Know-how for Horticulture™

Improved seed potato production

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Tasmanian Institute of Agricultural Research

Project Number: PT98008

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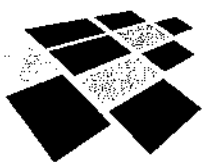


Horticulture Australia

Final Report

Improving Seed Potato Production

Project number: PT98008

October 2001

Dr Philip Brown

Tasmanian Institute of Agricultural Research

CONTENTS

Industry Summary

Introduction

The seed potato industry is responsible for the multiplication of early generation, disease free material to produce certified seed tubers for the commercial ware and processing potato growers. 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. The maintenance of low disease status in seed crops has been examined in numerous research projects in Australia, and forms the basis of the seed certification scheme. In contrast, little research has been undertaken on seed physiological quality. This project examined aspects of seed physiological quality and investigated treatments to manipulate stem number per seed piece and tuber number per plant in seed potato crops. The results of the project demonstrate the importance of tuber physiological condition in seed potato production and identify a number of key areas in the management of seed tuber physiological condition.

The Concept of Physiological Age

The importance of seed tuber physiological age is a well known in the potato industry but surprisingly little is done to manage physiological age in commercial production. It is common knowledge 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 (Table 1). Seed growers therefore prefer to use older seed while growers of processing potato crops aim to use young seed. The difficulty at present is that prediction of physiological age in Australia is unreliable, with duration and temperature of storage the only information (and even this information is often not recorded) available to seed buyers for prediction of tuber physiological condition.

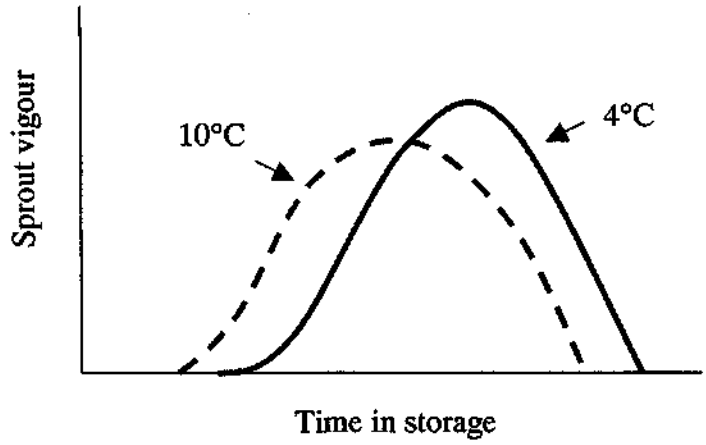
Table 1. Characteristic behaviour of physiologically young and old seed tubers.

Young Seed	Old Seed
Slow emergence	Rapid emergence
Apical dominance	Multiple main stems
Few main stems	Increased stem branching
Vigorous, large plants and root systems	Smaller, weaker plants and root systems
Fewer tubers per plant	Many tubers per plant
Long bulking period	Rapid bulking
Long tuberization period	Relatively uniform tuber set
Large tubers at harvest	Smaller average tuber size
High yields	Lower yields
Delayed senescence	Early senescence

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

(Figure 1). 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. 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 results of this study indicate that seed growing environment and the conditions under which the seed is then planted contribute significantly to crop performance (stem number and vigour).

Figure 1. Effect of storage temperature on sprout vigour



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. Several markers were examined in the project but none were able to accurately indicate the sprouting pattern and vigour of seed.

Sprouting of tubers under standard conditions is a useful indicator of seed condition and was used to demonstrate the importance of growing conditions on seed ageing. Seed from 13 locations in Tasmania was stored at 4°C for 10 weeks following haulm death and then sprouted in moist sand at 20°C for 4 weeks. The tuber sprouting capacity (total sprout weight as a percentage of tuber weight) varied from 0.25 to 1.35 – in other words the most vigorous seed lots produced over five times the weight of sprouts as the weakest seed lots. There were also big differences between seed lots in the number of sprouts produced per tuber. Seed produced from crops left to die off naturally 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 killed early displayed the characteristic ageing cycle (dormancy, single sprout/apical dominance phase, multi-sprout stage, sprout branching stage, little tuber stage). The original research on physiological ageing, done in Europe where seed crops are killed off early, therefore needs to be carefully interpreted in Australia given the range of climatic conditions under which crops are grown and the range of crop management practices used. More attention may need to be paid to matching seed

physiological condition (strongly influenced by seed crop growing conditions) to likely planting conditions instead of concentrating on management of ageing in storage.

