Know-how for Horticulture™

Optimising production and storage conditions for seed potato physiological quality

Dr Philip Brown
University of Tasmania

Project Number: PT02012

PT02012

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

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the processed potato industry and the fresh potato industry.

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ISBN 0 7341 1239 4

Published and distributed by:
Horticulture Australia Ltd
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50 Carrington Street
Sydney NSW 2000
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E-Mail: horticulture@horticulture.com.au

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Final Report

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Project number: PT02012 (November 2005)

Dr Philip Brown *et al*
Tasmanian Institute of Agricultural Research

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This report documents research investigating factors influencing performance of seed potato tubers undertaken over the 3 year period from 2002 to 2005. The quality of the seed tubers used in commercial potato crops is acknowledged as having a significant contribution to the potential yield and quality of tubers produced. The effects of seed production practices, seed storage treatments and ware crop management practices on both performance of the seed and the yield and quality of the ware crop are reported. The key finding from the project is that the quality of seed cannot be defined independently of the conditions under which it will be used.

Acknowledgements

The financial and in kind support from the Australian potato industry allowed this project to be undertaken. In particular the support of Simplot Aust and McCain Foods (Aust) Pty Ltd in Tasmania and Safries in South Australia allowed many aspects of this project to be completed successfully. Chris Russell, Mark Heap, Les Murdoch, Greg Bullock and Paul Frost facilited access to crop records and assisted with field trials, and their help is gratefully acknowledged

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Media Summary

The appearance of the seed tubers has little to do with quality, so selecting and purchasing seed that will perform well is a difficult process for potato growers. Seed quality is affected by numerous factors that are hard to measure, much less understand. Certification schemes provide assurance that levels of disease in the seed are low, but variations in physiological age or physiological condition of seed between certified seed lots can result in big differences in crop performance and yield. This objective of project was to identify the major contributors to seed physiological quality in seed crops. The relative contributions of seed crop growing environment, haulm kill treatments and harvest timing, storage environment and post storage treatments to crop performance and yield were examined.

The project identified production and storage treatments that affect seed tuber physiological quality. Significant correlations between seed performance attributes (speed of emergence, stems per plant, yield) and both seed and ware crop management factors were found. The performance characteristics that are expressed early in crop development (speed of emergence and stems per plant) were linked to several aspects of seed and ware crop management, but the seed performance attributes of crop yield and percentage of tubers of processing size were not influenced significantly by the management practices recorded. Time of emergence in the ware crop was linked to seed crop planting date, date of senescence and crop digging date (date of harvest from the field), days in cool store, seed cutting date, date of planting of the ware crop and soil structure. The number of stems per plant in the ware crop was influenced by seed crop digging date and duration of in ground storage between crop senescence and digging, length of storage of the seed in cold store and date of cutting of the seed, planting date and planting density of the ware crop, and soil structure, and moisture levels during ware crop establishment.

Crop management practices linked to the key factors influencing seed performance were examined in multi-season trials. Consistent results were not obtained, reinforcing the conclusion that seed lot performance cannot be predicted or controlled purely by seed crop and seed storage management. Understanding the interaction between seed physiological status and planting environment will be the key to developing recommendations for supplying seed matched to ware crop growing conditions.

Technical Report

Introduction

The project focused on the field performance of seed potatoes, and aimed to identify seed crop management strategies and storage procedures that contribute to seed physiological quality. Physiological quality refers to the internal composition and processes in a tuber that influence its growth (uniform sprouting, sprout vigour, sprout number, crop emergence, and other aspects of plant growth) but does not include the effect of diseases or pests on seed quality and performance. Differences in the quality of seed tubers, often referred to as differences in physiological age, can have a major impact on potato crop establishment and yield. Both conditions experienced by the seed crop during growth and conditions experienced by the tubers in storage affect the physiological quality of the tubers.

Potato crop performance has been stated to be directly related to seed tuber performance (Rex, 1990), indicating the importance many in the potato industry place on seed quality. As in all annual cropping systems, the first step towards obtaining a good yield is to achieve a high percentage of uniformly emerging, disease free plants. In other annual crop systems, a range of techniques for predicting and evaluating the field performance of seed have been developed. Researchers have also identified environmental characteristics that impact on field performance. In contrast, the quality of potato seed tubers is generally only measured in terms of disease status, tuber size (or size of cut seed). These measurements do not allow the reliable prediction of tuber performance (stem number per seed/seed piece, stem vigour, evenness of emergence) and the capacity to match tuber characteristics with predicted growth environment and desired crop growth patterns is therefore restricted. The accurate assessment of germination percentage and vigour in true seed of other vegetable crops, and knowledge of the interactions between seed characteristics and growth conditions, enables producers to specify seed quality attributes required for the anticipated growing conditions. Knowledge of seed quality attributes can be used by seed growers to produce high performing seed, and to handle and store the seed to maintain its ability to perform. This means vegetable crop establishment problems are reduced, growers know what they are getting, and seed growers can demand a premium for top quality seed.

Good quality seed tubers must be able to produce healthy, vigorous plants that produce a high yield of good quality within the time limits set by the growing season in which the seed is going to be used and given the socio-economic and agronomic environment in which the seed will be planted (Struik and Wiersema, 1999). Internationally, increased attention in seed potato research is being focussed on understanding seed quality and crop performance. At the most recent conference of the European Association for Potato Research 10 papers examining aspects of tuber quality and management of seed tubers to maximise yield were presented. To date, the emphasis has been on looking at how particular tuber characteristics influence seed performance. There has been little examination of which of these characteristics are most important, nor how seed potato performance can be measured. The short growing season experienced in many European and North American potato production regions creates a greater need for management of tuber sprouting patterns and vigour as rapid crop emergence and canopy closure are required to maximise interception of sunlight and therefore yield.

Seed failing to emerge is the most basic index of field performance. However, other indices are of equal importance. These include stem number per plant and the speed and evenness of emergence. Stem number per plant influences tuber number per plant and size distribution of tubers within a crop. Speed and evenness of emergence influence yield. Plants that emerge substantially later than most other plants are likely to make a relatively small contribution to the overall yield. Furthermore, a crop with plants of uneven age may be more difficult and more expensive to manage than an evenly emerged crop. Work has been done on the impact of uniformity of seed spacing (McPhee et al, 1996) and plant density (Rykbost and Maxwell, 1993; Love and Thompson-Johns, 1999), but no such reports have been written on uniformity of emergence time.

Tuber physiological age is generally regarded as the major factor influencing stem number per plant as well as speed and evenness of emergence. Aging of the potato begins from the moment the tuber begins to grow (Knowles and Botar, 1991). Perhaps the most important factor which influences physiological age is temperature, but other factors such as cutting, moisture, bruising and variety also have an impact. Physiological age can be estimated using an accumulated temperature sum (day degrees) during storage, but this measure is prone to error as conditions during production of seed tubers (temperature, irrigation, soil type, etc) influence the rate of aging in storage. At present, no accepted techniques are available for determining the physiological age of stored seed.

Sprout developmental stage at the time of planting can have a profound impact on the rate and uniformity of stem emergence and yield (McKeown, 1990ab; McKeown, 1994). Rate of sprout elongation is characterised by a lag phase followed by rapid linear growth. Lag phase in stem elongation varies with a range of seed characteristics such as sprout length, seed age, and warming after cool storage (Firman et al, 1992). If before being planted, sprouts are allowed to develop in light through most of the lag phase (to make them resistant to breakage) rapid emergence will occur. If sprouts begin to elongate (pip) in darkness, they become susceptible to breakage and the result may actually be a significant delay in emergence. Time to emergence is particularly important in potato production, since slowness increases the time that the stems are susceptible to a range of seed and soil born diseases.

While the physiological age and the status of the sprout at planting have received most research attention with respect to potato seed quality, there is evidence that the performance of a batch of seed may also be influenced by the environmental conditions it is exposed to after planting. The physiological and health characteristics of the seed cannot be viewed in isolation from the environment in which the seed is expected to perform. Knowing the conditions under which the seed is expected to be used can help inform decisions on how to prepare the seed for planting. Seed quality is therefore best viewed as a function of the biological characteristics of the seed and the environment for which it is intended.

The two major environmental factors impacting on seed performance are temperature and moisture. The base temperature, below which plant development does not visibly occur, is reported to be 0-2°C (Firman *et al.*, 1992), although for sprout elongation the base temperature is reported to be in the range 2-6°C (Sands, 1989). The optimum temperature for sprout growth was between 20-25°C (Sale, 1979). Warm soil temperatures can lead to increased incidence of seed breakdown (Marinus, 1993) Low soil moisture has been reported by various workers to increase time to emergence (Firman *et al.*, 1992). Shallow planting, which results in the seed being located drier soil, can decrease the rate of emergence (Firman *et al.*, 1992).

Certification schemes and standard germination tests for seed are both intended to provide the user with confidence that the seed is of a certain minimum standard. The standard germination test provides information on the viability, trueness to type, purity and freedom from disease. The test does not provide information on expected field performance. In potato seed certification, assessments are largely confined to evaluation of disease incidence in the parent crop and visual assessment of tuber diseases. Some certification schemes include diagnostic tests for various diseases (Dehaan, 1994) or grow out trials. Certification therefore focuses on identification of faults rather than providing information on potential seed performance. The potato industry in Australia, with the exception of a recent seed grow out program by Simplot in Tasmania, does not currently test seed for its potential field performance.

A survey of the literature found no evidence of work being conducted to unite the broad array of factors that contribute to the capacity of seed potatoes to perform. Where work has been conducted on a particular aspect of seed quality, treatments are generally not evaluated under stressful field conditions. Furthermore, experimental treatments rarely take into account other seed based factors which lie outside the discipline of the researcher. This lack of an interdisciplinary approach to seed evaluation is likely to result in conflicting recommendations.

The approach taken in this project was to analyse field performance of seed in commercial crops as well as under field trial conditions in order to identify the relative importance of seed production, seed storage and ware crop management on seed performance.

1. Indicators of Physiological age

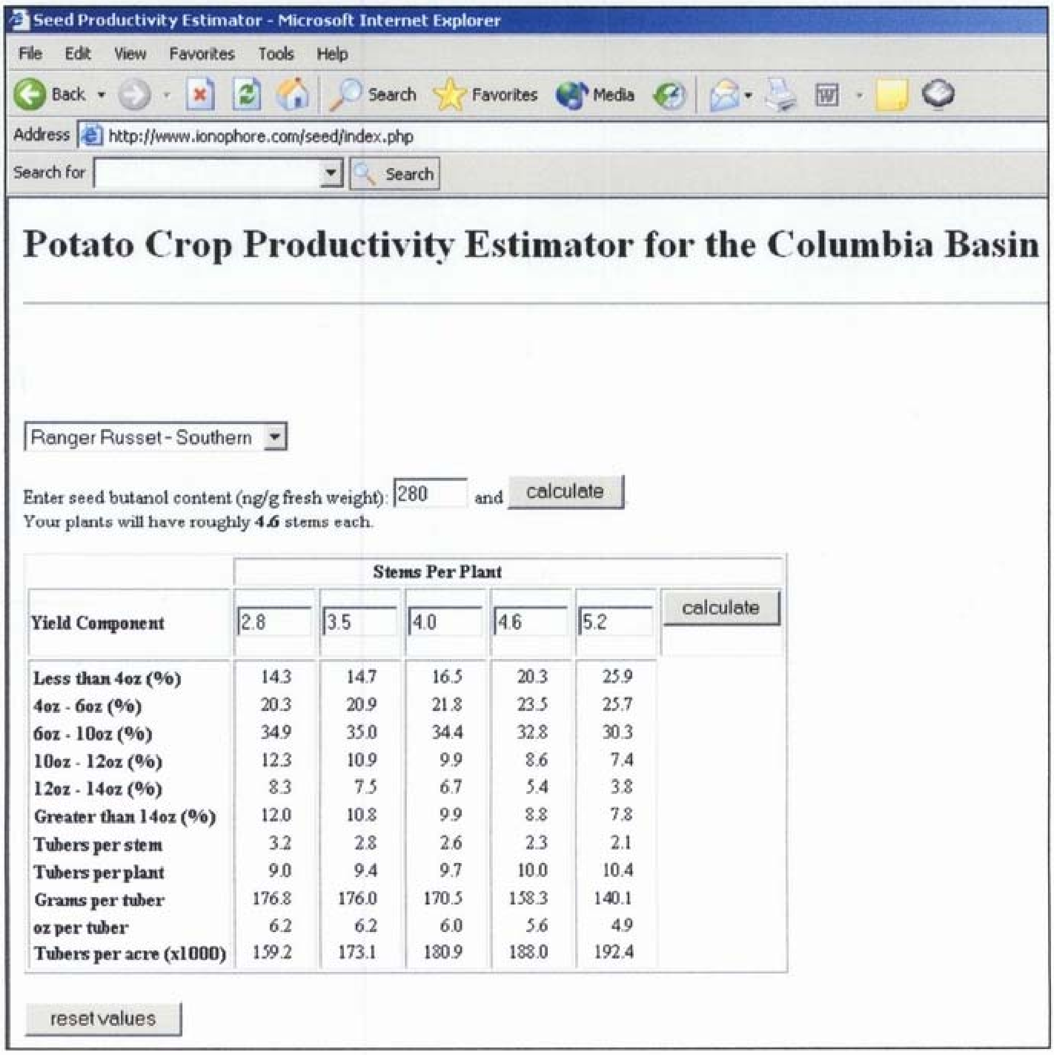
Introduction
A report from a US research group that the concentration of the chemical 2-methyl-1-butanol in seed tubers could be used to predict seed age was published shortly before this project commenced. The decision was taken to assess the indicator as, if accurate, it offered a method to determine seed physiological quality prior to planting. Rick Knowles from Washington State Uni reported that “2-methyl-1-butanol content of seed at planting correlated with the number of aboveground mainstems over 3 years of field trials, providing a consistent biochemical marker of seed age and relative productivity.” The work has been published in the attached Potato Progress article. The butanol test has now been developed into a “seed productivity estimator” which calculates tuber numbers and yields based on the butanol levels. The estimator can be accessed on the internet at http://www.ionophore.com/seed/.

The Concept of Physiological Age
The importance of seed tuber physiological age is a well known in the potato industry but there are lots of different views on how to manage physiological age in commercial production. The physiological age theory is that young seed gives rise to fewer stems and fewer tubers per plant but can support higher yields over a long growing season, while older seed results in more stems and more tubers but a shorter growing period and lower overall crop yield. Seed growers therefore prefer to use older seed while growers of processing potato crops aim to use young seed. The difficulty has always been getting seed tubers of the desired physiological age.

Seed tubers are living organisms and they age over time. The rate of ageing varies with production and storage conditions – the term physiological age (indicating status of tuber internal processes) is therefore used to separate the response from chronological age (time from tuber set or harvest to planting). Temperature is regarded as the most important factor influencing the rate of physiological ageing. Temperature management in storage, along with time in storage, is the major method of managing tuber physiological age. There are, however, a number of other factors known to influence physiological age and seed performance after planting. These include the seed growing environment (temperature, moisture, fertility, seed maturity at harvest, harvest conditions), storage environment (temperature, humidity, light, CO_2, O_2) and planting environment (temperature, moisture, soil conditions). The long term objective of the TIAR research is to understand the effects of these factors sufficiently to be able to manipulate seed production and storage to produce seed of the desired physiological age. As it is likely to take many years to achieve this, the short term goal is to develop ways of predicting the age of seed.

Measuring Physiological Age
The mechanisms underlying the process of physiological ageing are complex and poorly understood. While a number of internal changes during ageing are known, there is as yet no specific physiological marker that can be used to accurately determine the physiological age of a tuber. The butanol test release

by Prof Rick Knowles is the first indicator of physiological age based on assessment of a chemical change in the tubers during storage.


