01	0.41	0.33	0.52	0.21	0.50	-0.23	0.90	1.00																
Major rhizoctonia	0.19	0.03	0.24	-0.18	0.43	-0.19	-0.21	0.45	0.29	-0.27	0.31	-0.28	0.31	-0.31	0.05	0.32	-0.25	-0.24	-0.24	-0.15	-0.39	-0.33	-0.42	0.74	-0.28	-0.31	-0.04	-0.36	0.16	0.42	-0.34	0.20	-0.14	-0.43	-0.43	-0.37	0.23	0.05	0.33	0.40	-0.04	1.00															
Total second-growth	0.77	0.20	0.08	-0.40	0.48	-0.47	-0.53	0.37	0.13	0.23	0.13	-0.28	0.48	-0.48	0.04	0.28	-0.22	0.21	0.20	0.23	-0.18	-0.10	-0.04	0.61	-0.37	-0.33	0.51	-0.28	0.28	0.61	-0.71	0.27	-0.17	-0.64	-0.69	-0.48	0.15	-0.08	0.35	0.26	0.11	0.37	1.00														
Total knobs	0.33	0.19	-0.04	-0.36	0.34	-0.28	-0.20	0.16	0.23	0.07	0.09	-0.15	0.43	-0.43	0.02	0.21	-0.18	0.20	0.19	0.22	-0.15	-0.04	-0.17	0.69	-0.22	-0.10	0.10	-0.16	0.30	0.42	-0.47	0.26	0.07	-0.39	-0.46	-0.19	0.32	0.10	0.43	0.53	0.22	0.76	0.61	1.00													
Swollen eyes	0.54	0.59	0.01	-0.21	0.21	0.12	-0.15	0.09	0.11	0.15	0.12	-0.24	0.68	-0.68	0.48	0.29	0.14	0.44	0.46	0.15	0.23	0.40	-0.15	0.35	0.31	-0.07	0.65	0.03	0.14	0.05	-0.65	-0.18	-0.26	-0.09	-0.11	-0.03	0.01	0.05	-0.04	0.51	0.59	-0.06	0.66	0.31	1.00												
Major knobs	0.77	-0.06	-0.08	-0.41	0.27	-0.64	-0.56	0.22	-0.04	0.38	-0.10	-0.06	0.18	-0.18	-0.16	0.10	-0.24	0.15	0.14	0.19	-0.12	-0.12	0.20	0.28	-0.45	-0.21	0.39	-0.18	0.23	0.56	-0.38	0.42	0.07	-0.52	-0.58	-0.33	0.10	-0.13	0.34	-0.11	-0.09	-0.07	0.84	0.21	0.50	1.00											
Pointed stolon end	0.58	0.05	0.31	-0.06	0.64	-0.43	-0.39	0.65	-0.08	-0.01	0.36	-0.48	0.30	-0.30	-0.12	0.28	-0.37	-0.20	-0.21	0.02	-0.42	-0.41	-0.12	0.53	-0.44	-0.38	0.36	-0.43	0.25	0.69	-0.59	0.23	-0.32	-0.65	-0.66	-0.56	0.18	0.08	0.20	0.24	-0.06	0.68	0.73	0.55	0.17	0.49	1.00										
Pointed rose end	0.37	-0.44	-0.14	-0.16	0.14	-0.54	0.07	0.25	-0.33	0.24	-0.24	0.20	-0.37	0.37	-0.47	-0.23	-0.20	-0.12	-0.10	-0.27	-0.38	-0.37	-0.08	-0.21	-0.41	-0.08	-0.11	-0.16	0.46	0.46	0.56	0.57	0.66	-0.04	-0.12	0.13	0.00	-0.04	0.05	-0.33	-0.28	-0.17	-0.02	-0.24	-0.27	0.26	0.01	1.00									
Elongated	0.09	0.03	-0.22	-0.56	-0.12	-0.10	-0.31	-0.26	0.61	0.23	-0.31	0.30	0.17	-0.17	0.15	0.08	0.07	0.43	0.43	0.31	0.14	0.20	-0.05	0.45	-0.26	-0.12	-0.04	0.07	0.04	0.06	-0.22	0.11	0.14	-0.30	-0.32	-0.22	0.08	-0.35	0.56	-0.01	-0.06	0.10	0.40	0.42	0.36	0.33	-0.16	-0.15	1.00								
Scabs	0.12	-0.47	-0.19	-0.10	-0.22	-0.47	-0.16	-0.05	-0.25	-0.05	-0.13	0.20	0.21	-0.21	-0.07	0.11	-0.16	-0.32	-0.32	-0.26	-0.50	-0.63	-0.35	-0.06	-0.16	-0.13	-0.22	-0.46	-0.19	-0.07	0.31	0.56	0.05	-0.08	-0.03	-0.17	-0.27	-0.18	-0.24	-0.44	-0.41	-0.16	0.06	-0.26	0.00	0.24	0.00	0.47	-0.09	1.00							
Minor scabs	0.18	-0.40	-0.14	-0.08	-0.15	-0.45	-0.17	0.01	-0.25	-0.04	-0.08	0.13	0.27	-0.27	-0.06	0.10	-0.14	-0.30	-0.30	-0.23	-0.54	-0.65	-0.37	-0.04	-0.15	-0.22	-0.14	-0.53	-0.19	-0.05	0.20	0.53	-0.04	-0.13	-0.07	-0.23	-0.27	-0.16	-0.26	-0.40	-0.37	-0.13	0.13	-0.24	0.08	0.28	0.08	0.43	-0.11	0.99	1.00						
Major scabs	-0.10	-0.63	-0.35	-0.16	-0.45	-0.46	-0.11	-0.26	-0.20	-0.07	-0.30	0.44	-0.06	0.06	-0.12	0.11	-0.20	-0.36	-0.35	-0.33	-0.24	-0.44	-0.18	-0.12	-0.14	0.24	-0.48	-0.13	-0.15	-0.14	0.68	0.58	0.40	0.12	0.13	0.10	-0.21	-0.22	-0.10	-0.53	-0.47	-0.23	-0.23	-0.31	-0.29	0.06	-0.30	0.51	0.00	0.85	0.76	1.00					
Insect damage	0.10	0.22	0.28	0.38	0.37	0.19	0.22	0.18	-0.31	-0.44	0.49	-0.43	-0.13	0.13	0.01	0.11	-0.10	0.17	0.18	0.01	0.35	0.45	0.19	-0.24	0.29	0.01	0.56	0.47	0.06	0.18	-0.35	-0.46	-0.30	-0.03	-0.04	-0.01	-0.55	-0.32	-0.56	0.19	0.23	-0.03	0.00	-0.10	0.09	-0.09	0.17	-0.14	-0.37	-0.42	-0.38	-0.52	1.00				
Minor insect damage	-0.08	0.26	0.25	0.41	0.17	0.43	0.31	0.04	-0.18	-0.50	0.41	-0.30	-0.16	0.16	0.18	0.13	0.04	0.15	0.18	-0.12	0.50	0.61	0.14	-0.30	0.49	0.10	0.46	0.59	-0.08	-0.10	-0.21	-0.62	-0.29	0.21	0.23	0.16	-0.58	-0.33	-0.59	0.17	0.28	-0.20	-0.23	-0.30	0.09	-0.27	-0.15	-0.23	-0.29	-0.44	-0.42	-0.45	0.92	1.00			
Major insect damage	0.47	-0.11	0.09	-0.06	0.51	-0.61	-0.22	0.34	-0.32	0.16	0.19	-0.33	0.06	-0.06	-0.43	-0.03	-0.35	0.04	0.01	0.32	-0.36	-0.40	0.15	0.17	-0.50	-0.22	0.25	-0.30	0.34	0.69	-0.35	0.41	-0.03	-0.60	-0.66	-0.41	0.06	0.02	0.08	0.07	-0.13	0.43	0.59	0.52	0.01	0.47	0.82	0.23	-0.21	0.04	0.09	-0.17	0.20	-0.20	1.00		
Soft rots	0.25	-0.14	0.05	0.08	0.05	-0.20	-0.48	0.26	-0.08	0.04	-0.02	0.01	-0.42	0.42	-0.26	0.08	-0.30	-0.32	-0.32	-0.23	0.02	-0.01	0.38	-0.12	-0.26	-0.30	0.16	0.05	-0.26	0.39	-0.21	-0.13	-0.25	-0.18	-0.15	-0.21	-0.17	-0.18	-0.06	-0.19	-0.14	-0.15	0.20	-0.40	-0.03	0.41	0.25	0.14	-0.12	-0.06	-0.02	-0.17	0.38	0.37	0.03	1.00	
Minor soft rots	-0.41	-0.22	-0.22	0.20	-0.38	0.04	-0.28	-0.24	-0.01	-0.03	-0.23	0.32	-0.71	0.71	-0.39	-0.12	-0.24	-0.30	-0.31	-0.10	0.18	0.13	0.56	-0.35	-0.10	-0.12	-0.33	0.28	-0.59	0.06	0.04	-0.30	-0.17	0.13	0.17	0.04	-0.25	-0.17	-0.22	-0.13	-0.09	-0.10	-0.32	-0.35	-0.41	-0.21	-0.16	-0.15	-0.08	-0.34	-0.35	-0.23	0.39	0.47	-0.21	0.88	1.00	
Major soft rots	0.74	0.03	0.28	-0.09	0.45	-0.31	-0.37	0.59	-0.10	0.09	0.20	-0.31	0.15	-0.15	0.05	0.23	-0.17	-0.14	-0.13	-0.21	-0.15	-0.14	-0.05	0.20	-0.26	-0.28	0.54	-0.21	0.24	0.46	-0.32	0.12	-0.17	-0.38	-0.38	-0.33	0.02	-0.07	0.11	-0.13	-0.09	-0.10	0.59	-0.20	0.36	0.76	0.49	0.33	-0.08	0.26	0.32	0.00	0.12	0.03	0.24	0.68	-0.08	1.00