Physiological Age and Planting Conditions
Soil temperature and soil moisture content influence the sprouting pattern and vigour of the planted seed tubers. Cooler temperatures or limited water availability at planting tend to produce slow emerging plants with few stems. These plants develop larger, more vigorous haulm and root systems, characteristic of young seed. The influence of planting conditions on sprouting behaviour were demonstrated in a field trial conducted in 2000/2001; seed was planted at one site on 30th October and 22nd November, and at a second site on 1st November, and resulted in 2.1, 1.5 and 2.5 stems per plant respectively. The seed planted at the first site performed like younger seed at the second planting date compared to the first planting date.

Management of Tuber Number
The density of stems within a crop has a major impact on the number of tubers produced. Management of stem density has generally been achieved by changing plant spacings and, if possible, selecting appropriately aged seed tubers. It is interesting to review previous research on round seed production in Australia to highlight the difficulty in managing seed age – in almost all cases optimum spacings vary between sites and between seed lots at any one site. At this stage the best strategy available to growers to manage seed physiological age is to identify a reliable supplier whose seed performs well under your own growing conditions and stick with that supplier. It is also worth considering that there are likely to be large differences in performance (vigour and sprout number) between seed lots, so trialing seed from a number of sources (if possible stored under identical conditions) may be a useful strategy to identify the best supplier.

Given the difficulties in prediction and management of physiological age, alternative strategies to manipulate the sprouting behaviour of seed tubers and the tuberisation response in crops were also examined. Much of the work undertaken in the project concentrated on managing stem number (and therefore tuber number) by application of the sprout suppressant carvone prior to planting. This treatment increased tuber numbers on average by around five percent for Russet Burbank. The results were, however, not consistent; there was no response in some trials, decreased yield and tuber number in others, and increased tuber number in the remaining trials. Application of the growth retardant paclobutrazol (Cultar) at tuber initiation has also been shown to significantly increase tuber set, and other treatments applied at this stage have also given promising results in an observational trial.

Technical Report

Introduction

The number of tubers produced per plant in a seed potato crop is influenced by the number of stems developing from each seed piece/whole seed and by the number of tubers set per stem. Management of stem density within a crop is therefore desirable in order to obtain the desired tuber size distribution within the crop. Stem density can be manipulated by altering the planting density of the crop, but variability in number of stems produced per seed piece/seed tuber limit the effectiveness of this practice in Australia. The lack of predicability in stem number is linked to differences in the physiological age or sprouting capacity of the tubers; physiologically young seed tends to display apical dominance with few stems emerging from the seed, thus limiting sites for tuber initiation in the crop, while physiologically old tubers produce more stems but these stems can lack vigour if the seed is aged for too long. Two logical avenues for research from this scenario are firstly the development of methods to accurately measure the physiological condition of seed tubers, and secondly the combined use of treatments to manipulate physiological condition or sprouting pattern to produce seed which behaves in a predictable manner. Research in both of these areas is documented in this report.

The Technical Report is divided into four sections; a review of physiological age, research examining indicators of physiological age, research examining factors influencing physiological age, and treatments used to manipulate stem number and tuber number in seed crops. The review outlines the concept of physiological age and summarises the literature relevant to this study. Research on indicators or markers of physiological age includes biochemical, morphological and descriptive characteristics and correlated these characteristics with sprouting performance of the seed lots tested. Preharvest conditions in seed crops (crop growth environment, crop management practices, crop harvest strategies) and post planting conditions were identified in the project as major contributors to seed performance, and results of studies on some of these factors are reported in the third section of the report. The final section details experiments conducted on manipulation of seed crop stem number and tuber size distribution using a range of chemical treatments. The Technical Report concludes with a summary of important findings and recommendations for future research.

What is Physiological Age?