Seed Productivity Estimator - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://www.ionophore.com/seed/index.php

Potato Crop Productivity Estimator for the Columbia Basin

Ranger Russet - Southern

Enter seed butanol content (ng/g fresh weight): 280 and calculate

Your plants will have roughly **4.6** stems each.

	Stems Per Plant					
Yield Component	2.8	3.5	4.0	4.6	5.2	calculate
Less than 4oz (%)	14.3	14.7	16.5	20.3	25.9	
4oz - 6oz (%)	20.3	20.9	21.8	23.5	25.7	
6oz - 10oz (%)	34.9	35.0	34.4	32.8	30.3	
10oz - 12oz (%)	12.3	10.9	9.9	8.6	7.4	
12oz - 14oz (%)	8.3	7.5	6.7	5.4	3.8	
Greater than 14oz (%)	12.0	10.8	9.9	8.8	7.8	
Tubers per stem	3.2	2.8	2.6	2.3	2.1	
Tubers per plant	9.0	9.4	9.7	10.0	10.4	
Grams per tuber	176.8	176.0	170.5	158.3	140.1	
oz per tuber	6.2	6.2	6.0	5.6	4.9	
Tubers per acre (x1000)	159.2	173.1	180.9	188.0	192.4	

reset values

Trials were undertaken in the 2003/04 and 2004/05 seasons to assess the accuracy of the butanol test in predicting stem number.

In addition, trials were undertaken in both seasons to test the hypothesis that sugar concentrations in seed tubers at harvest (chemical maturity monitoring of tubers, commonly used to predict likelihood of cold induced sweetening in tubers stored for processing) could be used to predict the rate of physiological aging during storage.

During tuber growth, sucrose (the sugar transported from the leaves to the developing tubers) accumulates in the expanding tuber. Sucrose can be broken down into glucose and fructose molecules, and these may then be converted to starch. During late tuber development, the sucrose concentration in the tuber decreases, while glucose and fructose concentrations can increase if the plant is stressed. Tuber sucrose concentration is therefore a useful indicator of tuber maturity, while concentration ratios between sucrose and the reducing sugars fructose and glucose can indicate stress during late tuber development.

Assessment of tuber sucrose concentrations is used in some countries as an indicator of tuber maturity (chemical maturity monitoring) and is gives an indication of the likely speed at which tuber sugar concentrations will change during storage (cold temperature sweetening). Tubers harvested at an immature stage are more likely to accumulate undesirably high sugar concentrations during storage and be unacceptable for processing.

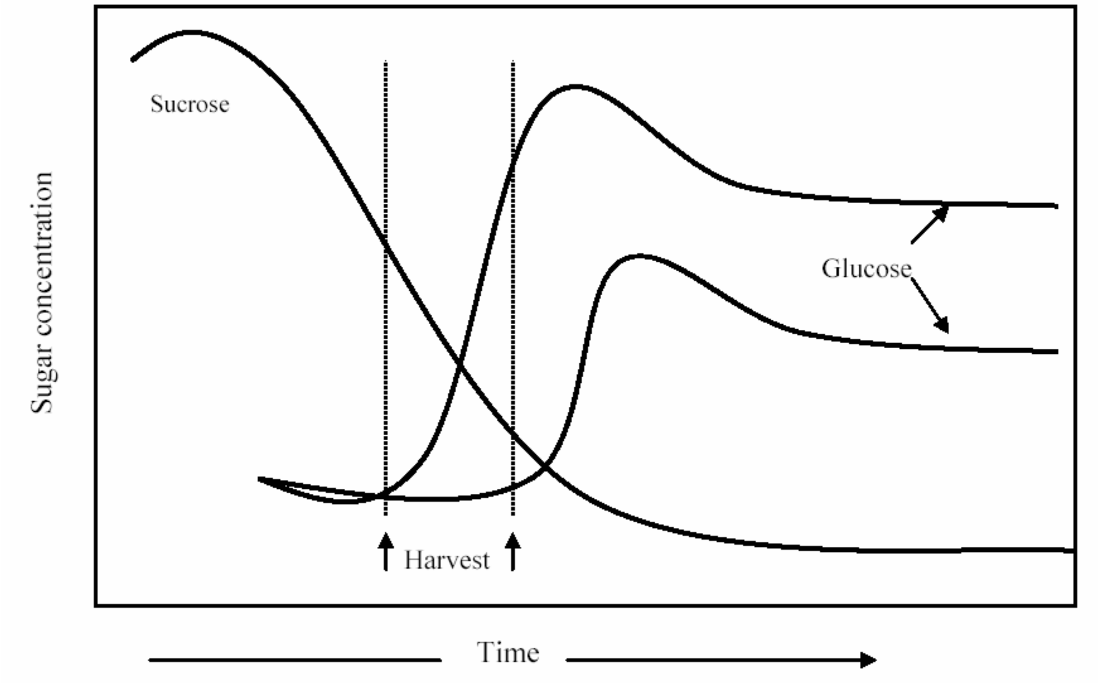


Figure 1. Changes in sugar concentrations in tubers during tuber growth and after harvest. Tubers at the first harvest point are immature (high sucrose levels) and will accumulate higher glucose levels during storage than tubers harvested at the later date when chemically mature. (Source: Pritchard, 2002)

Conditions such as water and heat stress to the crop during late tuber development promote increased tuber sucrose levels. These conditions are also thought to promote more rapid physiological aging of tubers and therefore may impact on seed performance. Chemical maturity monitoring (assessment of tuber sugar concentrations before harvest) may therefore provide an indication of potential performance of the seed tubers. No research has been published on chemical maturity monitoring as an predictor of rate of seed physiological aging, but the easy and timing of the test (prediction based on sampling at the point of seed harvest or entry into storage rather than during storage or prior to planting) made it an attractive option for testing in this project.

Materials and Methods

Trial 1: Butanol testing, 2003/04 (Safries)

The trial was conducted in South Australia and coordinated by Paul Frost of Safries. Seed tubers from 6 different sources (referred to as seedlots) were planted at 2 different locations in a replicated experimental design. Four of the seedlots were planted at both locations and each of the other two seedlots was planted at only one location. The different seedlots were chosen so that a range of physiological ages was assessed. Two sites were chosen in order to assess the relative effects of seed source and planting environment on crop performance.

Seed samples were collected prior to planting, frozen and sent to the laboratory in Tasmania for butanol testing. The concentration of 2-methyl-1-butanol in tubers was determined by HPLC-MS analysis following solvent extraction. Crop emergence, stem and plant counts per plot, and tuber numbers and yields in different size classes were recorded in the trial.

<u>Trial 2: Butanol testing, 2004/05 (Simplot)</u>

The trial was conducted in Tasmania in collaboration with Simplot Aust. Following last years trials, further work was undertaken to assess the use of Methyl Butanol as an indicator of physiological age in seed tubers. Tuber samples from 24 seed lots were collected just prior to planting. Methyl butanol concentration was determined from the tuber samples. Seed lots were grown out at a single location in a replicated plot design and stem number recorded.

<u>Trial 3: Chemical maturity monitoring as a P-age indicator</u>

Preliminary work on sugar maturity monitoring as a potential indicator of physiological age was conducted in the 2002/03 and 2003/04 seasons using tuber samples provide by Simplot Aust and McCain Foods (Aust) Pty Ltd. Sugar concentrations were recorded in the tubers and matched to seed performance in grow out trials the following season. While the studies were unreplicated, a trend towards increasing stem number with higher sucrose concentrations at harvest was noted. An intensive, replicated trial was therefore conducted in 2004/05 to test the chemical maturity monitoring method as an indicator of potential seed performance.

Tuber samples were collected from plants grown in a seed production trial in 2003/04. Treatments imposed when producing the seed were three planting dates (3 weeks apart) with three haulm kill dates. Planting dates were 20 Nov 03 (planting 1), 15 Dec 03 (planting 2) and 9 Jan 04. Haulms were killed by top pulling at approximately 100 days after planting (DAP), 112 DAP and 126 DAP in each of the planting date treatments. Soluble sugars were extracted using 80% ethanol from pooled tissue of 10 tuber samples for each treatment and sample date. Extracts were analysed for sugar concentration using an HPLC-MS analytical technique. Correlative analysis was used to compare sugar concentrations at harvest with performance of the seed in grow out trials the following season.

Results

Trial 1: Butanol testing, 2003/04 (Safries)

Trial results are summarised in the table below.

	Butanol	Stems/plant	Tubers/plant	Yield (t/ha)
(Site 1)				
Seedlot 1	655	5.3	10.6	81.4
Seedlot 2	510	4.8	9.8	80.4
Seedlot 3	390	3.6	8	82.4
Seedlot 4	530	5.0	8.7	79.2
Seedlot 5	530	6.6	10.2	81.3
(Site 2)				
Seedlot 1	665	3.6	9.1	78.3
Seedlot 2	490	3.1	10	70.5
Seedlot 3	390	3.7	10.3	54.5
Seedlot 4	530	3.8	8.6	75.2
Seedlot 6	430	3.6	10.8	74.4

Table 1. Concentrations of 2-methyl-1-butanol in tubers prior to planting, and corresponding performance of the tubers when grown out at two locations.

Butanol concentrations (measured in parts per million or ng/g) were very similar for seedlots planted at the two sites. For example, seedlot 2 sampled before planting at site 1 had a butanol concentration of 510ppm and when sampled before planting at site 2 had a butanol concentration of 490ppm. Butanol concentrations were found to be high (indicating physiologically old tubers) in comparison to the levels reported by Rick Knowles for Russet Burbank tubers in the US. Stem numbers varied significantly at site 1 (possibly due to rhizoctonia) but were lower and varied less between seedlots at site 2. Large differences between sites, but not seedlots within sites, in processing yield were found. Seedlot 3 performed poorly at site 2 but yield at site 1 was not significantly different from the other seedlots.

Relationship between butanol concentration and stem number per plant

The main objective of the trial was to assess the butanol test as a predictor of tuber physiological age. Stem number generally increased with butanol concentration at site 1 but at site 2 stem number was independent of butanol concentration. The results indicate that the butanol test is not a reliable predictor of stem number or tuber physiological age.

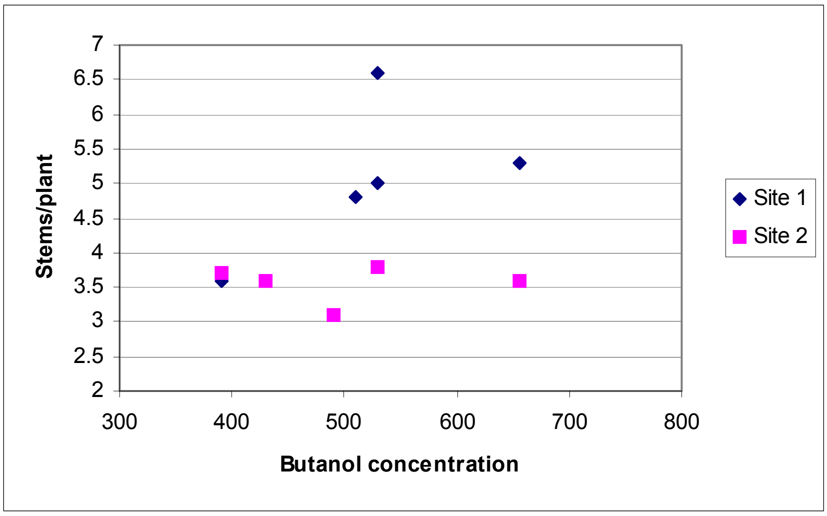


Figure 2. Relationship between butanol concentration and stem number per plant.

Relationships between stem number, tuber number and yield

Statistical analysis of the trial data revealed few significant differences. Relationships between stem number and tuber number per plant, and between stem number and processing yield were examined as the physiological age concept suggests aging increases stem number and tuber number, thus reducing the number (and yield) of processing sized tubers per plant. At each of the two sites three replicate plots of the five seedlots were harvested, resulting in 15 plots (data points) for each site. When stem number per plant is graphed against tuber number per plant it is clear that the number of tubers per plant is not strongly influenced by the number of stems per plant.

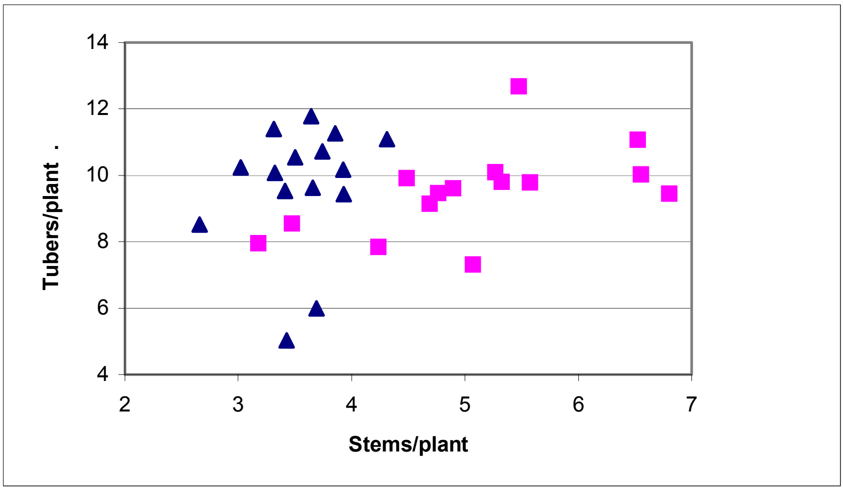


Figure 3. Relationship between stem number and tuber number per plant.

Processing yield was also not related to stem number per plant.

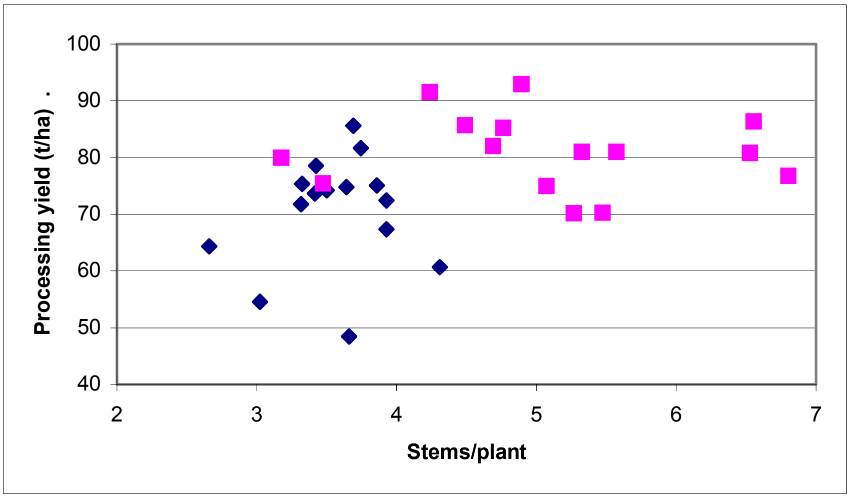


Figure 4. Relationship between stem number per plant and processing tuber yield.

It was concluded that, in this trial, site conditions after planting had a greater impact on stem number and yield than seedlot. This is an important finding given that the seedlots were chosen to represent a range of physiological ages.

Trial 2: Butanol testing, 2004/05 (Simplot)

Butanol concentrations in the seedlots tested varied from 167 ppm to 682 ppm, representing a range from physiologically young to old according to the butanol predictor developed by Rick Knowles. Stem number was plotted against butanol concentration. Each point on the graph below indicates the methyl butanol concentration from a seed line and the stem number for that seed line when grown in the trial.