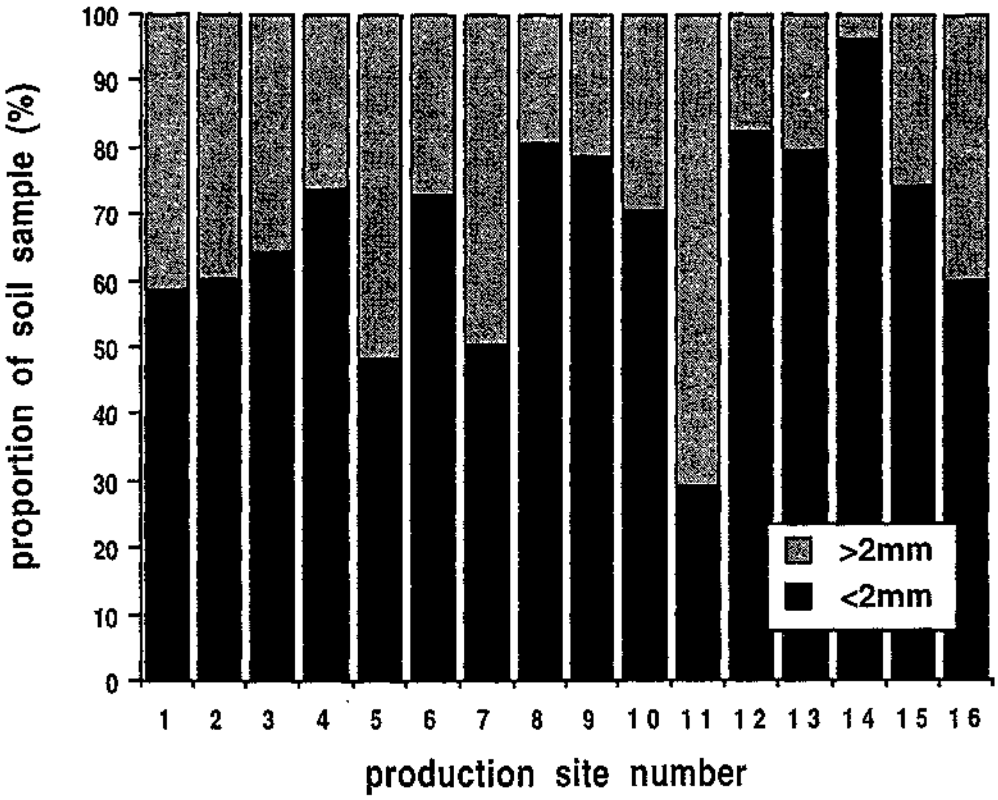

Fig 5.1. Comparison of sample production site tuber zone soils in terms of coarse fractions.

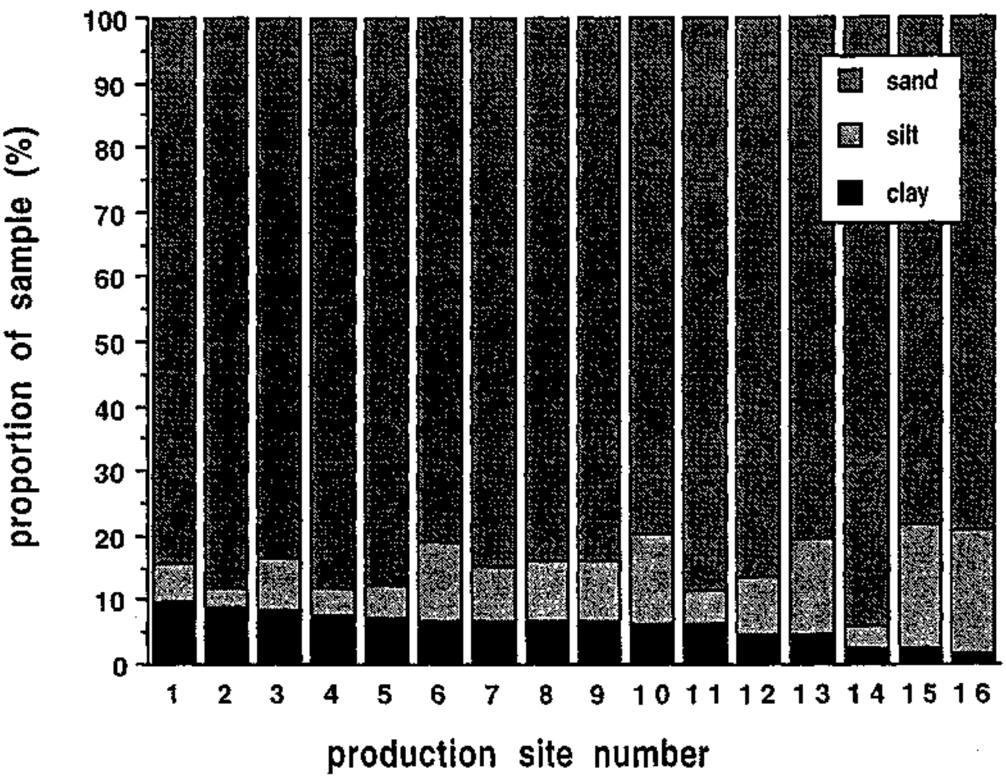

Fig 5.2. A breakdown of proportional sand, silt and clay in the <2mm fraction of sample tuber zone soil for Delaware production sites in the Manjimup/Pemberton region.

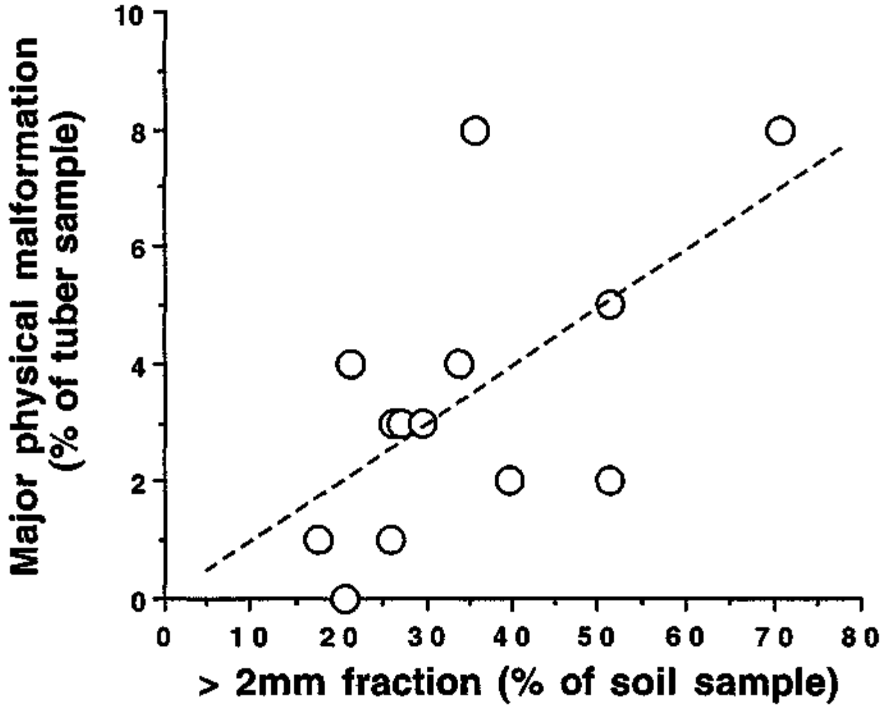

Fig 5.3. The relationship between major physical malformation occurring in Delaware tubers and the above 2 mm fraction of sample production site soils in the Manjimup/Pemberton region