Potato tuber meristems (eyes) exhibit a period of endodormancy (dormancy regulated by internal mechanisms) that begins prior to harvest and extends, in a cultivar-dependent manner during postharvest storage. During prolonged low temperature storage potatoes gradually exit the endodormant state and enter into a low-temperature-imposed state of ecodormancy (quiescence) (Campbell et al, 1996). Seed potatoes are held under low temperature conditions from harvest to planting and undergo a series of physiological changes during the low-temperature-imposed ecodormancy period. These changes in the physiological condition of the tuber influence the sprouting pattern and vigour of the sprouts emerging from the tuber following planting. Variation in the physiological status of the seed tuber has been likened to variation in age and the term physiological age is generally applied to describe this condition (Madec and Perennec, 1962). No precise physiological definition exists, however, since the mechanisms of ageing are largely unknown.

The physiological condition or physiological age of seed tubers is an important yield determinant in potato crops. Physiologically young seed may show delayed emergence and strong apical dominance (few stems emerging), while early vigour and stem number are increased as tubers reach older physiological age. Extended storage of tubers results in loss of apical dominance, reduced sprout vigour and in extreme cases formation of tubers on sprouts and no vegetative shoot growth (little potato phenomenon). The physiological condition of the seed tuber thus has a major impact on total tuber production as well as tuber number and therefore tuber size. The calculation of tuber physiological age has been used as a means of determining optimum storage length for seed tubers prior to planting, but is not always reliable as it is an approximation based on time and storage temperature rather than the physiological changes involved in the ageing process.

The temperature dependence of sprout growth, and by implication the ageing process, has resulted in the use of accumulated heat units or day-degrees from dormancy break as a quantitative measure of physiological age (Wurr, 1978). A base temperature of 4°C is widely accepted although in several cultivars sprout growth is not arrested at this temperature (O'Brien *et al*, 1983). The system assumes that age is a function of heat unit total and is unaffected by the actual temperatures or the chronological time at which day-degrees are accumulated. This assumption may not always be valid as accumulation of day-degrees late in the storage period has been demonstrated to produce different rate of early crop growth than accumulation of the same number of day-degrees early in the storage period (Jenkins et al, 1993). Similarly, treatment with reversible sprout suppressants (carvone, DMN) or desprouting of tubers may also result different early growth responses without altering accumulated heat units (Brown and Baker, unpublished data). Another major weakness of the system is that the physiological age model does not take into account the physiological condition of the tubers prior to storage. The physiological condition of the tuber at any point in time is the net result of all its environmental experiences from the time of its initiation on the mother plant. Weather conditions during tuber development, soil type and conditions during growth, and time of harvest can all influence the physiological condition of the tubers in storage (van Es and Hartmans, 1987).

Other attempts have been made to quantify physiological age, such as assessment of "sprouting capacity" (Krijthe, 1962; Hartmans and Van Loon, 1987; Moll, 1994) which is a measure of sprout growth under standard conditions following desprouting. This approach is however largely unproven and of doubtful practical applicability. No method has yet been suggested that accounts for the physiological nature of the process. Obviously a greater understanding of the key physiological changes occurring during ageing is required in order to develop useful methods for quantifying physiological age.

The anatomical and physiological changes occurring during ageing of tubers are numerous and include changes in carbohydrate composition and distribution, plant hormone concentrations, enzyme activities, and membrane properties. Sucrose, glucose and fructose accumulate in tubers during storage, particularly at low temperature, due to increased activity of starch hydrolizing enzymes and sucrose phosphate synthase (Deiting et al, 1998). Studies on gene expression and protein patterns have shown that 25% of proteins found in ageing tubers are not present during tuber filling (Borgmann et al, 1994), indicating that dramatic changes in many metabolic pathways are occurring. Massive changes also occur at the plasma membrane during ageing (Frommer and Sonnewald, 1995). The decline in sprouting capacity of aged tubers has been linked to an increase in electrolyte leakage (Deweerd et al, 1995), suggesting that membrane integrity is one determinant of vigour in seed potato tubers. The pattern of electrolyte flux indicates that changes in membrane integrity are the major determinant of the observed change, but changes in number and activity of membrane transport proteins are also likely have occurred (Borgmann et al, 1994). Plasma membrane ATPase activity increases significantly as tubers age, while oxidative stress also increases as evidenced by increased activity of the glutathione-mediated free-radical-scavenging system (Kumar and Knowles, 1996a). Increased ATPase activity and activiation of systems to counter oxidative stress are likely to contribute to increased respiration rates noted in older tubers (Kumar and Knowles, 1996b), and thus older tubers consume more ATP during sprouting to fuel metabolic processes that do not contribute directly to sprout growth.