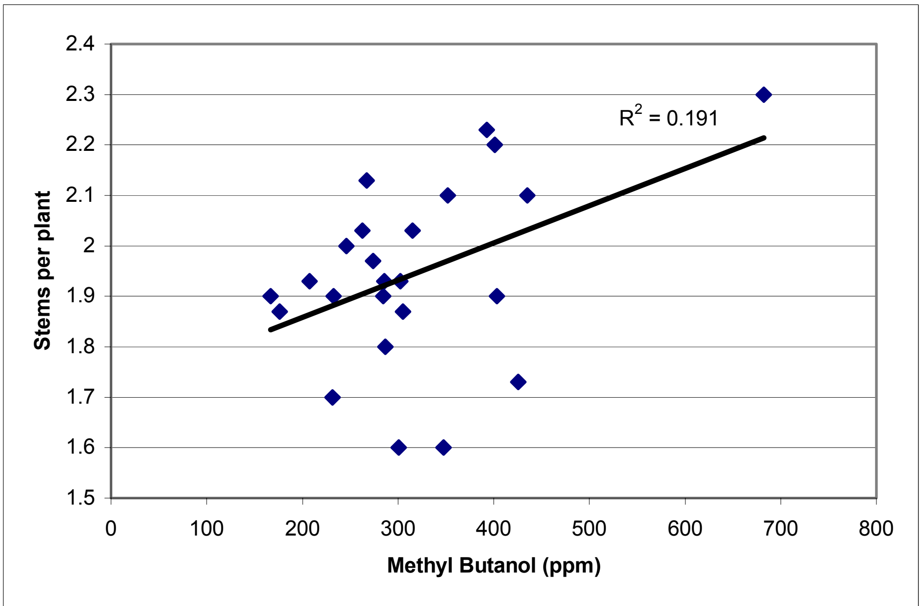


Figure 5. Relationship between butanol concentration and stem number per plant. Each point represents a single seed lot.

Based on these results plus the previous seasons Safries trial results, it was concluded that the methyl butanol test is not useful for predicting stem number (physiological age) in seed lots.

Trial 3: Chemical maturity monitoring as a P-age indicator

Tuber sugar concentrations displayed similar trends to those reported in US and Canadian studies, but the rate of decrease in concentration of sucrose in tubers during later stages of crop development was less than previously reported. There were small differences between planting dates, with later planted material displaying a more pronounced decline in sucrose concentration during late tuber development that crops planted in November and December.

Trends in sugar concentration during crop development are shown in figure 6 below.

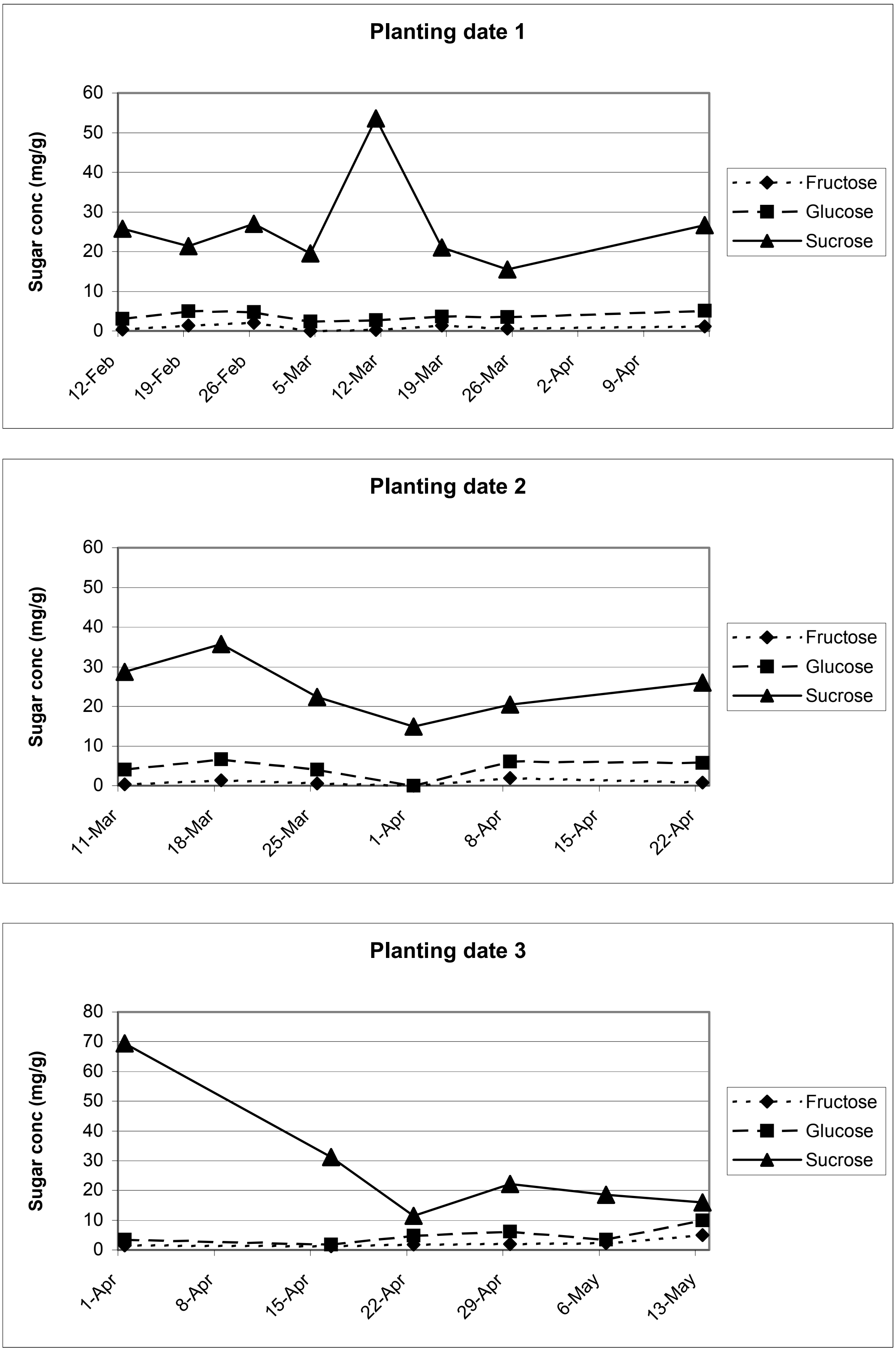


Figure 6. Changes in tuber sugar concentrations (mg sugar/g tuber dry weight) during crop development for planting dates 1 (20 Nov 03), 2 (15 Dec 03) and 3 (9 Jan 04).

The concentrations of sucrose, glucose and fructose in tubers varied between treatments at the point of harvest in the planting date by haulm kill date by harvest date trial. The planting dates used in the trial were 20 Nov 03 (planting 1), 15 Dec 03 (planting 2) and 9 Jan 04 (planting 3). In each planting date treatment, haulms were killed by top pulling at approximately 100 days after planting (DAP), 112 DAP and 126 DAP. Tubers were harvested from each treatment 10 days after haulm death (harvest 1) or at 150 days after planting (harvest 2).

Planting date	Haulm kill date	Harvest	Total yield (t/ha)	Stem number/plant	sucrose	fructose	glucose
1	1	1	75.63	3.43	53.6	0.2	2.7
1	1	2	76.67	3.20	12	11.3	20.7
1	2	1	72.99	3.68	15.5	0.6	3.5
1	2	2	74.63	3.32	4.7	6.9	11.5
1	3	1	74.55	3.27	26.7	1.1	5.1
1	3	2	72.06	3.10	13.9	7.5	14.7
2	1	1	73.88	2.95	17.2	2.6	5.6
2	1	2	73.95	2.74	12.5	6.8	13.9
2	2	1	72.96	2.81	10.7	0.8	3.3
2	2	2	71.32	2.75	13.5	6.2	11.7
2	3	1	73.20	2.91	14.1	0.6	2.4
2	3	2	70.42	2.73	14.8	0.8	3.7
3	1	1	69.86	2.83	54.2	0.8	6.4
3	1	2	68.14	2.53	6.1	7.6	16.1
3	2	1	69.11	2.70	28.5	2.4	8.4
3	2	2	71.79	2.81	4.6	7.9	15.2
3	3	1	68.80	2.78	23.4	3.8	9.2
3	3	2	71.97	2.71	12.1	9.3	16.7

Table 2. Tuber sugar concentrations at harvest and performance of seed the following season under different planting date, haulm kill date and harvest date treatments

Sucrose concentrations were higher in tubers harvested 10 days after haulm killing compared to tubers from the same haulm killing treatment stored for up to 50 days in the ground prior to harvest. The decrease in tuber sucrose concentration during in-ground storage was matched by an increase in tuber glucose and fructose concentration.

Correlative analysis revealed no relationships between sugar concentrations in the tubers at the point of harvest and performance of the seed the following season. The range of yield between treatments was low, but larger variation in stem number per plant between treatments was recorded. The was an overall trend of increased stem number per plant with early harvest compared to late harvest (in-ground storage), and for higher sucrose concentrations and lower glucose and fructose concentrations with early compared to late harvest, but the relationship was not statistically significant when analysed over all data. It was therefore concluded that, while the sugar profiles at harvest may influence the subsequent rate of aging during storage and potential for sprouting the following season, the relationship was not strong enough to make chemical maturity monitoring a reliable indicator of potential seed performance.

Conclusions

Development of a predictive tool for assessing the physiological quality of seed tubers has been an active area of potato research for decades, but to date no reliable indicators have been uncovered. The butanol test is the most recent indicator to be proposed, and while results from US studies on the method have been encouraging the analysis undertaken in this project has indicated that the butanol test is not a reliable indicator of potential stem number and crop yield under Australian conditions. Similarly, chemical maturity monitoring (sugar concentrations in tubers) was shown not to be an accurate predictor of stem number or yield. It was therefore concluded that prediction of stem number per plant is not possible at present using analytical tests, and that prediction based on previous experience (growers using seed from a single supplier over a number of seasons, and planting in similar conditions each year) remains the most accurate method of physiological age assessment.

Over the course of the project it became increasingly obvious that factors other than the inherent physiological quality or state of the tuber at the point of planting have a significant impact on stem number and subsequent growth and performance of the crop. It is therefore unlikely that any indicator of tuber physiological quality can be used to reliably predict performance unless the interaction between tuber physiological state and the planting environment is understood. The focus of the project was originally on seed production and storage conditions influencing seed physiological quality, but by the completion of the project the focus had shifted to the physiological quality by planting environment interaction. The remaining sections of the report document the progression from a seed quality focus to identification of other key factors affecting crop performance.

2. Multivariate Analysis

Introduction

Seed tuber physiological age or physiological quality is an important determinant of potato crop establishment and early performance. While the concept of physiological age is well established, the effects of many factors that affect age are not well understood. For example, crop management practices and growing climate of the previous generation(s) of seed potatoes can have a significant effect on physiological ageing, but the relative contribution of the full range of management practices and environmental conditions that the tubers may be exposed to is not known. The effects of temperature during seed storage and the duration of storage are well described, but other aspects of store management such as speed of tuber cooling when entering stores, oxygen and carbon dioxide concentrations in stores, and management of tuber warming and cutting after storage have not been studied in detail. In addition to these aspects of seed crop and store management influencing tuber physiological state, the performance of the seed, from a ware crop productivity perspective, is also affected by the many aspects of ware crop management during crop establishment and subsequent crop development through to harvest. Obviously there are many factors that will ultimately influence the yield potential of the ware crop, and separating the seed quality impacts from other factors is not straightforward. Any attempt to isolate individual factors (univariate analysis) to determine their effect on crop performance must be analysed carefully as interactions between the selected factor and the myriad of other factors is not taken into account. A multivariate approach using large data sets is commonly used in research fields such as ecological studies to identify the major factors or groups of factors influencing an end point characteristics (such as yield), to rank the contribution of various factors to the end point characteristic, and to model the interactions between the various factors.

The seed quality attributes of most interest to potato growers are vigour (the speed at which the sprout grows) and stem number per seed tuber or tuber piece. These characteristics of seed tubers are composite traits that may vary together in response to imposed cultural practices and environmental factors. Identifying a single component determining the complex trait may not be possible (and research on indicators of physiological age has to date been unsuccessful in this area), so to explain the trait research must be done on all the related components. Even then, interactions between components limits the interpretation of research findings on specific components. For example, many trials examining effects of single components such as tuber size on sprout number have been published but sprout number cannot be predicted based on tuber size as other factors such as tuber nutrient levels and specific gravity may interact with size to determine sprout growth. Multivariate analysis can be used to narrow the focus of univariate research approaches to those factors that have the greatest contribution to the end point characteristic being assessed, and can provide an indication of the areas of interaction between groups of factors.

The objective of this component of the project was to utilise data collected during commercial seed and processing crop production in a multivariate analysis to identify key areas of seed production, storage and ware crop establishment that impact on seed performance in the ware crop.

Materials and Methods

Commercial processing potato crop and seed potato crop data were kindly provided by Simplot Australia and McCain Foods (Aust) Pty Ltd over the three years of the project. Different levels of information were recorded for crops between seasons and between companies. All data, plus information generated in field trials conducted during the project, was entered into a database for multivariate analysis. The analysis was aimed at identifying seed crop management factors, storage practices and ware crop production factors that impact on the performance of seed tubers. The seed performance attributes chosen for the study were: time from planting to emergence, stems per plant, yield, and percentage of tubers in the processing size grade. The %size attribute was chosen as a measure of tuber size distribution – tuber number per plant would be a more desirable measure of seed performance but for obvious reasons is not measured commercially. In addition to these seed performance attributes, the quality of the ware crop was assessed for commercially important attributes: tuber specific gravity, percentage bruise free, and percentage rejected tubers.

For each commercial processing crop and trial plot, data were collected on the history of the seed used to plant the crop as well as management of the crop. The seed crop production data categories were: seed grower (ID numbers were used rather than names), district that the seed crop was grown, planting date, soil type, previous summer crop, previous winter crop, summer crop 2 seasons previous, winter crop 2 seasons previous, number of years since potatoes were grown in the paddock, soil temperature at planting, seed temperature at planting, spacing, irrigation type, irrigation frequency (days), irrigation amount (mm), haulm killing method, date of senescence, total crop growing days, date the crop was harvested, duration of in-ground storage, and seed crop yield (T/ha). The seed storage information categories were: coolstore operator, date out of coolstore, duration of storage, seed cutter, days warming prior to cutting, date cut, and days from cutting to planting. Ware crop information categories were: grower (ID number), district, crop area (Ha), planting date, soil type, row width, density, previous summer crop, summer crop 2 seasons previous, number of years since potatoes were grown in the paddock, number of years since pasture was grown in the paddock, soil structure (ranked on a scale of 1 to 10), soil moisture during establishment (ranking 1-3), and time of 50% senescence of the crop.

SAS (Statistical Analysis Software, version 8.2; SAS Institute, Cary, North Carolina, USA) statistical package (version 12.0) was used in all analyses. The following procedures were used; PROC CORR for correlative analyses, PROC REG for single and multiple regression models and PROC GLM to compare intercepts and slopes of dependant or discrete variables. The MAXR model was used in the multiple regressions.

Results

Analysis of the combined seed and ware crop data revealed significant correlations between seed performance attributes (speed of emergence, stems per plant, yield) and both seed and ware crop management factors. The performance characteristics that are expressed early in crop development (speed of emergence and stems per plant) were linked to several aspects of seed and ware crop management, but the seed performance attributes of crop yield and percentage of tubers of processing size were not influenced significantly by the management practices recorded. Yield and size distribution are complex characteristics influenced by nearly all crop management practices, so it was not surprising that a significant proportion of the variability in yield between crops could not be explained by any one management practice.

The full matrix of correlative relationships examined in the data set is presented in the appendix at the end of this report. A summary of the significant correlations identified in the matrix is shown below in Table 1.