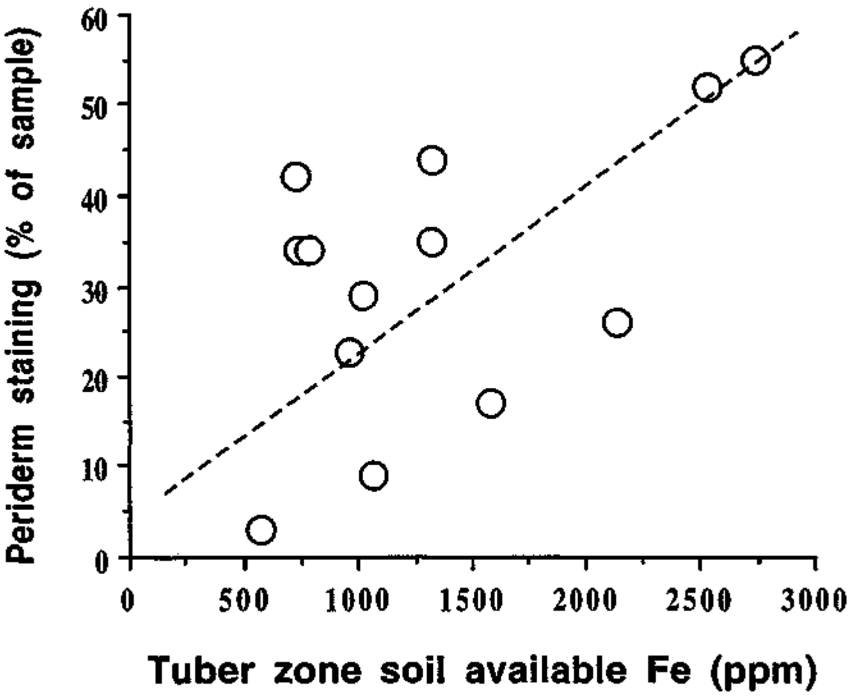

Fig 5.4. The relationship between available iron (Fe) and occurrence of periderm staining in Delaware tubers from the 1991/92 Manjimup/Pemberton production period.

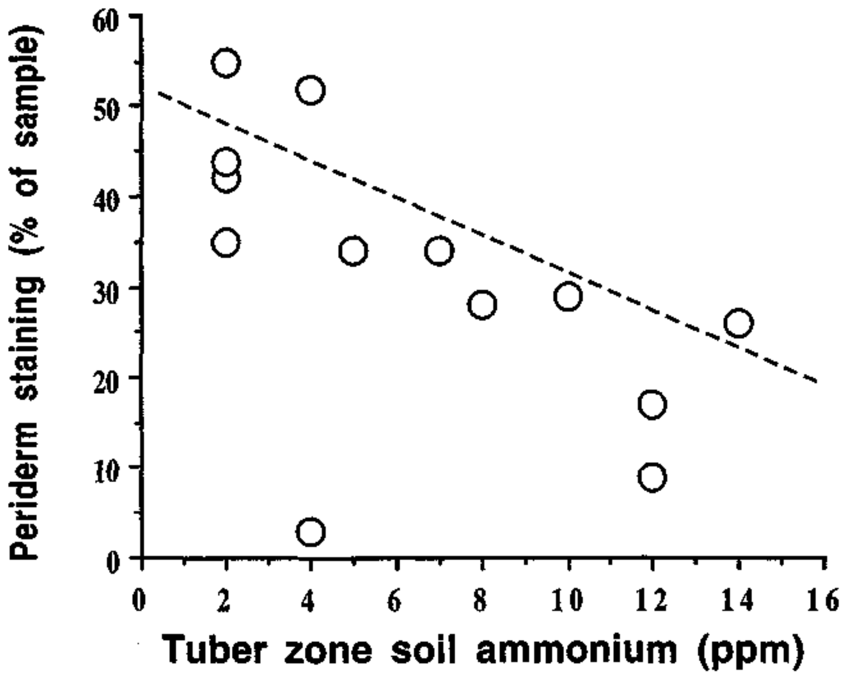

Fig 5.5. The relationship between nitrogen (N) in ammonium form and the occurrence of peridermal staining in Delaware tubers from the 1991/92 Manjimup/Pemberton production period.

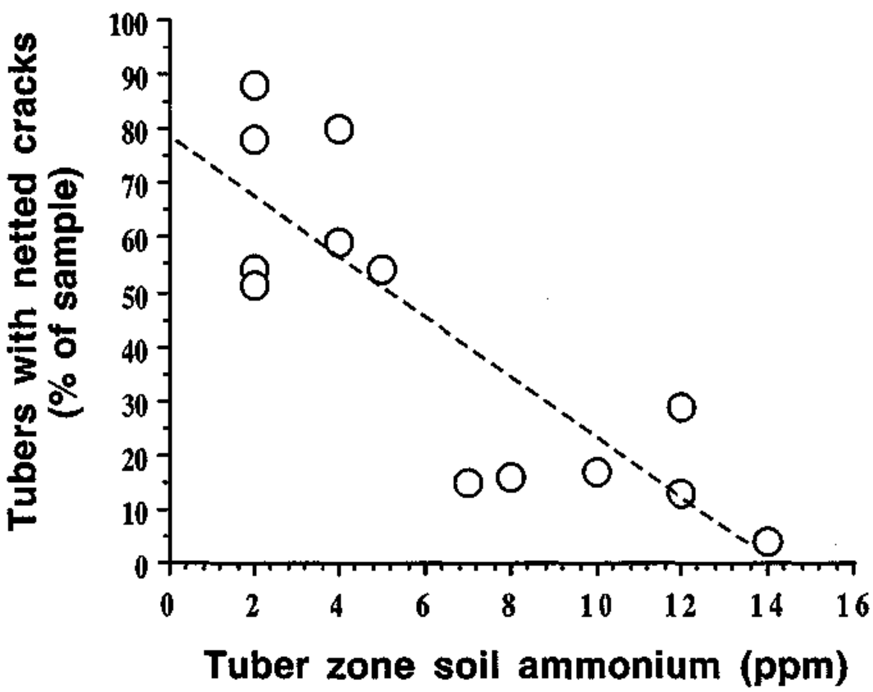

Fig 5.6. The relationship between nitrogen (N) in ammonium form and occurrence of netted growth cracks in Delaware tubers from the 1991/92 Manjimup/Pemberton production period.

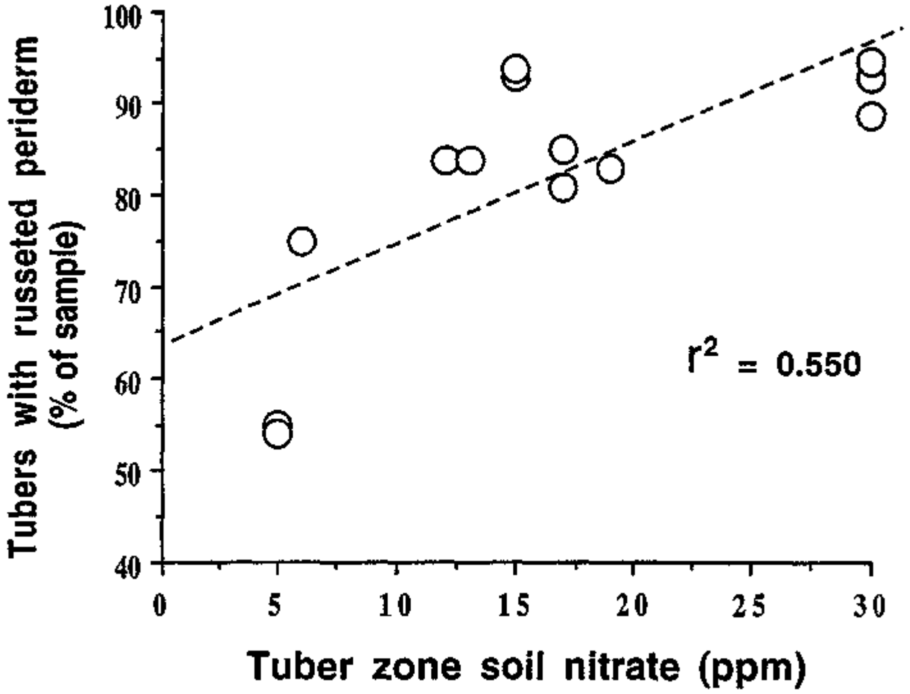

Fig 5.7. The relationship between tuber zone soil nitrate and occurrence of russeted peridem in Delaware tubers from the 1991/92 Manjimup/Pemberton production period.