Ware Crop Factors

	Planting date	Planting density	Years since pasture	Years Since Potato	Soil structure	Moisture	Date of 50% Senescence
Time to emergence	<.0001	0.0002	0.0024	0.4928	0.0005	0.234	0.0432
Stems per plant	<.0001	<.0001	0.0307	0.9852	0.0016	0.003	0.0003
Yield	0.6956	0.219	0.6322	0.6343	0.1917	0.1437	0.0483
%size	0.6722	0.296	0.3251	0.814	0.8798	0.894	0.7066

Seed Crop factors

	Planting date	Date of Senescence	Growing Days	Digging Date	In ground	Days in cool store	Date Cut
Time to emergence	0.0401	0.0216	0.1914	0.0257	0.8685	<.0001	<.0001
Stems per plant	0.1207	0.3738	0.8684	0.0032	0.0011	0.0274	<.0001
Yield	0.4154	0.7985	0.9256	0.6858	0.2882	0.2123	0.408
%size	0.4637	0.2402	0.1552	0.4621	0.5935	0.4989	0.5026

Table 3. Significant relationships between seed performance attributes and ware and seed crop factors. Figures are P values from the correlation matrix output of the multivariate analysis (figures less than 0.05 indicate significance at the 95% confidence interval).

Time of emergence in the ware crop was linked to 5 ware crop factors and 5 seed crop and seed storage factors. Seed crop planting date, date of senescence and crop digging date (date of harvest from the field) were positively correlated, with later planting dates, senescence dates and digging dates resulting in longer time to emergence when the seed was grown out in the following season. In contrast days in cool store and seed cutting date were negatively correlated, so shorter duration in store and cutting earlier in the season resulted in increased time to emergence. The date of planting of the ware crop was strongly correlated to emergence time with later planting date leading to earlier emergence. Later planting dates would most likely correspond to increasing soil temperature, so the planting date effect suggests soil temperature has a significant effect on seed vigour. Emergence time was also correlated to plant density, years since pasture, soil structure and date of 50% crop senescence. The link to plant density is difficult to explain but may reflect variation in planting density associated with planting date. Soil structure and years since pasture (probably related as paddocks recently out of pasture generally consist of well structured soils) are likely to have influenced growth rate of the sprouts following planting through soil structure effects on temperature and soil moisture levels. The relationship between emergence time and time to 50% senescence was more difficult to explain. Conventional physiological age theory suggests young seed will be slower to emerge and have fewer stems than old seed but will produce a longer growing season crop. In the Tasmanian commercial crop analysis, early emergence was linked to delayed senescence.

The number of stems per plant in the ware crop was influenced by seed crop digging date and duration of in ground storage between crop senescence and digging, length of storage of the seed in cold store and date of cutting of the seed, planting date and planting density of the ware crop, and soil structure (plus years since pasture) and moisture levels during ware crop establishment. Stem number per plant was positively correlated to date of senescence, meaning that crops with fewer stems senesced earlier than those with more stems. This may simply reflect the effect of ware crop planting date on stem number, with earlier planting dates linked to lower stem number per plant and also planting date would likely influence time of senescence of the crop (earlier planted crops would generally senesce earlier). The effects of seed crop digging date was consistent with physiological age theory as later digging date and therefore most likely shorter storage duration led to fewer stems as the seed would most likely be young. Duration of cool storage was also positively correlated to stem number. However, longer in ground storage before harvest, which would age seed, was linked to fewer stems per plant when the seed was grown out the following season. Clearly conventional physiological age theory cannot explain all factors influencing stem number. In addition, much of the variation in stem number per plant was explained by planting date and planting conditions (moisture, soil structure, planting date). These factors affect the expression of the physiological state (capacity of the sprouts to grow) rather than the actual state or age of the seed.

No significant correlations were found between seed or ware crop production factors and yield or percentage of tubers of processing size. The only exception was a significant positive correlation between time of 50% senescence in the ware crop and yield. Later senescence of ware crops was linked to higher yields.

While no significant relationships were established for the yield and percentage size characteristics using the individual factors recorded for each crop, the ware crop growers were demonstrated to have a significant influence on percentage size and also percentage rejected tubers. Using data for growers who produced 3 or more crops in the 2004 season, the relationships between the seed performance attributes (yield, %size, %bruise free, specific gravity, %rejection, time of emergence and stems per plant) and ware grower (using grower ID as a discrete variable rather than the set of factors used as continuous variables in the previous analysis) were examined. The differences in crop performance between growers is displayed in the following figures.

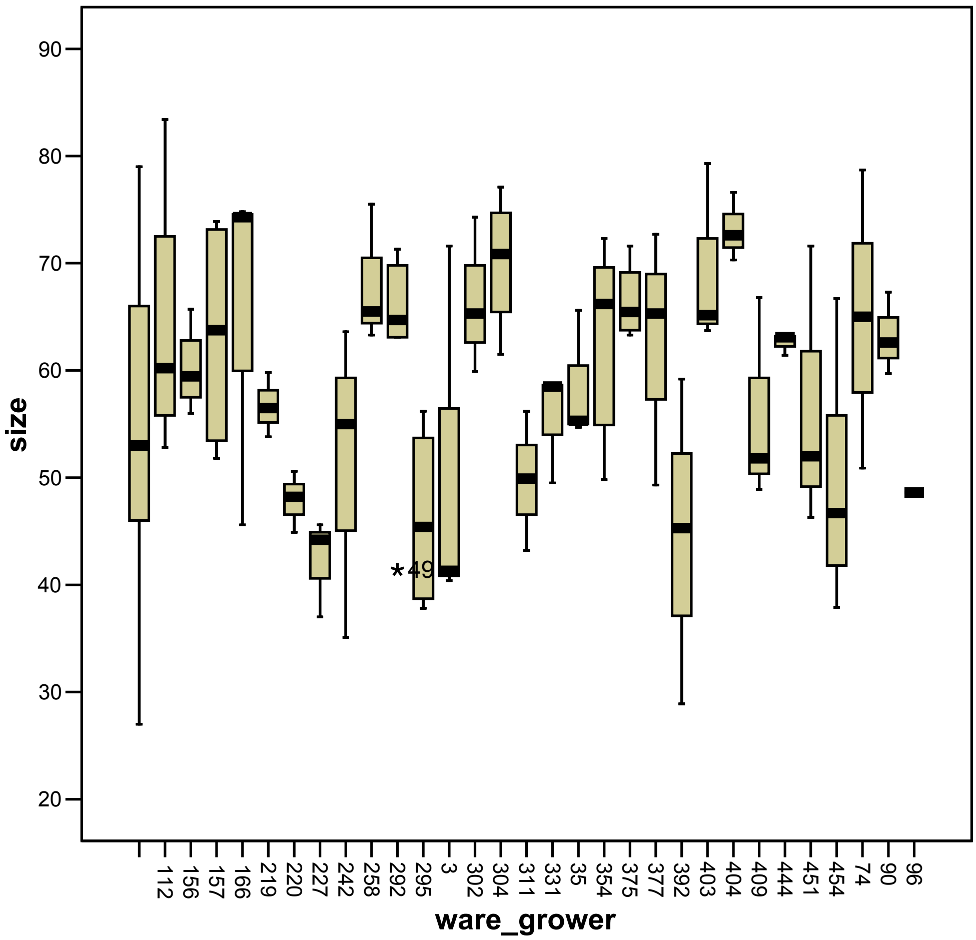


Figure 7. Performance (%processing sized tubers) of commercial crops for growers producing more the 3 crops in the 2004/05 season. Long bars indicate the full range of values recorded for each grower, the mid rectangular mid section indicates the range in which 50% of the growers crops fitted, and the black bar in the rectangular section indicates the mean value for the growers crops.

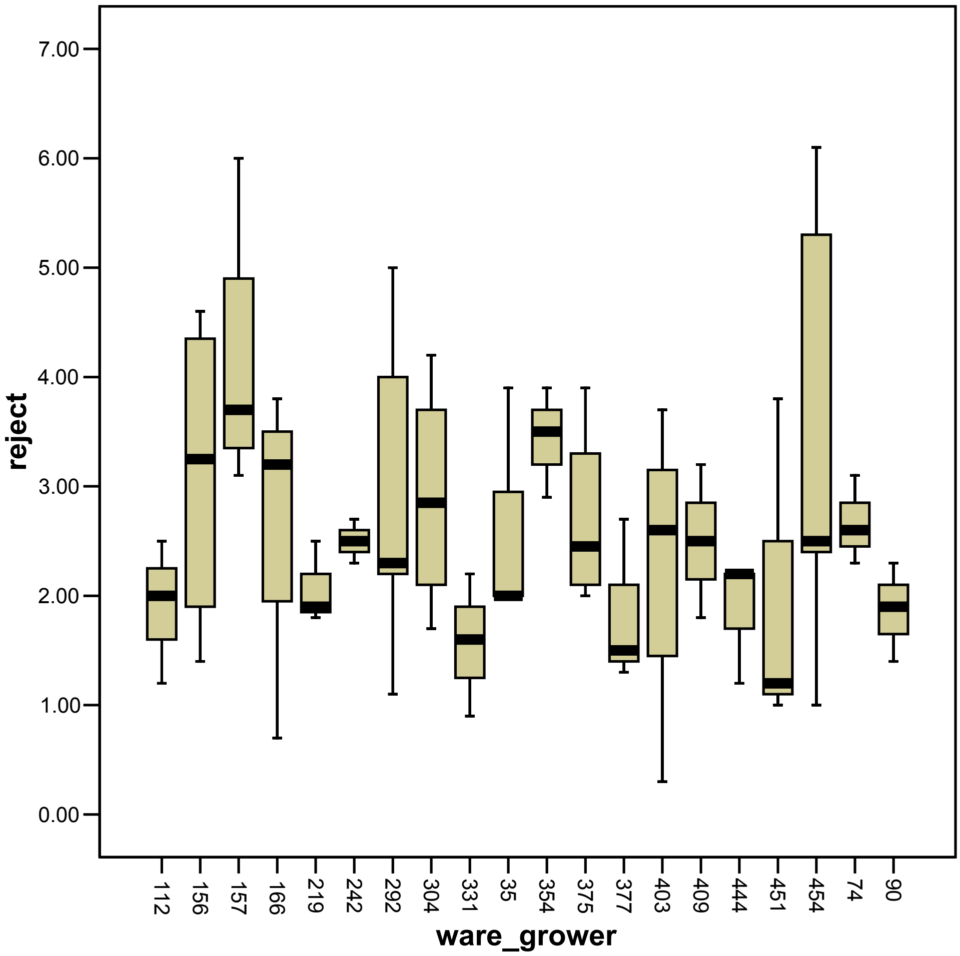


Figure 8. Performance (%rejected tubers) of commercial crops for growers producing more the 3 crops in the 2004/05 season. Long bars indicate the full range of values recorded for each grower, the mid rectangular mid section indicates the range in which 50% of the growers crops fitted, and the black bar in the rectangular section indicates the mean value for the growers crops.

The number of stems per plant in the ware crop was shown to be linked to the seed grower but not the ware grower. Given the relationship demonstrated in the previous analysis between stem number and time of seed crop digging, duration of in-ground storage, and duration of cold storage, it is not surprising that significant differences in this aspect of seed performance was linked to seed grower. The performance of seed from individual seed growers is shown in the following figure. Only seed growers who’s seed tubers were used in three or more commercial ware crops were used in the analysis.

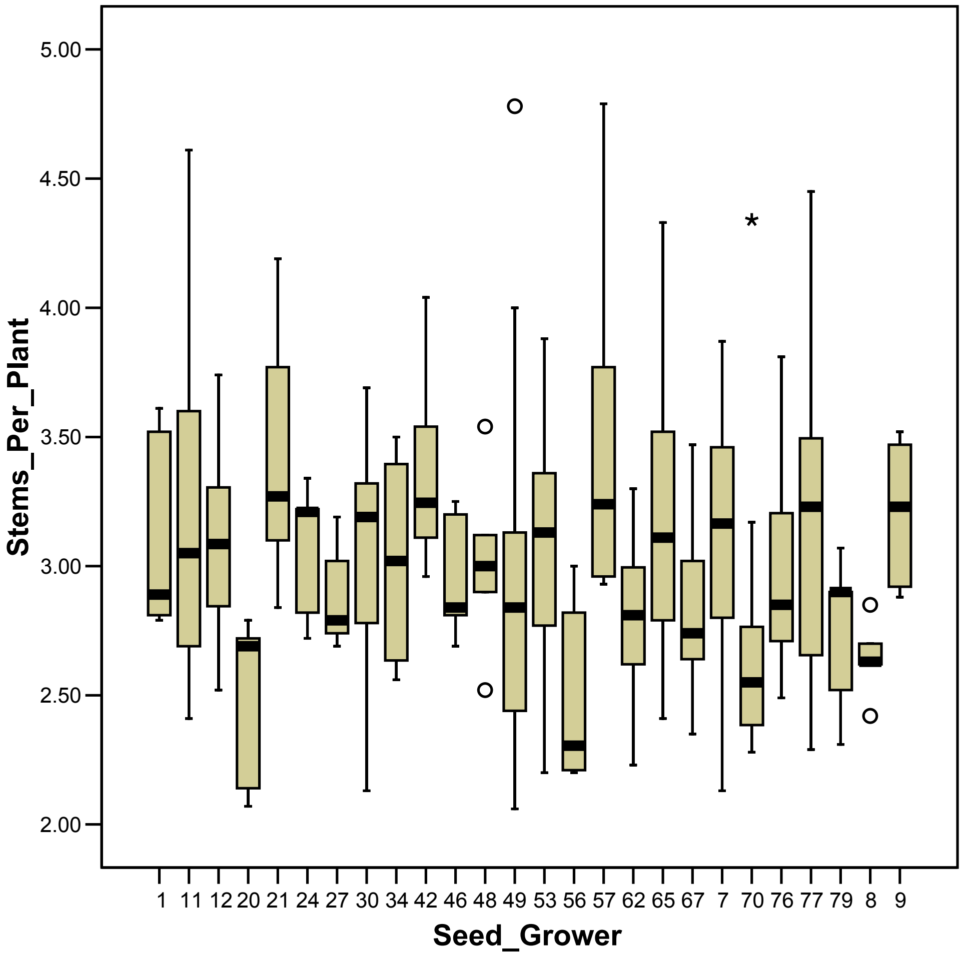


Figure 9. Performance (stems per plant) of ware crops using seed from seed growers supplying seed for 3 or more ware crops in the 2004/05 season. Long bars indicate the full range of values recorded for each grower, the mid rectangular mid section indicates the range in which 50% of the growers crops fitted, and the black bar in the rectangular section indicates the mean value for the growers crops.

Simplot Seed Trial

Analysis of data generated by Simplot Aust over the past 5 seasons in performance trials comparing seed lots at a single location in a replicated trial design revealed a significant effect of season on stems per plant and on yield. The seasonal effect on stems per plant was particularly dramatic, with no overlap in the range of stems per plant between some seasons for the 50 plus seed lots used. All seed lots in 2004 produced less that 2 stems per plant while in 2001, 2002 and 2003 all seed lots produced more than 2 stems per plant. The number of stems per plant recorded at the seed trials location did not correspond to the stem number recorded for the same seed lines when grown at different locations in ware crops in the same season. This results clearly demonstrates that stems per plant is determined by both the physiological state of the seed tuber before planting and the environment in which the seed tuber is planted.

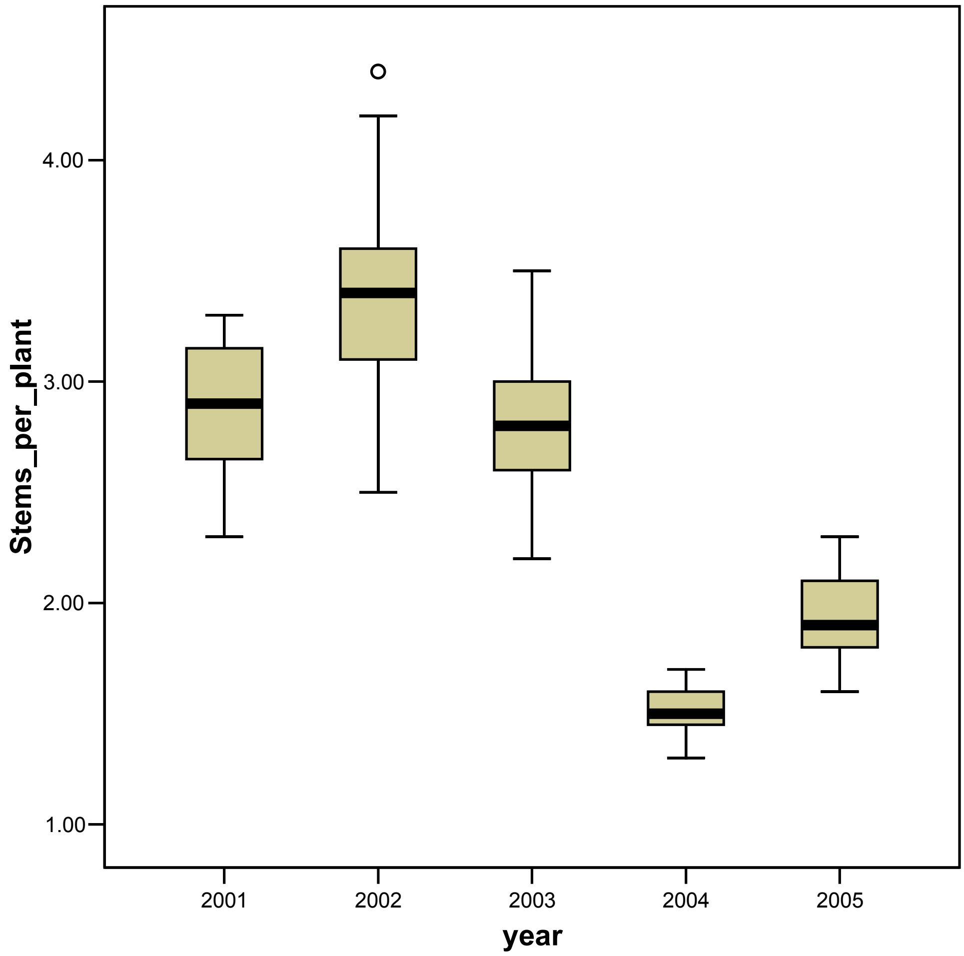


Figure 10. Stems per plant for all seed lots grown in the Simplot seedlot trials at a single location each season. Long bars indicate the full range of values recorded for each season, the mid rectangular mid section indicates the range in which 50% of the seed lots fitted, and the black bar in the rectangular section indicates the mean value for the growers crops. There were significant differences between seasons, with 2002>2001, and 2003>2005>2004.

Yield differences between years were not as large as the stems per plant variation, but significant difference were recorded. Differences in yield per season were as follows: 2001>2005>2002=2003=2004.

It is interesting to note that no significant relationship existed between stems per plant and yield either between seasons or within seasons. There was however a significant relationship between stems per plant and percent size, with an increasing percentage of tubers falling into the processing size category with reduced numbers of stems per plant.

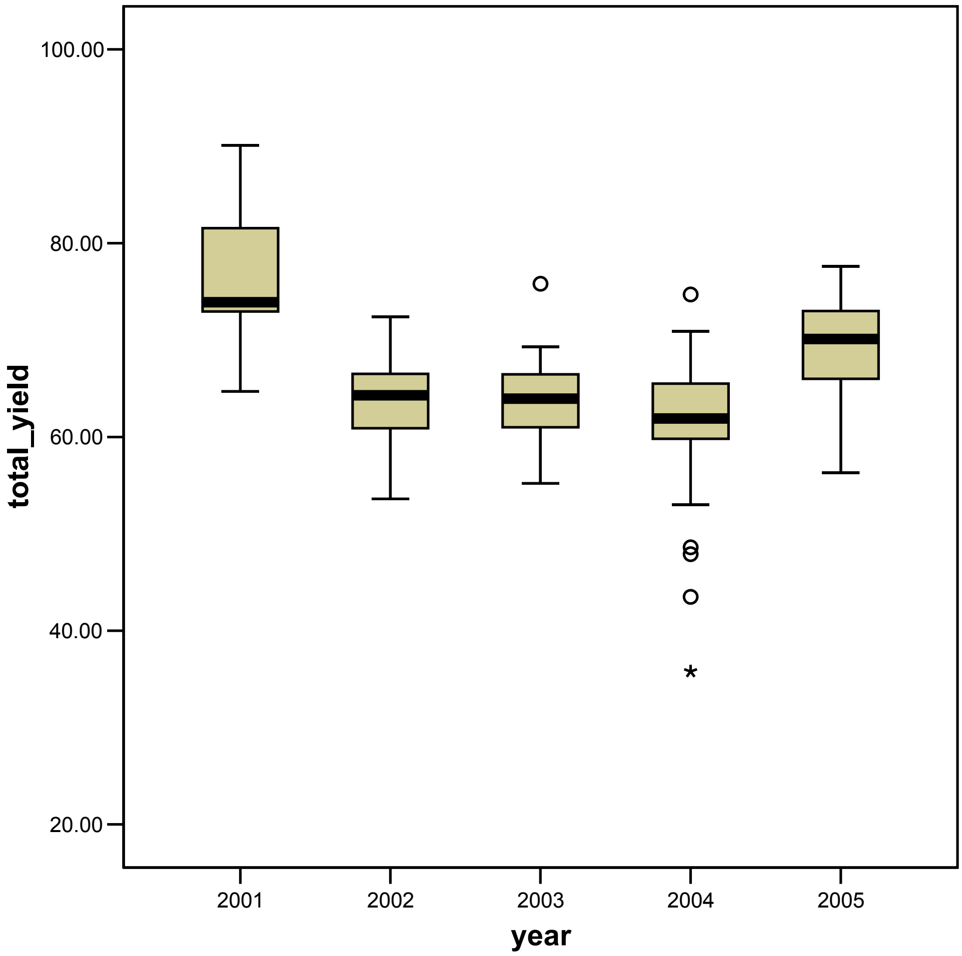


Figure 11. Yield for all seed lots grown in the Simplot seed lot trials at a single location each season. Long bars indicate the full range of values recorded for each season, the mid rectangular mid section indicates the range in which 50% of the seed lots fitted, and the black bar in the rectangular section indicates the mean value for the growers crops.

Conclusions

The multivariate analysis identified the major areas of seed crop management, seed storage and ware crop management impacting on key seed performance attributes. Ware crop yield and the proportion of harvested tubers in the processing size grade could not be linked to any of the seed crop, seed storage or early ware crop management practices. The factors driving both yield and percentage processing size are currently more closely linked to ware crop management than seed quality. Significant differences existed between ware crop growers in both the percentage of tubers of processing size and the percentage of tubers in the crop rejected due to faults such as hollow heart and bruising. Ware crop yield is a complex characteristics influenced by a large array of crop management practices and environmental variables, so it is not surprising that no single factors were identified as explaining a significant percentage of the variability in yield between the crops used in the analysis. A more comprehensive data set may allow significant correlations and interactions to be identified.

Factors that had a significant impact on the seed performance characteristics (stem number per plant and speed of emergence) were identified. In both cases, aspects of seed crop management, seed storage and ware crop management during the crop establishment phase were correlated to performance. The dates of seed crop planting, senescence and harvesting were positively correlated to time of emergence of the ware crop, while duration in store was negatively correlated. In simple terms, seed from crops that were planted earlier, senesced earlier and/or were harvested earlier tended to emerge faster following planting the next season, while seed that had spent longer in store (presumably reflecting earlier planting, senescence and harvesting, but also linked to ware crop planting date) emerged faster than seed that had been stored for a lesser duration. Stem number per plant was also correlated to seed crop harvest date and duration of storage. Ware crop establishment conditions were also significantly correlated to emergence time and stems per plant. Soil structure and soil moisture were linked to the seed quality attributes, confirming the view that prediction of seed performance prior to planting is not possible since planting environment will affect expression of the seed quality attributes.

The multivariate analysis narrow down the focus of seed crop management to the aspects involving timing of crop senescence and harvest and in-ground storage, with these areas then impacting on storage duration. While it is recognised that the effect of changes in seed quality resulting from different ways of managing seed crop senescence timing and harvesting on seed performance when planted in the ware crop cannot be predicted as planting environment also impacts on seed performance, more detailed examination of this area of seed crop management is warranted.

3. Effects of planting date, haulm kill date and harvest date

Introduction

The production of certified seed generally includes several cycles of field multiplication, and during this time the crop must be managed to limit the risk of disease contamination as well as to maintain the yield and quality of the seed tubers. Seed tuber yield and physiological quality characteristics include the tuber size, duration of tuber dormancy, and stem number plus vigour of the seed tubers when planted. Multivariate analysis of commercial crop data from Tasmania indicated that seed crop management practices such as planting date, duration of crop growth and harvest date may influence seed physiological quality. These factors have received very little research attention in comparison to storage factors influencing seed physiological age.

The effects of duration and temperature of storage on tuber physiological age have been reported in the literature (see review by Struik and Wiersema, 1999) and are used in the prediction of physiological age based on thermal time or accumulated day degrees (O'Brien *et al*, 1983). Temperature and time in storage are, however, not the only factors that influence tuber physiological aging and accumulated day degrees may not always adequately assess tuber physiological condition (Jenkins et al, 1993). Since reliable physiological markers of tuber physiological age have not yet been identified, knowledge of the impact of other factors on rate of tuber aging is critical in improving prediction of physiological age based on thermal time.

Growing environment and industry structure in Tasmania, Australia, dictates that seed potato crops are produced under a wide range of field conditions and crop management practices. For example, soil types range from sandy to heavy clay, mean maximum temperatures vary by over 5 degrees between different production locations, and crops may be killed off prior to lifting or left to senesce naturally. The rate of physiological ageing of seed potatoes produced under these conditions has been reported by industry to vary significantly when cold stored for similar durations, suggesting that conditions during the production of the seed tubers have a major impact on physiological seed quality. The multivariate analysis reported in chapter 2 supported this view. The experiments described in this chapter were undertaken to examine the impact of plant spacing, planting date and timing of haulm death on seed performance. The timing of haulm death, either through natural senescence or following treatments to kill the haulms, is an aspect of seed crop management that may influence seed physiological quality and can be manipulated commercially under the production conditions in Tasmania, Australia. Trials were conducted over 3 seasons investigating the effects of timing of haulm kill, in combination with different planting date and harvest date treatments, on seed quality.

Materials and Methods

Trial 1 (2002/03, FVRS)
An experiment was conducted at Forthside Vegetable Research Station (FVRS), North West Tasmania to examine effects of (a) haulm kill date, and (b) planting date and density in seed crops on performance of the seed in the following season. Russet Burbank seed tubers for the experiments were produced in the 2001/2002 season at FVRS. Planting date for the trial was 23rd October. Haulm kill treatments were 92, 111, 125 and 141 DAP. Haulms were killed by physical removal and the final kill date, 141 DAP, corresponded to natural haulm death. Tubers from each treatment were harvested either 10 days following haulm death (early harvest) or at 151 DAP (late harvest). Seed lots were therefore produced with the following combinations of days to haulm death and days between haulm death and harvest: 92/10, 92/59, 111/10, 111/40, 125/10, 125/26 and 141/10. Seed tubers were harvested and cold stored following standard commercial practice.

The experiment assessing the effects of the seed crop management practices on seed performance was planted on 26th October 2002 at Forthside Vegetable Research Station. The experiment was laid out in a replicated complete block design incorporating 3 replicates per treatment. Each plot consisted of 2 five metre double rows, with buffer rows on each side of the plots. Four metre lengths in the centre of each double row, containing a total of 32 plants, were harvested in each plot. Harvest occurred approximately 1 week following natural haulm death. Tuber number and tuber yield per plot were recorded. Data was examined using analysis of variance and least significant difference (LSD) determined where significance was indicated at the 5% level.

Trial 2 (2002/03, FVRS)
In a second trial, seed sourced from 2 different locations was planted on 23rd October and 15th November. Seed from one location was planted at densities of 6.5 plants per m2 (standard density) and 12 plants per m2 (high density), while seed from the second source was planted at standard density. Replicated plots of the two density treatments were located at three positions within the trial design. Natural haulm death occurred 141 DAP and 134 DAP respectively for the two planting dates. Seed was harvested 10 days after haulm death. Seed tubers were harvested and cold stored following standard commercial practice.

The experiment assessing the effects of the seed crop management practices on seed performance was planted on 14 November 2003 at Forthside Vegetable Research Station. The experiment was laid out in a replicated complete block design incorporating 3 replicates per treatment. Each plot consisted of 2 five metre double rows, with buffer rows on each side of the plots. Four metre lengths in the centre of each double row, containing a total of 32 plants, were harvested in each plot. Harvest occurred approximately 1 week following natural haulm death. Tuber number and tuber yield per plot were recorded. Data was examined using analysis of variance and least significant difference (LSD) determined where significance was indicated at the 5% level.

Trial 3 (2003/04, FVRS)

A second field trial examining the effects of timing of haulm kill on seed performance was completed in 2003/04. Seed harvested from two commercial seed crops given haulm removal treatments at five dates over a seven week period in the 2002/03 season were planted in the trial. Seed was hand harvested and stored according to standard commercial practice.

The experiment was laid out in a replicated complete block design incorporating 5 replicates per treatment. Each plot consisted of 2 five metre double rows, with buffer rows on each side of the plots. Four metre lengths in the centre of each double row, containing a total of 32 plants, were harvested in each plot. Harvest occurred approximately 1 week following natural haulm death. Tuber number and tuber yield per plot were recorded. Data was examined using analysis of variance and least significant difference (LSD) determined where significance was indicated at the 5% level.

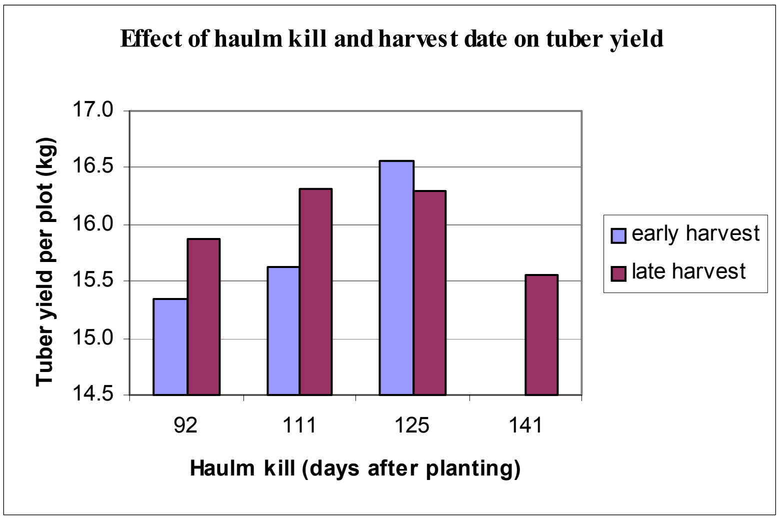
Trial 4 (2004/05, FVRS)

A third haulm kill trial was established in the 2004/05 season using seed grown the previous season. The treatments imposed when producing the seed were three planting dates (3 weeks apart) with three haulm kill dates. Planting dates were 20 Nov 03 (planting 1), 15 Dec 03 (planting 2) and 9 Jan 04. Haulms were killed by top pulling at approximately 100 days after planting (DAP), 112 DAP and 126 DAP in each of the planting date treatments. Tubers were harvested from each treatment 10 days after haulm death (harvest 1) or at 150 days after planting (harvest 2) to allow comparison between early harvest and in ground storage of tubers on seed performance. Sprouting of standard sized seed tubers under standard temperature and moisture conditions (4 weeks at 15 C in moist sand) was undertaken monthly during storage and has revealed differences in the number of sprouts per tuber and the timing and vigour of sprout growth in tubers from different planting date and haulm kill date treatments.