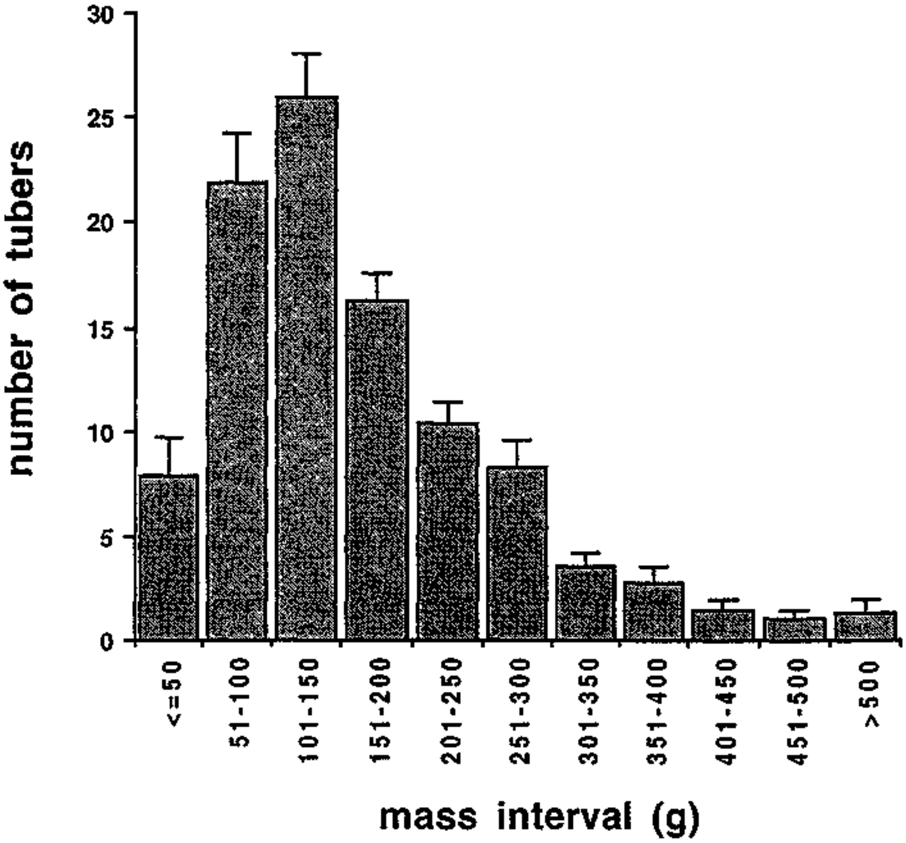

Fig 5.8. The distribution of tuber mass within a randomly sampled population of Delaware tubers. Lines extending from the columns represent standard errrors of the means (n=16).

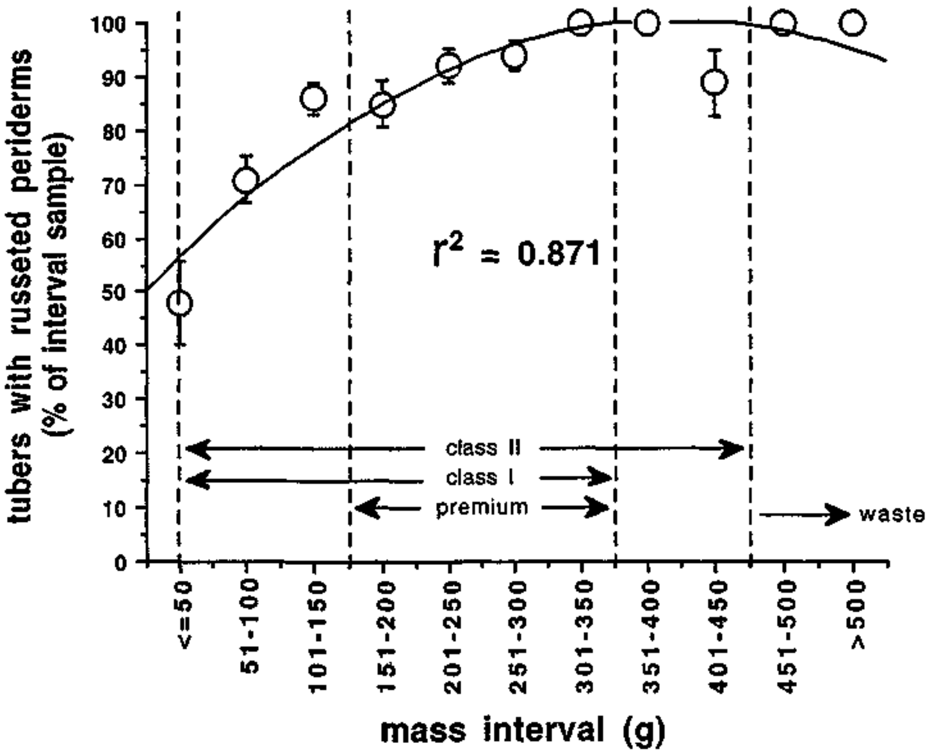

Fig 5.9. The relationship between tuber mass and occurrence of russeted periderm in Delaware tubers from the 1991/92 Manjimup /Pemberton production period. Lines extending from the means represent standard errors.

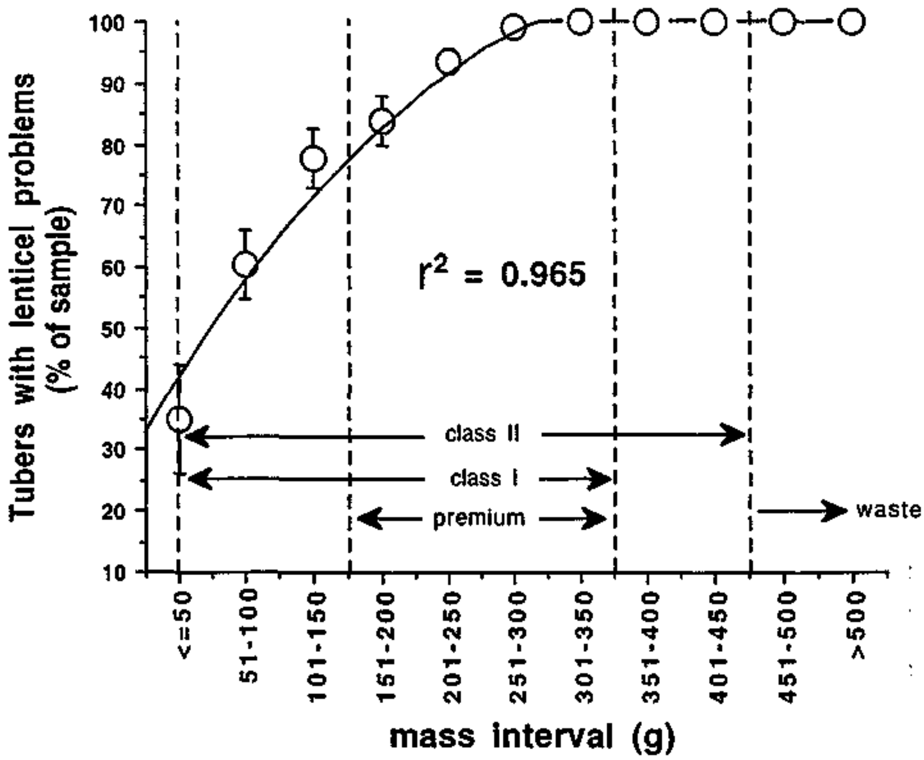

Fig 5.10. The relationship between tuber mass and occurrence of lenticel problems in Delaware tubers from the 1991/92 Manjimup /Pemberton production period. Lines extending from the means represent standard errors.

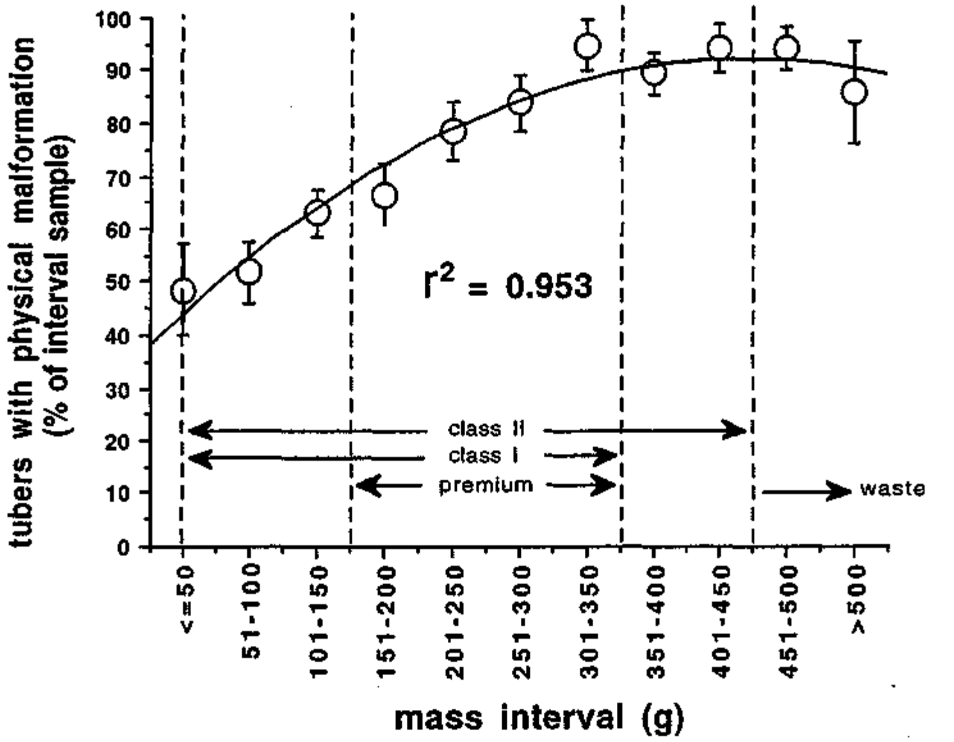

Fig 5.11. The relationship between tuber mass and occurrence of physical malformation in Delaware tubers from the 1991/92 Manjimup/Pemberton production period. Lines extending from the means represent standard errors.

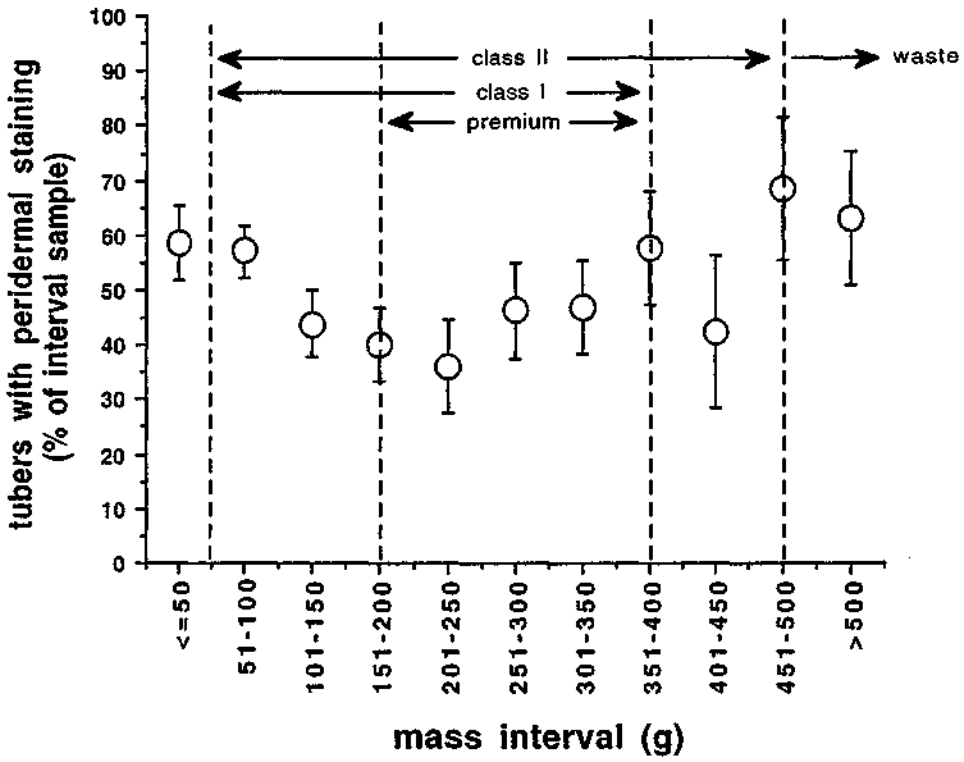

Fig 5.12. The relationship between tuber mass and occurrence of peridermal staining in Delaware tubers from the 1991/92 Manjimup/Pemberton production period. Lines extending from the means represent standard errors.

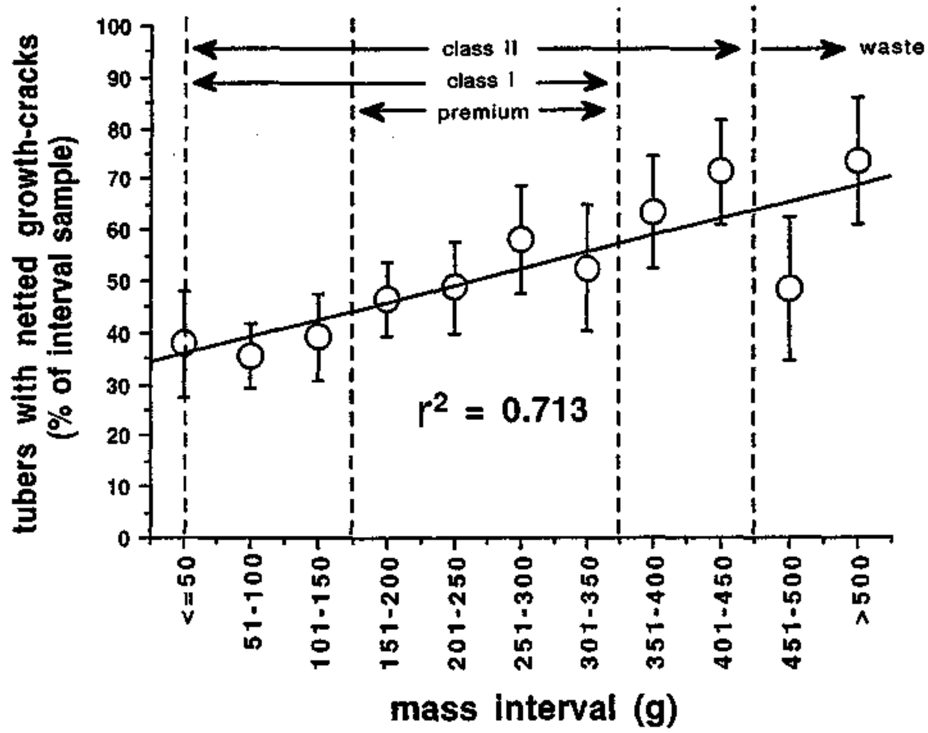

Fig 5.13. The relationship between tuber mass and occurrence of netted growth-cracks in Delaware from the 1991/92 Manjimup /Pemberton production period. Lines extending from the means represent standard errors.

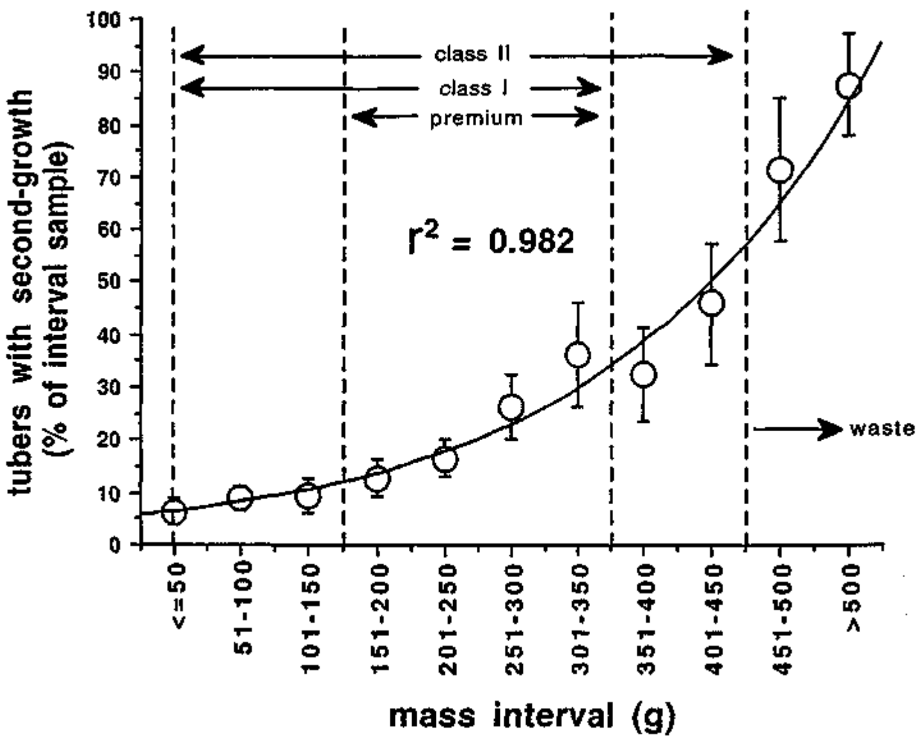

Fig 5.14. The relationship between tuber mass and occurrence of second-growth in Delaware tubers from the 1991/92 Manjimup /Pemberton production period. Lines extending from the means represent standard errors.