The experiment was laid out in a replicated complete block design incorporating 5 replicates per treatment. Each plot consisted of 2 five metre double rows, with buffer rows on each side of the plots. Four metre lengths in the centre of each double row, containing a total of 32 plants, were harvested in each plot. Harvest occurred approximately 1 week following natural haulm death. Tuber number and tuber yield per plot were recorded. Data was examined using analysis of variance and least significant difference (LSD) determined where significance was indicated at the 5% level.

Results

Trial 1 (2002/03, FVRS)
Seed tubers produced from plants where a haulm death treatment was imposed 2 weeks prior to natural haulm death (128 DAP) had the best performance, producing the highest number and weight of tubers. Both tuber number and weight were significantly higher than the natural haulm death (141 DAP) and earliest haulm death (92 DAP) treatments for the late harvested seed. In ground storage of tubers for 59 days (92 DAP haulm kill) or 40 days (111 DAP haulm kill) after haulm kill resulted in superior seed performance compared to harvest 10 days following haulm kill.



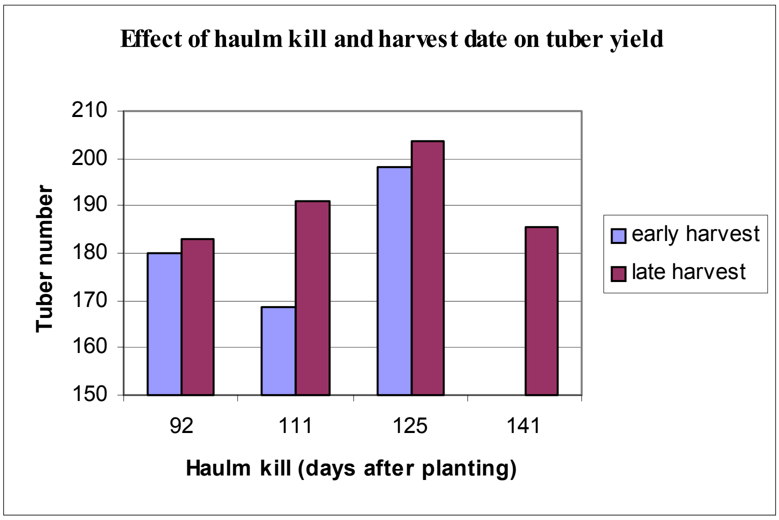


Figure 12 Effect of haulm kill date of seed crop on tuber yield (top) and tuber number (bottom) per plot. Seed tubers were harvested 10 days after haulm kill (early harvest) or at the end of the season (late harvest).

Trial 2 (2002/03, FVRS)
Different trends in effect of planting date on seed performance were noted for the two seed lots used in the study (Figure 4). While the only significant differences recorded were higher plot yield for November planted seed crop for seed lot 1 and higher tuber number in October planted seed crop for seed lot 2, the trend was for seed sourced from the November planting to perform better that seed from the October planting for seed lot 1 and the reverse for seed lot 2.

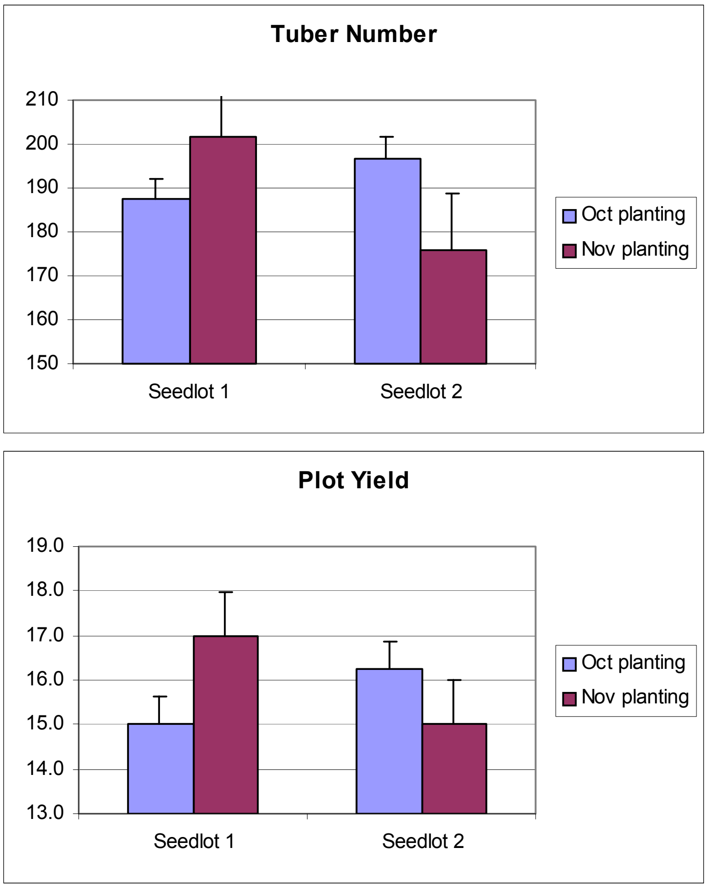
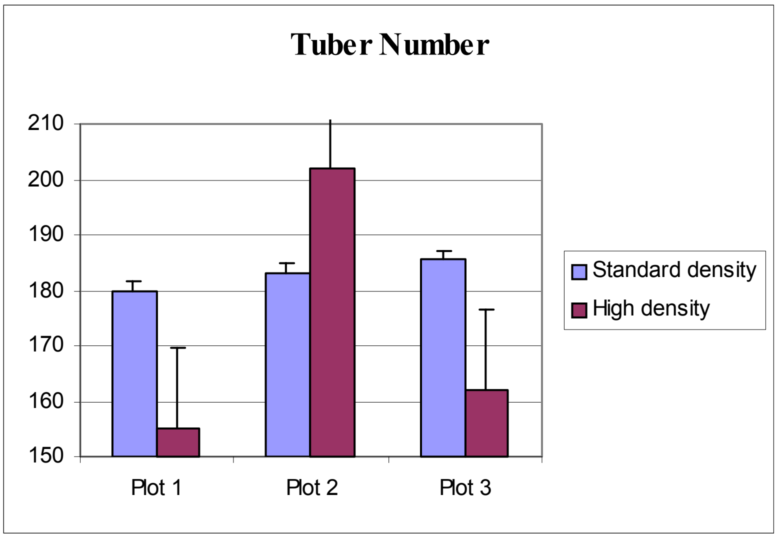


Figure 13. Effect of seed crop planting date on tuber number (top) and tuber yield (bottom) per plot. Bars are means of 3 replicates ± standard error.

Seed crop planting density had no effect on seed performance the following season. The only significantly different means were the plot 1 and plot 2 high density seed. Plot 1 was located at the edge of an irrigator run, and it is probable that water stress during seed tuber development influenced the performance of the seed produced.



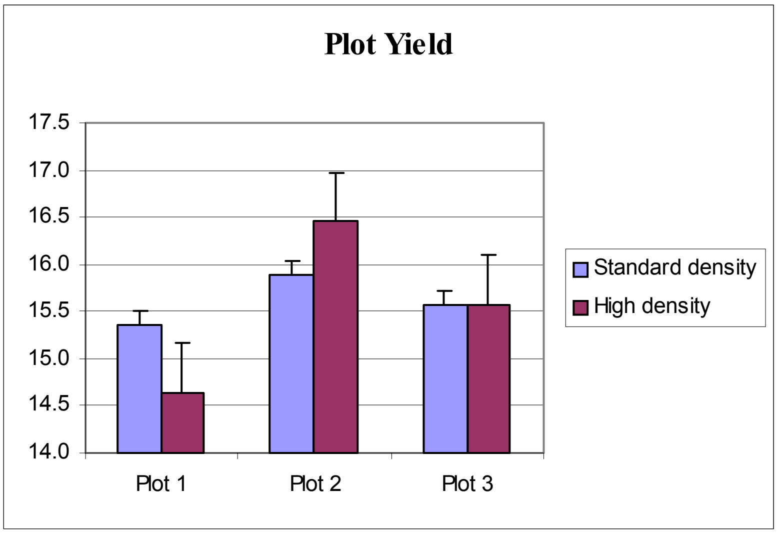


Figure 14. Effect of seed crop planting density on tuber number (top) and tuber yield (bottom) for seed lots produced at three locations (plots) at one site. Bars are means of 3 replicates ± standard error.

Trial 3 (2003/04, FVRS)

Timing of haulm kill in the seed crop influenced both stem number and yield in the following season. There was a significant difference in stem number per plant between treatments, with highest stem numbers recorded from seed generated from the earliest haulm kill treatments and harvested 2 weeks after haulm kill. When haulms were killed early, but tubers not harvested until 10 weeks later, the number of stems produced by the seed was not different to the number produced by seed from plants left to senesce naturally. No significant differences in yield were found between the treatments, although there was a trend towards higher yields from the seed producing the most stems (early haulm kill, harvested within 2 weeks). The haulm kill treatments therefore affected seed physiological age (stem number) but had little effect on crop yield.

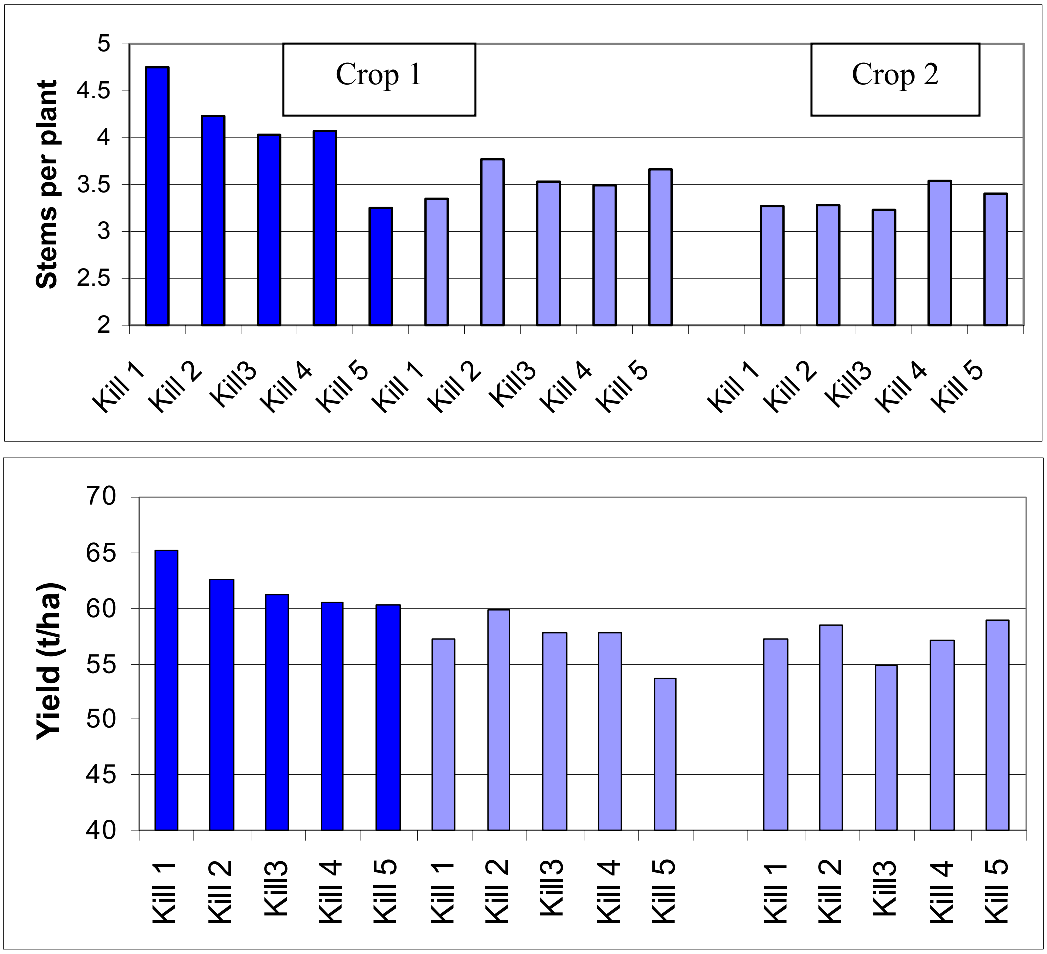


Figure 15. Effect of haulm kill treatments on seed performance in the following season. Kill 1 to 5 correspond to haulm kill date commencing 100 days after planting (Kill1) and ending with natural haulm death (Kill 5). Dark bars are for seed harvested 2 weeks after haulm kill, light bars are for seed harvested 4 weeks after natural haulm death.

<u>Trial 4 (2004/05, FVRS)</u>

The effect of the seed crop treatments on seed performance were assessed both during storage and in the field in the following season. The storage assessment consisted of measurement of sprout weight and sprout number produced by tubers under standard conditions (4 weeks at 15 C in moist sand). Seed crop planting date had a larger effect on total sprout weight per tuber than timing of haulm death, reflecting the greater age of tubers from the earlier planting date at harvest. Planting date treatments did not, however, have a significant effect on sprout number. Sprouting patterns for seed tubers harvested 10 days after haulm kill were similar to those shown above for seed tubers harvested at the end of the season (145 DAP) (data not shown).

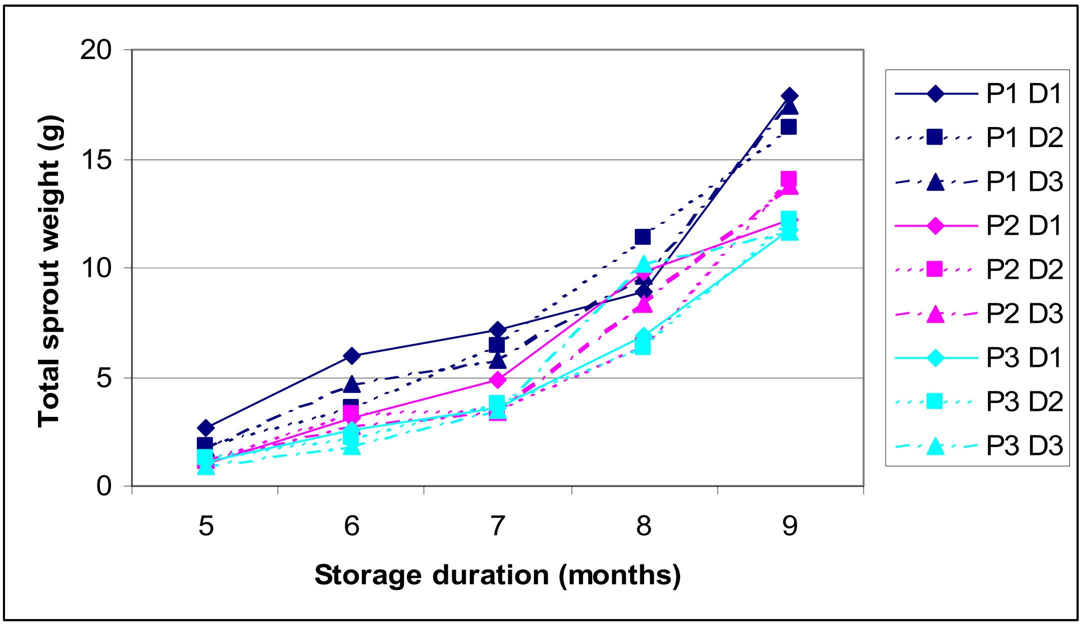


Figure 16. Changes in total sprout weight per tuber with increasing duration in storage. Treatments refer to planting date of the crop from which the seed was generated (P1 = 20 November, P2 = 15 December, P3 = 9 January) and date of haulm removal (D1 = 90 DAP, D2 = 110 DAP, D3 = 130 DAP).