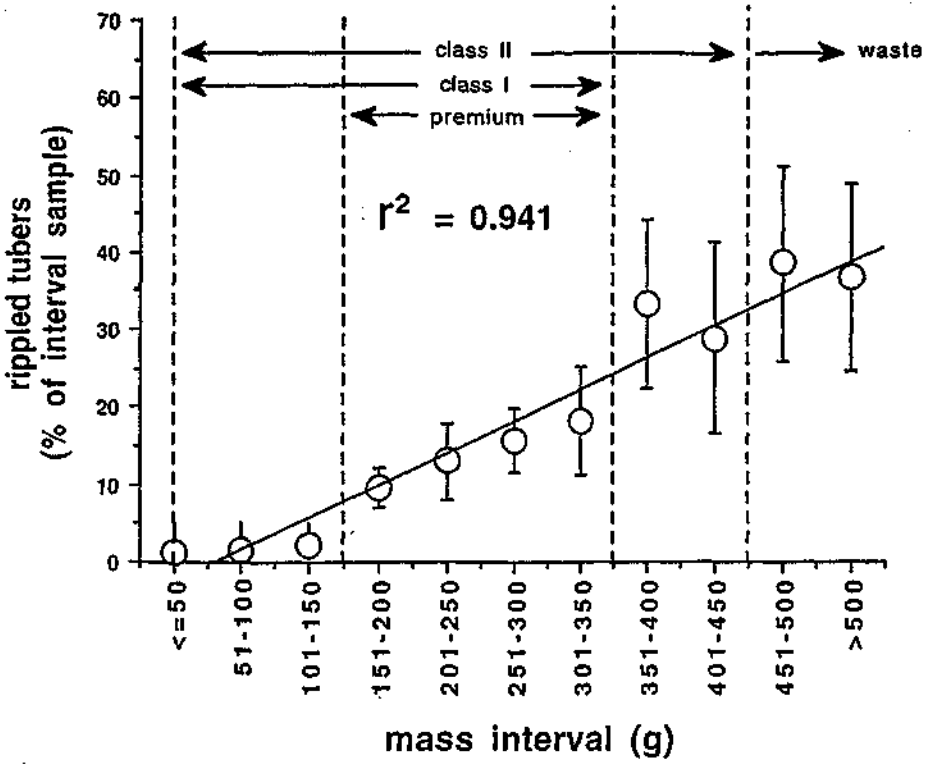

Fig 5.15. The relationship between tuber mass and occurrence of rippling in Delaware tubers from the1991/92 Manjimup/Pemberton production period. Lines extending from the means represent standard errors.

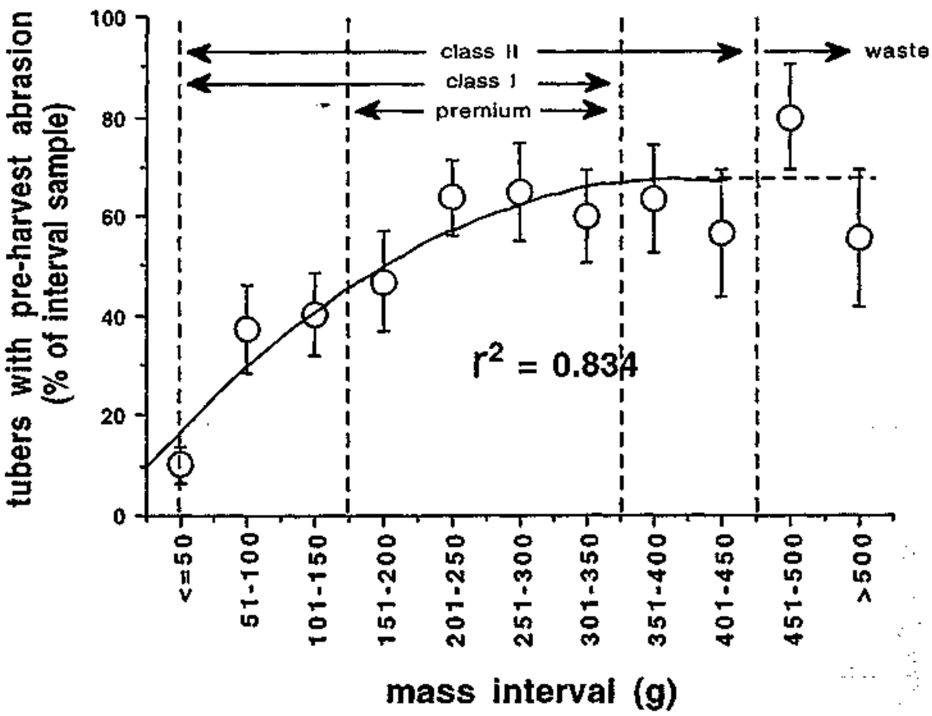

Fig 5.16. The relationship between tuber mass and occurrence of pre-harvest abrasion in Delaware tubers from the 1991/92 Manjimup/Pemberton production period. Lines extending from the means represent standard errors.

5.5. Discussion.

Correlation matrix

A high value of **r** (closer to -1 or +1) between two variables does not necessarily indicate a cause/effect relationship (Freund, 1984). Both variables may in fact be dependant on a third factor for their close correlation ie they are co-responsive. An apparent lack of correlation in the matrix does not therefore preclude more complex intra and inter-relationships between the cosmetic quality factors and various edaphic and other parameters measured for Delaware production sites. Further work along these lines is required. Some obvious complex relationships exist. For example the interplay between staining, physiological stress and tuber zone Fe and ammonium (Table 5.1). The relationship of rippled tuber occurrence to soil phosphorus, soil nitrate, and known second growth forms is another example of this.

Peridermal Staining

Staining of the periderm appears to be related in some manner to the presence of Fe. The discolouration is confined to a sub-peridermal layer or layers of cells, and may be the product of abnormal deposition in the cell walls of some substance with a high elemental Fe content. Examination of transverse sections of periderm using fluorescent microscopy has shown differences between the cell morphology of stained and clear samples (data not shown). Stained periderm appears to be not significantly thicker than clear periderm in terms of cell number. However, the stained periderm has a flattened or crushed morphology, which may be compounding the discolouration effect. Tuber periderm consists of differing layers, these being the cork or phellem (outer layer), the phellogen (middle layer) and the phelloderm (inner layer) (Raven and Johnson 1988). Tubers grown under relatively high soil temperatures (>20°C) are prone to have thick periderms, with a very compressed phellogen layer (Yammaguchi *et al.* 1964). Collapse of the periderm has also been attributed to pathogenic infection (Heiny and McIntyre 1983). Potato periderm infected with *Helminthosporium solani* (Silver scurf) was found to bear layers of collapsed and suberised periderm and cortical cells. However, in this study a negative correlation was found between levels of peridermal staining and silver scurf/black dot infections (Table 5.1). Staining bears a positive correlation with second-growth (total second growth, knobs and pointed stolon end), insect damage to tubers and available Fe in the tuber zone soil (Table 5.1). Peridermal staining may therefore be some form of complex response to plant stress and iron levels in the soil.

Soil compactibility

The susceptibility of the sample soils to compaction (Cn ratio) was found to bear only weak relationships to some cosmetic quality problem categories (Table 5.1). However, no indication can be given of the treatment of these soils during potato production. That is, a susceptible soil may not have been subjected to compaction processes. Clearly, a more detailed treatment of the presumed compaction problem is needed.

Cosmetic quality and tuber mass

The increase with tuber mass of russeting (Fig 5.9), lenticel problems (Fig 5.10), physical malformation (Fig 5.11), growth-cracking (Fig 5.13), second growth (Fig 5.14) and pre-harvest abrasion (Fig 5.16) indicates that these problems are related to the development of the tuber over time. The lack of any relationship between tuber mass and peridermal staining is evidence for a response of the tuber to factors other than those related to increase in growth, in particular the presence of Fe in the tuber zone soil. The positive relationship between staining and tuber zone levels of available Fe (Fig 5.4), coupled with the EDAX qualitative analysis results (Table 5.2) supports this argument. Rippling of tubers, while assumed to be a form of second-growth, bears a linear relationship to tuber mass (Fig 5.15). This shape problem may therefore be the result of on-going minor stresses, rather than a trigger effect as is the case with other forms of second growth. Second growth and rippling of tubers are clearly having greater roles in the down-grading of tubers from class II to waste than between other grades. Russeting, lenticel problems, physical malformation and pre-harvest abrasion are having an effect across all grades. The susceptibility of a tuber to pre-harvest abrasion is most likely related to peridermal strength, which is a product of developmental and varietal differences.

5.6. Literature cited.

Anonymous (1986). *The Potato Retailer.* WA Potato Marketing Board, March/April edition.

Day, P.R. (1965) Particle fraction standard particle size analysis, in *Methods of Soil Analysis, Part 1,* Agron. Series no. 9, Am. Soc. of Agronomy.

Freund, J.E. (1984). *Modern Elementary Statistics* 6th edition. Prentice-Hall, Inc. New Jersey.

Heiny, D.K., and McIntyre, G.A. (1983). *Helminthosporium solani* Dur. and Mont. development on potato periderm *Am. Pot. J.* **60:** 773-789

Mead, R., and Curnow, R.N. (1986). *Statistical Methods in Agriculture and Experimental Biology* Chapman and Hall, London.

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Snedecor, G.W., and Cochran, W.G. (1962). *Statistical Methods* 5th edition. Iowa State University Press, Iowa

Yammaguchi, M., Timm, H., and Spurr, A.R. (1964). Effects of soil temperature on growth and nutrition of potato plants and tuberization, composition, and periderm structure of tubers. *Am. Soc. Hort. Sci.* **84:** 412-423

6.0. Recommendations

6.1. Pre-harvest problems

Production sites known to have high aggregate levels and compaction /drainage problems should be avoided wherever possible. Irrigation regimes should be modelled on those supplied by the WA Department of Agriculture for the soils in the Manjimup/Pemberton area. Where applicable, increased irrigation frequency to avoid stress related problems such as second-growth and netted growth cracking is advisable. Use of tensiometers to monitor soil moisture levels is recommended to allow accurate timing of irrigation. Regular random sampling by growers across the tuber development period will enable prompt identification and action to rectify problems of known origin and treatment (eg. pests/disease, irrigation related problems). The use of wider ridges is recommended for production areas producing high levels of pre-harvest greening.

6.2. Postharvest Problems

The greatest problem with minor impact splitting and bruising is that it is only noticeable on close inspection. Growers can reduce the susceptibility of the tuber to mechanical damage by cultural practices pre-harvest and during harvest. Leaving tubers in the ground long enough after haulm killing to form thicker periderms is recommended. Lifting of tubers when the soil temperature is between 15 - 20°C also decreases tuber injury (Anon. 1980). Extreme conditions of soil moisture content (ie. very wet or very dry) when lifting should also be avoided (Anon. 1980). During and after harvest, growers should ensure that recommended chain speeds and the maximum drop height are not exceeded. The maximum recommended drop height is 0.5m, but drops should be kept significantly less than this (Anon. 1980). All collision surfaces should be padded wherever possible, and an impact mat should be used during bulk transferral to transport bins. Farm roads used in transport of tubers should be kept well graded to decrease the incidence of mechanical damage.

6.3. Further Research Avenues

Soil compaction related problems

A soil compaction survey should be conducted across production sites in the Manjimup/Pemberton area. Determination of the existence of hard pans and their distribution within production areas could be correlated with a detailed cultural practices survey. Mapping of the distribution of soils susceptible to compaction within the region would also be beneficial. An extension programme covering compaction avoidance techniques on susceptible soils can be coupled to this work. Crop scale field trials with treatments designed to alleviate soil compaction (ie precision tillage, general deep ripping, gypsum application) can be conducted. Additionally, the role of soil compaction can be investigated under tightly controlled experimental conditions in the glasshouse.

Physiological shape problems

Experimentation to discern the real nature of the relationship between rippling, soil phosphorus and the presence of fungal diseases is needed. Tissue growth rate measurement and histological work could define the mechanism of rippling, while pot experiments could determine the key factors for occurrence. Tuber rippling has the potential to become a major shape related reason for downgrading.

Assessment of the variation between seed potatoes based on clonal source and pre-planting treatment in response to timing and severity of stress is needed. The results of an investigation of the effects of varying storage time and temperature within and between cultivars could be used to advise seed growers.

Peridermal Staining

The relationship between physiological stress, soil nutrient levels, and peridermal staining should be investigated using glasshouse and field experiments. Further histological and SEM work to characterise the problem is needed.

Postharvest problems

The relatively high levels of minor mechanical damage present in Delaware may be extrapolated to other varieties produced within the Manjimup /Pemberton region. Clearly, a further detailed survey to define points of occurrence of postharvest damage in the production chain is necessary. Aspects of handling such as drop heights during bulk tuber transferral and machinery settings currently in use should be investigated. The survey should deal with potato production across the state to determine whether the problem is localised or wide-spread.

6.4. Literature cited

Anonymous (1980). *Handling Damage in the Australian Potato Industry.* National Materials Handling Bureau.

APPENDICES

A.1. Glossary of Terms

In order to uniformly assess shape and superficial quality problem levels within Delaware tuber samples, a list of standard descriptive comments was created. Each tuber was compared to this list and the suitable or nearest descriptor noted on the data sheets.

1.0. Shape descriptors

1.1. Malformation - any dent, fold, cleft, lump, or bend that affects the smooth botuliform shape (Radford *et. al.,* 1974) of the Delaware tuber.

(a) **Minor malformation** - A degree of malformation that would not overly interfere with the normal peeling process e.g. shallow dents, bending of tubers.
(b) **Major malformation** - A degree of malformation that would severly impair the peeling process e.g. deep dents, folds, or severe bending of tubers.
(c) **Dent** - Any obvious dent in the tuber not associated with a bud/bud axil. Causal agents can range from rock, aggregate and compacted soil (clods).
(d) **Longitudinal stunt** - Tubers displaying retarded longitudinal expansion (tuber stunted on the stolon to rose-end axis).
(e) **Radial stunt** - Tubers displaying retarded radial expansion (ie flattened or squared radially).
(f) **Bent** - Tuber bent along the longitudinal axis.
(g) **Cleft/fold** - Tuber folded onto itself, ie severely bent. Usually associated with the longitudinal axis, rarely associated with radial growth.

1.2. Second growth - describes the switching of tuber growth from the longitudinal axis to one or several of the radial axes (ie the axis taken at right angles from the longitudinal axis through the buds or eyes).

(a) **Minor second growth** - A degree of second growth that would not overly interfere with the normal peeling process
(b) **Major second growth** - A degree of second growth that interferes with the normal peeling process.
(c) **Swollen nodes** - Swelling of the bud (eye) of the tuber, to the point where the bud is level or mounded above the normal surface of the tuber.
(d) **Knobs** - Formation of a distinct tuber or tubers at the bud.
(e) **Pointed Stolon end** - Elongation of the tuber at the stolon or stem end due to second growth causing stresses.
(f) **Pointed Rose end** - Elongation of the tuber at the rose or bud end due to second growth causing stresses.
(g) **Rippling** - Lumps in the tuber not associated with dents or the bud/bud axils. Internodal swellings that follow the phyllotaxy of the tuber eyes.

1.3. Cleavage type Growth cracks - Cleavage of the periderm and cortex by wide, healed or raw splits or rifts, due to sudden rapid or differential growth of the tuber.

2.0. Periderm appearance/colour descriptors

2.1. **Russeted Periderm** - Any russeting or fine netting of the outer peridermal layer due to tenaciously adhereing periderm layers.

2.2. **Netted growth cracks** - A shallow but extensive pattern of minor peridermal cracking that does not impinge on the cortex of the tuber.

2.3. **Smooth stain** - Discoloured sub-peridermal layer (usually a tan/light brown colour) with no associated netting or russetting of the outer peridermal layer.

2.4. **Suberized periderm** - Entire periderm is thick, corky and dark brown. Outer periderm layer usually heavily russeted.

2.5. **Pre-harvest Greening** - Chlorophyll formation due to exposure of the tuber to light in the field.

(a) **Minor pre-harvest greening** - Less than 10% (estimated) of the tuber surface area affected.
(b) **Major pre-harvest greening** - 10% or more (estimated) of the tuber surface area affected.