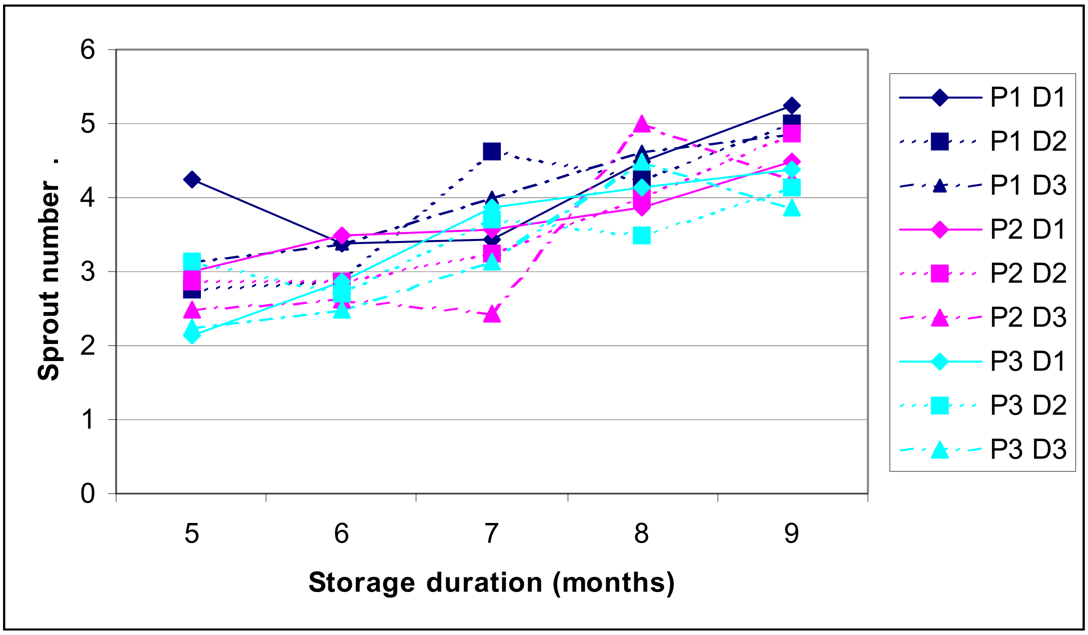


Figure 17. Changes in sprout number per tuber with storage duration.

Performance of the seed when planted in the field was consistent with the sprouting performance noted during storage. Seed crop planting dates were 20 Nov 03 (planting 1), 15 Dec 03 (planting 2) and 9 Jan 04. Haulms were killed by top pulling at approximately 100 days after planting (DAP), 112 DAP and 126 DAP in each of the planting date treatments. These treatments are referred to as time of death (TOD) 1, 2 and 3 respectively in the table below. Tubers were then harvested either 2 weeks after haulm death (harvest 1) or field stored until approximately 170 DAP.

Planting	TOD	Harvest	Total Yld (t/ha)	Tuber number /plant	Stem number /plant
1	1	1	75.63	11.29	3.43
1	1	2	76.67	10.98	3.20
1	2	1	72.99	11.11	3.68
1	2	2	74.63	10.73	3.32
1	3	1	74.55	10.21	3.27
1	3	2	72.06	10.26	3.10
2	1	1	73.88	10.94	2.95
2	1	2	73.95	9.79	2.74
2	2	1	72.96	9.88	2.81
2	2	2	71.32	10.23	2.75
2	3	1	73.20	10.64	2.91
2	3	2	70.42	9.78	2.73
3	1	1	69.86	9.85	2.83
3	1	2	68.14	9.86	2.53
3	2	1	69.11	10.02	2.70
3	2	2	71.79	10.58	2.81
3	3	1	68.80	10.26	2.78
3	3	2	71.97	10.46	2.71

Table 4. Performance of seed produced under different planting date, haulm kill date and harvest date treatments. Treatments refer to planting date of the crop from which the seed was generated (P1 = 20 November, P2 = 15 December, P3 = 9 January) and date of haulm removal (TOD1 = 90 DAP, TOD2 = 110 DAP, TOD3 = 130 DAP). Tubers were harvested either 10 days after haulm killing (Harvest 1) or at the completion of the trial 150 days after planting (Harvest 2). Tuber yield, number and stem number per plant were recorded when seed was grown out in the following season.

Seed produced from the November planting produced significantly higher yield and stem number per plant than seed from the December and January plantings. Time of haulm kill and time of harvest had no significant difference on seed performance the following season. There was a trend toward increased stem number with early harvest (2 weeks after haulm kill) compared to field storage for up to 3 months before harvest.

Conclusions

In each of the trials undertaken in the project, significant effects of timing of haulm kill in the seed crop, duration of in-ground storage in the crop and timing of planting of the seed crop on seed performance were recorded. However, no consistent patterns were found. In the 2002/03 trial, haulm kill date had a significant impact on yield and tuber number the following season, with seed performance reduced by early haulm killing and by allowing the crop to senesce naturally. Duration of in-ground storage was not a major determinant of seed performance in this trial. In contrast, in the 2003/04 trial seed performance decreased with later haulm kill treatments, and in-ground storage had a significant impact on seed performance. In the 2004/05 season, neither timing of haulm kill or duration of in-ground storage had a significant effect on seed performance. It was concluded that, while timing of haulm kill and duration of in-ground storage can affect seed physiological quality, the effect of the treatments must depend on other processes occurring in the tubers during late development and/or the impact of the physiological changes must be modified by storage and planting environment conditions.

Planting date of the seed crop was shown to affect seed performance in both the 2002/03 and 2004/05 trials, with the latest trial indicating that seed from a November planting in Tasmania could out-yield seed from December and January plantings when grown out in the following season. The planting date effect was less distinct in the 2002/03 trial, with the earlier planting date generating better quality seed in one seed lot but the later planting producing better quality seed in a second seed lot.

These results highlight the difficulties in interpreting results from studies examining individual factors influencing seed quality and performance in isolation. While significant effects of treatments can be identified in individual trials, the results can rarely be extended to a broader range of seed production and seed planting environments as other factors associated with seed production, seed storage and ware crop planting environment interact to determine seed performance.

4. Location effects on seed performance

Introduction

Significant differences in seed lot performance have been demonstrated in Tasmania in recent years. Seed sourced from different seed growers and planted at a single location can commonly have a difference in yield of 10 to 20%. Efforts have therefore been made to identify high quality seed lots. The performance of seed (number of stems per seed piece, and yield from the crop when well managed) is, however, the result of an interaction between the quality of the seed and the environment in which it is planted. Seed that performs well at one location may not perform well at another. Trials were conducted in the three years of this project initially to evaluate differences in seed performance associated with production location but in the final season the trials aimed to assess if ranking of seed lot performance (listing of best to worst) was consistent between sites (ie even if total yield varies between locations, will ‘good’ seed lots always outperform ‘poor’ seed lots). Given the difficulties in determining the impact of factors on seed quality, this final area of analysis is important in determining if the traditional view of seed quality (potential performance is set in the seed, and subsequent handling and planting only influence the expression of that potential) needs to be reviewed and relaced with concept of seed attributes needing to be matched to planting conditions to optimise performance.

Materials and Methods

Trial 1 (Sprouting assessment)

The environment in which seed crops are grown and the management practices used on the crops are factors that potentially influence the rate of physiological ageing after harvest. A trial was conducted to assess the effect of production location on physiological ageing in seed tubers. Russet Burbank seed tubers were sourced from seven different production locations from North West, North East, Midlands and Southern Tasmania, Australia (Table 5). A total of thirteen seed lots were collected from seven locations. The approximate date of haulm death and the date of harvest of each seed lot were recorded. The time of haulm senescence varied from 114 to 147 days after planting (DAP), while time of harvest varied from 27 to 43 days after haulm death. Six of the seed lots were obtained from a research trial conducted at Burnie, and differed in treatments imposed on seed prior to planting of the crop. These treatments were the use of cut seed 50-80g either untreated (seed lot 8) or treated with the sprout retardants carvone (seed lot 9) or dimethylnaphthalene (seed lot 10) seven weeks prior to planting, whole seed of 50-80g (seed lot 11), cut seed 30-50g (seed lot 12), and cut seed 80-120g (seed lot 13)

Seed lot number	Production region	Haulm death (Days after planting)	Tuber harvest (Days after haulm death)
1	Ulverstone	135	33
2	Rianna	142	30
3	Oatlands	135	43
4	Rianna	127	27
5	Derwent	139	31
6	North East	147	29
7	Cressy	132	29
8	Burnie	114	37
9	Burnie	114	37
10	Burnie	114	37
11	Burnie	114	37
12	Burnie	114	37
13	Burnie	114	37

Table 5. Details of seed lots used in the seed production location trial

Approximately 8kg samples were collected for all seed lots. The tuber samples were collected at harvest, 3 – 4 weeks after haulm senescence. Tubers in the seed lots were graded according to weight and 40 healthy, spherical to ovoid shaped tubers within the 50 to 60g weight range were selected from each seed lot. Of these 40 tubers, 20 were allocated for sprouting capacity assessment and the remaining 20 were used for dormancy assessment. The tuber samples were labelled and stored until required. Two storage temperatures, 4°C and 10°C, were chosen to allow testing of tuber sprouting capacity at two physiological ages. Ten tubers of each seed lot were therefore held at each temperature for sprouting capacity assessment and 10 tubers for dormancy assessment.

Sprouting capacity was determined for each seed lot 20 weeks after the date of haulm death. The commencement of sprouting capacity assessment was therefore staggered as date of haulm death varied between the seed lots. The sprouting capacity of each seed lot was determined by placing tubers in moist sand in a controlled environment at 20˚C, 95%RH and darkness for thirty days. Sprout weight and tuber weight were recorded at the completion of the 30 day period and sprouting capacity recorded as sprout weight expressed as a percentage of tuber weight. Data was examined using analysis of variance and least significant difference (LSD) determined where significance was indicated at the 5% level. The duration of dormancy of each seed lot was determined using a visual assessment of tuber eye morphology. Dormancy was recorded as being completed when the eyes opened slightly and the sprout initial became visible.

Trial 2 (2004/05 Field assessment)

This trial was carried out in conjunction with the Simplot seed line evaluation trials. Six seed lots from the Simplot trial were selected and planted at Forthside Vegetable Research Station in a relicated block design with 4 replicates of each seed lot. Replicate plots were 10m double rows with buffer rows between plots. The central 5m double row section was harvested.. The seed lots were also planted at in the Simplot seed line evaluation trial. There was 2 days difference in planting date between the sites. Both sites were on the NW coast on krasnozem soils. Processing yield and stem numbers for the seed lots were determined at harvest at both sites.

Results

Trial 1 (Sprouting assessment)

Differences in sprout weight of up to 400% were recorded in Russet Burbank tubers from crops produced in different locations, harvested one week after haulm death and stored for 6 months at 4 °C. No significant differences between seed lots in duration of dormancy were recorded. The tuber sprouting capacity at 10°C varied from 0.25 to 1.35, with the most vigorous seed lots producing over five times the weight of sprouts as the weakest seed lots. The six seed lots collected from the Burnie field trial displayed significantly lower vigour than the remaining seed lots collected from commercial seed potato producers. The trends in sprouting capacity at 4°C (Figure 17) were similar to those of tubers stored at 10°C (Figure 18), but the tubers held at the higher temperature displayed higher sprouting capacity.

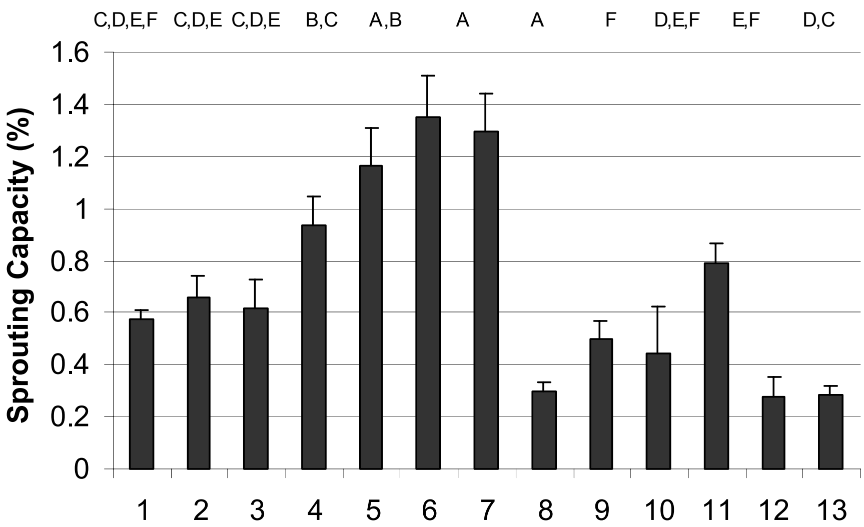


Figure 17 Sprouting capacity (sprout weight as a percentage of seed tuber weight) of tubers stored at 4 °C. Letters indicate differences in means significant at P=0.05.

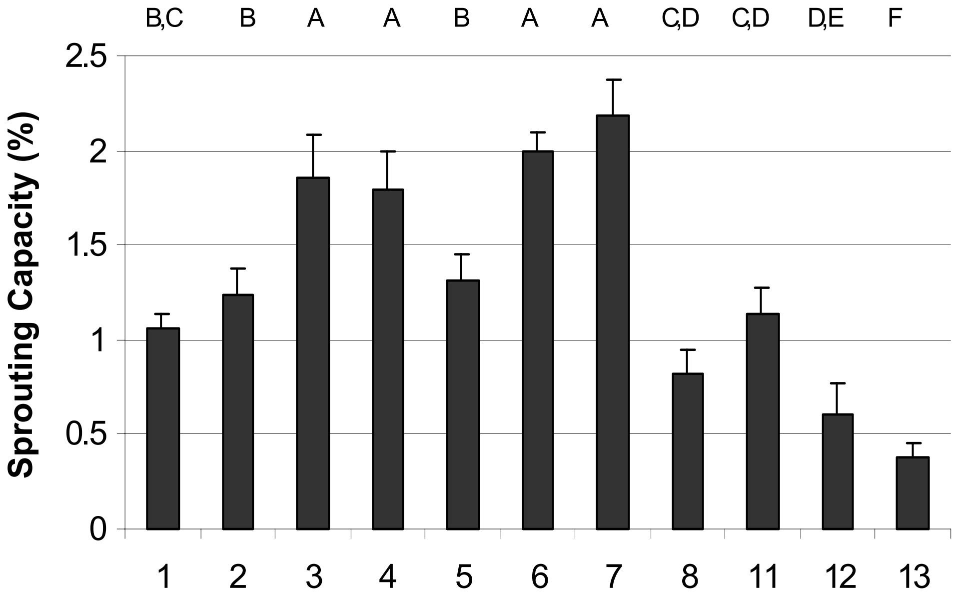


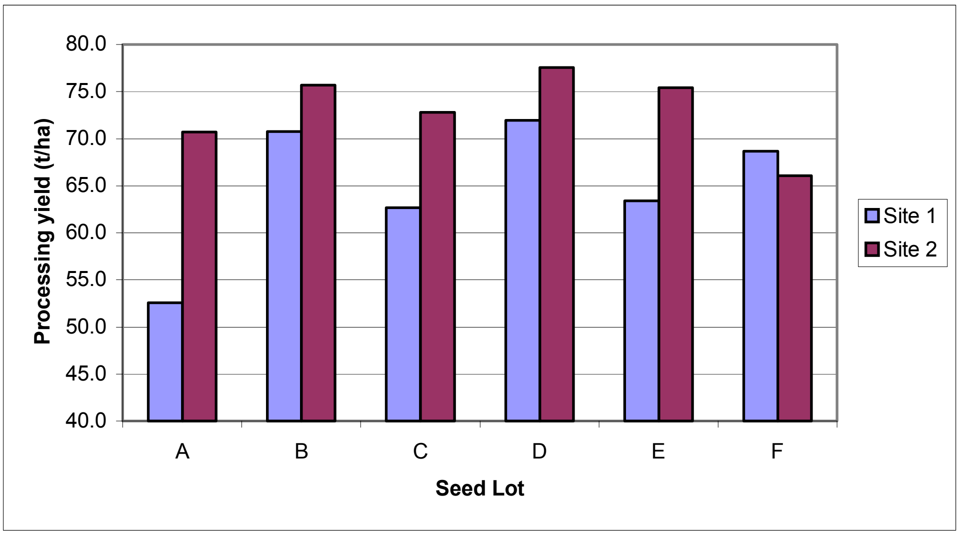
Figure 18 Sprouting capacity (sprout weight as a percentage of seed tuber weight) of tubers stored at 10 °C. Letters indicate differences in means significant at P=0.05. Insufficient tubers were available for 10°C storage from seed lots 9 and 10, resulting in the missing data).