2.6. **Postharvest Greening** - Chlorophyll formation due to exposure of the tuber to light after harvest.

(a) **Minor postharvest greening** - Less than 10% (estimated) of the tuber surface area affected.
(b) **Major postharvest greening** - 10% or more (estimated) of the tuber surface area affected.

2.7. **Pre-harvest Soil Abrasion** - Rasp-like markings on the tuber surface, usually associated with upraised portions. The markings may appear corky due to wound periderm formation.

(a) **Minor abrasions** - less than 10% (estimated) of the tuber surface area affected.
(b) **Major abrasion** - 10% or more (estimated) of the surface area affected.

2.8. **Post harvest Abrasion** - Fresh rasp-like markings on the tuber surface, usually associated with upraised portions, and skinning. Caused by machinery and handling.

(a) **Minor abrasion** - less than 10% (estimated) of the tuber surface area affected.
(b) **Major abrasion** - 10% or more (estimated) of the surface area affected.

3.0. Literature cited

Radford, A.E., Dickison, W.C., Massey, J.R. and Bell, C.R. (1974). Vascular Plant Systematics chapter 6: *Phytology - morphological evidence.* Harper and Row, New York.

A.2. Extension Activities

A.2.1. Media Reports

- West Australian - 2 reports 1991
- Countryman - Horticulture Lift out 1991
- Countryman - Horticulture Lift out - in press 1993
- Horticulture 2000 magazine 1991
- Bulletin magazine 1991
- Potato Times, WA Potato Marketing Authority, 1991
- Radio Interview - ABC Bunbury (694 am 6BS) 1991
- Radio Interview - ABC Canberra 1991
- Research News, UWA 1993
- Horticulture Today magazine, 1993

A.2.2. Seminars

- Horticultural Science Programme: Research in progress seminar series - Murdoch University, July 1991

- Seminar for Potato Growers - Manjimup, August 1991. Attendance - 50+ including Growers, PMA staff , Ag dept staff from South Perth, Bunbury, and Manjimup.

- WA Potato Researchers Workshop - Bunbury, July 1991

- Presentation to Potato Marketing Authority Board Members - PMA Board room, 1992

- Seminar for Potato Growers: Interim Results of 1991/92 production sampling - Manjimup, September 1992. Attendance - Approx 30, including Growers, PMA representative, Ag Dept staff from Bunbury and Manjimup.

A.2.3. Reports/Publications

- Harvey, A.D., and Considine, J.A. (1991). Improving cosmetic quality of ware potatoes: Interim report. (Unpublished) Horticultural Science, Murdoch University. August 1991

- Harvey, A.D., and Considine, J.A. (1991). Improving cosmetic quality of ware potatoes: Interim report addendum. (Unpublished) Horticultural Science, Murdoch University. September 1991

• Harvey, A.D., and Considine, J.A. (1992). Improving cosmetic quality of ware potatoes: HRDC Progress Report. (Unpublished) Horticultural Science, School of Agriculture, University of Western Australia, February 1992

• Harvey, A.D., and Considine, J.A. (1992). Improving cosmetic quality of ware potatoes: Australian Rural Research in Progress Report (ARRIP) (Unpublished) Horticultural Science, School of Agriculture, University of Western Australia, July 1992

• Harvey, A.D., and Considine, J.A. (1992). Preliminary results of 1991/92 production sampling. (Unpublished) Report for growers in conjunction with Manjimup seminar, September 1992

• Harvey, A.D., and Considine, J.A. (1993). Improving cosmetic quality of ware potatoes: Final report. (Unpublished) Horticultural Science, School of Agriculture, University of Western Australia.

• Harvey, A.D., and Considine, J.A. (1993). Cosmetic quality of Western Australian ware potatoes: Incidence of disorders related to soil conditions, pests and diseases and physiological status. *Proceedings of the 7th National Potato Research Workshop,* Ulverstone, Tasmania 1993. In press.

A.2.4. Posterboard Presentations

• Horticultural Research and Development Corporation Board Members - University of Western Australia, November 1991.

• Australian Tree and Nut Crop Conference - University of Western Australia, 1992 (Display for current Horticultural research at UWA)

A.2.5. Miscellaneous

• Registered to present a paper at the 7th National Potato Workshop, Tasmania, 25-28 May 1993.

• Cosmetic quality problem identification poster - to complement the improved reported quality section of the consignment pack-out slip.

A.3. Miscellaneous formulas/analysis

A.3.1. Transformation and statistical analysis of proportional data

Spreadsheet functions.

Data was processed using Microsoft® Excel™ version 2.2. and 3.0. The following Excel™ functions were used to perform basic statistical analyses.

Mean: *=AVERAGE(cell REF#:cell REF#)*

where AVERAGE = Excel average function
cell REF#:cell REF# = Excel cell range for calculation

Standard Error: *=SQRT(VAR(cell REF#:cell REF#)/COUNT(cell REF#:cell REF#))*

where SQRT = Excel square root function
VAR = Excel variance function
COUNT = Excel cell range count function

Angular transformation: *=(ASIN(SQRT(cell REF#/100)))*180/PI()*

where ASIN = Excel arc sine function
PI() = π
cell REF# = cell reference of datum to be angularly transformed .

note: Microsoft® Excel calculates ASIN in radians, therefore it is necessary to add the conversion factor ***180/PI()** to the function in order to express the results in degrees (as in angles)(Microsoft® Excel™, 1987).

Where necessary, the results were retransformed via the following spreadsheet function:

Retransformation: *= ((SIN(cell REF#/(180/PI())))^2)*100*

where SIN = Excel sine function

Angular transformation is necessary for proportional data as it gives a heavier weighting to the small and the large percentages which have a small variance (Snedecor and Cochran 1962). That is, the arc sine transformation prevents the variance being a function of the mean. The transformation compresses the middle of a distribution of percentages or proportions, and stretches out both tails (Sokal and Rohlf 1969). In short, the transformation allows valid statistical analysis of percentage data. In the process the raw percentage data is changed to degrees (as in angles), where 100% = 90° and 0% = 0° (Sokal and Rohlf 1969, Gomez and Gomez 1984).

A.3.2. Literature cited

Gomez, K.A., and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research* 2nd edition. John Wiley and Sons, New York.

Mead, R., and Curnow, R.N. (1986). *Statistical Methods in Agriculture and Experimental Biology* Chapman and Hall, London.

Microsoft® Excel (1987) *Arrays, Functions, and Macros - Reference manual*

Snedecor, G.W., and Cochran, W.G. (1962) *Statistical Methods* 5th ed. The Iowa State University Press, Ames, Iowa.

Sokal, R.R., and Rohlf, F.J (1969) *Biometry* W.H. Freeman and Company, San Fransisco

A.4. Quality problem identification poster

A.4.1. Background information

The analysis of stored data (section 2.0) highlighted inefficiencies in the way Quality Inspectors were able to report the incidence of cosmetic quality problems in consignments passing through the system. The redesigned indicated quality section of the pack-out slip improves the feedback system to the grower, and also eases the way for future historical analysis of quality problems from various areas of the state. The categories used in the quality section were altered to allow finer definition of problems. Logically, to ensure unity of reporting of such quality problems, a standard description or reference chart must be made available. A colour reference poster containing common shape and superficial quality problems affecting white potatoes was designed to fill this need.

A.4.2. Materials and Methods

Tubers were selected with only one particular quality problem to avoid confusion and excess labelling on the poster. 2.75" photographic transparencies for scanning were produced by the University of Western Australia Media Services Photographic unit. Poster production was handled by The Sign Post, Beaufort St Inglewood. Scanning and graphic reproduction was handled by Print Power, 105 Railway Rd Subiaco. Design and mock-ups were produced by Horticultural Science Group, University of Western Australia.

A.4.3. Results

See sample poster in attached pocket. The sample poster has been reduced from A2 to A3 for inclusion inthis report.

A.4.4. Discussion

The poster does not contain any pests/disease related quality problems. The priority was to clearly define the differences between physiological and physical shape problems. Superficial quality problems described in this report (russeting, pre-harvest abrasion, netted growth cracking, greening) were also addressed in the poster to enable clear identification of the problems in the future. A further colour photographic production of a poster or a technical bulletin dealing with pests/disease quality problem identification is needed to aid the industry in improving the feedback cycle currently in place.

The poster will be a visual aid to Quality Inspectors and the merchant wash-packers and allow standardised identification of the cosmetic quality problems which have been until recently loosely defined. The combination of the revised quality problem reporting to growers and the poster is intended to improve the Industry feedback cycle in terms of cosmetic quality.