Seed lots 3, 4, 5, 6 and 7 were produced on sandy loam to sandy soils, while the remaining seed lots were produced in clay soils. While the range of seed lots was limited, the data suggests that tubers from seed crops grown on sandy soils aged faster than tubers produced in clay soils. Seed lots 8 to 13, which were produced over the shortest growing season of all the seed lots, were apically dominant (producing one or few sprouts from the apical end of the tuber), suggesting that the seed was physiologically younger than the other seed lots.

There were differences between seed lots in the number of sprouts produced per tuber. Seed produced from crops where natural haulm death occurred (seed lots 1, 2, 3, 5 and 6) tended to have a very short or no single sprouting (apical dominance) phase but still displayed strong vigour associated with young seed. In contrast, seed from crops where haulms were killed early displayed the characteristic ageing cycle (dormancy, single sprout/apical dominance phase, multi-sprout stage).

Trial 2 (2004/05 Field assessment)

Significant differences between seed lots were recorded at each site, with yield ranging from 53 t/ha to 78 t/ha and stem numbers from 1.7 to 2.4 per plant. Site 1 (FVRS) tended to produce lower yields and higher stem numbers than site 2. However, trends (ranking of seed lots from best to worst) in both yield and stem number were not consistent between sites. Seed lots B and D performed well at both sites, but the other 4 seed lots performed poorly at one but not both sites. The potential performance of the seed lots could not be predicted based on their performance at one location. Clearly more needs to be known about the interaction between seed physiological age (quality) and planting environment before prediction of seed performance is possible.



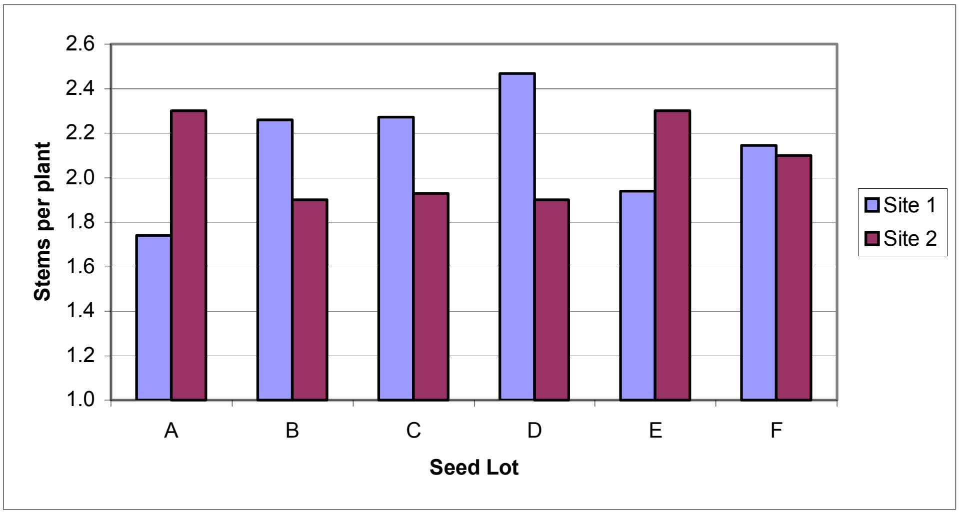


Figure 19. Performance of 6 seed lots at 2 locations.

Conclusions

Seed tuber physiological age is an important determinant of potato crop establishment and early performance. The initial trial reported in this chapter again demonstrated that crop management practices and growing climate of the previous generation(s) of seed potatoes can have a significant effect on physiological ageing. Differences in sprouting vigour of up to 400% between genetically similar seed lots produced at different locations were demonstrated. Soil type and temperature, particularly seasonal variations in night/day temperature differential, may have contributed to this result. In addition to climate and location effects, haulm killing approximately 3 weeks prior to natural haulm death resulted in improved crop yield compared to earlier haulm killing or natural haulm death. Planting density in the seed crop had no significant effect on seed performance, while planting date influenced performance but the effect was not uniform between seed lots.

While seed production practices may influence the physiological status of the seed tubers, that status cannot be classified as 'high quality' or 'low quality' in terms of potential performance. The performance of the seed tuber when planted is determined by both the planting environment and the physiological status of the tuber – rather than tubers having an inherent potential performance that may be reached under ideal conditions but not under less than ideal conditions, the potential performance of the seed varies with the conditions in which it may be planted. For example, consider seed lots A and F in the 2004/05 trial. Seed lot A performed very poorly at site 1 but achieved close to average yield for all seed lots at site 2, while seed lot F achieved above average yields at site 1 and the lowest yield of all seed lots at site 2. Clearly the performance of the seed lots was determined by the interaction between tuber physiological status and site conditions.

5. Discussion and Conclusions

This project set out to identify key aspects of seed crop management and storage that influence the physiological quality of the seed tubers. Two potential indicators of physiological quality were assessed, and neither proved to be an accurate indicator of stem number, one of the key seed quality attributes. While both the butanol test and chemical maturity monitoring were shown to be poor indicators of tuber physiological quality, it must be remembered that the testing was conducted only of Russet Burbank tubers grown under southern Australian conditions. One or both of these tests may prove to be valid indicators for other potato cultivars or for seed either produced under or grown out under different environmental and crop management conditions than those used in this study.

Analysis of factors impacting on seed performance demonstrated that assessment of seed physiological status per se is unlikely to be useful in predicting seed performance. Seed crop management factors, and specifically seed crop planting date, senescence date and harvest date, along with storage duration, do affect seed performance and this effect must be through changes in seed physiological state. However, ware crop planting environment also affects seed performance, and the interaction between seed physiological state and planting environment appears to have an overriding effect on crop growth. Knowledge of the seed tuber physiological state therefore cannot be used to predict performance while knowledge of the interaction between physiological state and planting environment remains negligible. This is the obvious area of seed potato physiology and agronomy research that needs to be addressed if the yield and quality (tuber numbers and sizes) potential of particular production regions is to be met.

The seed crop production practices that were identified as having the greatest impact on seed tuber quality related to time of seed crop senescence and harvest. While the effect was not significant in all trials, killing of haulms in seed crops generally increased seed performance in comparison to natural senescence of the crop. In-ground storage can decrease seed performance, but again the effect was not consistent between trials. The broad recommendation for seed production in Tasmania to produce seed most likely to have few stems is to plant the seed crop late (November/December) and kill the haulms between 120 and 140 days after planting. The seed may, however, still produce a large number of stems per plant when used under some planting conditions. Soil structure, temperature and moisture influence stems per plant, but as yet it is impossible to model this interaction between the seed production and storage aspects and planting environment to predict stem number.

Specific recommendations for seed crop management and storage cannot be made, and in fact will not be possible until the ware crop planting environment factors influencing seed performance are understood and the interaction between seed physiological state and planting environment is modelled.

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Appendix

The following pages are the full correlative matrix from analysis of commercial processing crop data. The first page includes all ware crop factors analysed and the second page lists seed crop and seed storage factors. Three figures are listed for each point in the matrix: the top figure is the r value for the correlation and indicates if a positive or negative correlation exists, the second figure is the P value and indicates significance (P<0.1 indicates significance at the 90% confidence interval, P<0.05 indicates significance at the 95% confidence interval and P<0.01 indicates significance at the 99% confidence interval), and the third vale is the number of crops included in the correlative analysis. As not all factors were recorded in each crop the number of crops used in each correlative analysis varies.

	Ha	Emergence	Tuber Initiation Date	Planting Date	Row width	Density	Years since pasture	Years Since Potato	Soil structure	Moisture	50% Senesced Date	Fungicide Start Date	Days to 1st Fungicide
Yield	-0.03345	0.02652	-0.06384	0.01603	0.03824	0.05885	-0.02497	0.02061	0.0568	0.06288	0.14498	0.0024	0.02295
	0.4061	0.5505	0.2119	0.6956	0.3902	0.219	0.6322	0.6343	0.1917	0.1437	0.0483	0.9589	0.6257
	619	509	384	598	507	438	370	535	530	542	186	464	454
%Size	-0.025	-0.00614	-0.04129	0.01842	0.0444	-0.05318	-0.05425	0.0108	-0.00701	0.00611	0.02917	-0.0521	-0.0655
	0.5592	0.8966	0.4466	0.6722	0.3484	0.296	0.3251	0.814	0.8798	0.894	0.7066	0.2885	0.1861
	548	451	342	530	448	388	331	477	468	478	169	417	409
% Bruise free	0.06988	0.03227	-0.00427	0.00542	-0.03143	0.01894	-0.0374	-0.01061	0.09154	-0.00087	0.00069	-0.02248	-0.00309
	0.101	0.4923	0.9371	0.9005	0.5051	0.7089	0.4951	0.8169	0.0469	0.9847	0.9929	0.6468	0.9503
	552	455	345	535	452	391	335	479	472	482	170	418	411
Specific gravity	0.00772	-0.01087	-0.08734	0.03372	0.02699	0.02928	-0.08948	0.00206	0.01319	0.00411	0.03555	-0.03389	-0.01835
	0.8562	0.817	0.1048	0.4364	0.5666	0.5633	0.1021	0.9641	0.7749	0.9282	0.6434	0.489	0.7108
	553	456	346	535	453	392	335	480	473	483	172	419	411
% rejection	-0.00175	-0.02071	-0.12885	0.04208	-0.0414	0.05463	-0.05398	0.09969	-0.01242	-0.102	-0.11162	-0.10343	-0.14316
	0.9696	0.6846	0.0269	0.3684	0.4167	0.3188	0.3547	0.0421	0.8025	0.0376	0.1753	0.0483	0.0068
	479	387	295	459	387	335	296	416	408	416	149	365	356
Days to emerge	0.0821	-0.00431	-0.08785	-0.42716	-0.0348	0.18453	0.17396	0.03274	0.16071	0.05448	-0.16534	-0.04591	0.24773
	0.0663	0.9233	0.0933	<.0001	0.46	0.0002	0.0024	0.4928	0.0005	0.234	0.0432	0.376	<.0001
	501	501	366	501	453	401	303	441	463	479	150	374	374
Stems per plant	-0.01226	0.3024	0.23782	0.36011	0.03758	-0.31212	0.12806	-0.00092	0.15053	0.14084	0.2677	0.23952	0.02339
	0.7922	<.0001	<.0001	<.0001	0.4507	<.0001	0.0307	0.9852	0.0016	0.003	0.0003	<.0001	0.6647
	464	415	321	449	405	405	285	409	435	443	179	356	346

	Planting date	Years since Potato	Coolstore	Irrigation Frequency	Irrigation Amount	Date Senesced	Growing Days	Digging Date	In ground	T/ha	Date out of coolstore	days in cool store	Days Warming	Date Cut	Days cutting to planting
Yield	-0.05691	0.05917	0.07247	0.01064	0.07069	-0.01785	0.00653	0.02828	0.07417	0.00479	0.01584	-0.10568	-0.06357	0.04374	-0.06308
	0.4154	0.4275	0.2994	0.8845	0.3338	0.7985	0.9256	0.6858	0.2882	0.9454	0.7585	0.2123	0.2584	0.408	0.2365
	207	182	207	189	189	207	207	207	207	207	379	141	318	360	354
%Size	-0.05527	-0.02743	-0.12221	0.03799	0.0904	0.08847	0.10699	0.05547	-0.04027	0.08665	0.0163	-0.06206	-0.03156	0.03779	-0.00524
	0.4637	0.7306	0.1041	0.6324	0.2541	0.2402	0.1552	0.4621	0.5935	0.2501	0.7677	0.4989	0.5997	0.5026	0.9265
	178	160	178	161	161	178	178	178	178	178	331	121	279	317	312
% Bruise free	-0.04596	0.11238	-0.07167	0.09027	0.01335	0.01086	0.02934	-0.00683	-0.0273	-0.01222	-0.02412	-0.08386	-0.02557	-0.06473	-0.05112
	0.539	0.1545	0.3377	0.2504	0.8653	0.8846	0.695	0.9273	0.7152	0.8703	0.6615	0.3544	0.67	0.2497	0.3666
	181	162	181	164	164	181	181	181	181	181	332	124	280	318	314
Specific gravity	-0.0322	-0.05262	0.26331	-0.12686	-0.22079	-0.03021	-0.01498	-0.04053	-0.02119	-0.02054	-0.00282	0.05393	-0.06214	0.01454	0.01396
	0.6678	0.5074	0.0004	0.1066	0.0046	0.6873	0.8418	0.5891	0.7777	0.7844	0.9591	0.5536	0.2993	0.7959	0.8054
	180	161	180	163	163	180	180	180	180	180	333	123	281	319	314
% rejection	0.12982	0.21458	-0.04975	-0.01152	-0.0636	0.22663	0.15779	0.11392	-0.18468	0.07491	-0.05121	-0.0309	0.05641	-0.01377	0.02386
	0.1305	0.0186	0.5637	0.8981	0.4792	0.0077	0.0656	0.185	0.0307	0.3843	0.3899	0.7737	0.3832	0.8221	0.6995
	137	120	137	126	126	137	137	137	137	137	284	89	241	269	264
Days to emerge	0.1479	0.10017	-0.0766	0.07011	-0.09864	0.16528	0.09445	0.16052	0.012	0.1134	-0.41965	-0.37031	0.11887	-0.39112	-0.04361
	0.0401	0.1924	0.2897	0.3565	0.1941	0.0216	0.1914	0.0257	0.8685	0.1164	<.0001	<.0001	0.0431	<.0001	0.4354
	193	171	193	175	175	193	193	193	193	193	343	136	290	322	322
Stems per plant	-0.11913	-0.11007	-0.02683	0.00299	0.08302	-0.06844	-0.01276	-0.22416	-0.24728	0.09101	0.27441	0.20304	0.09053	0.3655	0.09356
	0.1207	0.1814	0.7276	0.9704	0.3028	0.3738	0.8684	0.0032	0.0011	0.2365	<.0001	0.0274	0.1432	<.0001	0.1106
	171	149	171	156	156	171	171	171	171	171	318	118	263	298	292