A large volume of literature supporting a role for plant hormones in regulating age induced changes in sprouting capacity have been published. Much of this literature reports on the effects of applied plant hormones, with few studies of changes in endogenous concentrations. Care must thus be taken in interpreting these findings as the tuber responses to applied hormones may not reflect the normal pattern of change of endogenous concentrations. Dipping cut seed in gibberellic acid (GA) has been shown to increase stem and tuber numbers and reduce average tuber size in both Ranger Russet and Shepody with little effect on total yield (Mikitzel, 1993). The auxin NAA has also been shown to increase sprout vigour in aged tubers but decreased stem number (Shashirekha et al, 1991). The activity of the auxin catabolising enzymes IAA oxidase and peroxidase has been shown to increase as tubers age and the ability of sprouts to transport auxin basipetally is also reduced (Kumar and Knowles, 1993). The increased capacity for degradation of auxin and decreased ability to transport auxins in aged tubers may explain the loss of apical dominance and reduced sprout vigour in physiologically old tubers. The concentration of methylnaphthalenes, volatile chemicals produced by potato tubers,

has been shown to decrease during storage (Wiltshire and Cobb, 1996), and isomers of these chemicals (dimethylnaphthalene and diisopropylnaphthalene) have been shown to be effective sprout suppressants in stored potatoes (Lewis et al, 1997). It is possible that these chemicals have a role in regulating the sprouting process in tubers.

The complex nature of the ageing process and the many physiological changes involved in the process are highlighted in the literature review. A number of potential markers of tuber physiological condition or age can be identified from the literature. Measurement of sprouting capacity, or the sprouting response of tubers under controlled conditions, is the simplest indicator, but requires more extensive validation before it can be considered as a practical method for predicting tuber sprouting responses. Activities of key carbohydrate metabolising enzymes such as sucrose phosphate synthase offer a more direct assay of physiological condition and are likely to be useful research tools. Likewise, estimates of membrane condition (electrolyte leakage tests, concentration of membrane breakdown compounds) and hormone levels (auxins, methylnaphthalenes) may be used to predict sprouting behaviour through measurement of key physiological processes. Each of these indicators should be examined firstly to identify the key physiological processes linked to changes in crop performance due to the ageing process and secondly to enable the development of a practical assay of tuber physiological condition either based on the key physiological process(es) or on plant response assays (such as the sprouting capacity) which are strongly correlated with these key processes.

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Indicators of Physiological Age

Management of seed potato physiological age would be simplified if an indicator or marker of tuber physiological condition could be measured and used to predict performance of the seed lot. A number of research projects attempting to develop indicators of physiological age have been undertaken but calculation of accumulated day degrees remains the only widely recognised method. As this method does not always allow prediction of seed performance, other possible indicators of physiological age were investigated in this project. The indicators investigated were rate and pattern of sprout development under controlled conditions (sprouting index), production of dimethylnaphthalene, electrolyte leakage, and sucrose phosphate synthase activity.

Methods

Sprouting index

The sprouting index or sprouting capacity assessment was based on the methods of Moll (1994). Styrofoam boxes capable of holding ten tubers were prepared by punching three holes (approx. 3-4 cm diameter) on centre line of box base. Domestic wipes are pulled through holes and flattened on the inside base of the box. The wipes acted as passive wicks to supply water by capillary action to crushed quartz sand and potatoes. Inside of box is covered with a thin layer of sand. Ten desprouted potatoes were placed in the box and covered with 2-4 cm of sand. Boxes were placed on capillary matting which was kept wet. Boxes were placed in darkness at 20°C and 95%RH. After thirty days had elapsed, emerging stems were removed, counted and weighed.

It is then possible to calculate sprouting capacity, defined as sprout growth (re-growth after desprouting) measured as total sprout weight per uniform tuber for a given standard sprouting procedure, sprout number, and growth vigour (growth vigour being the dry weight per plant) (Struik & Weirsema, 1999). Growth vigour is defined as the potential to develop a well-developed, vigorous plant within a short period of time.

Note that morphological stages can be divided into break of dormancy, one sprout stage, multiple sprouting, multiple branched sprouting, hair sprouts, and finally, little tuber formation (senility) (Struik & Weirsema, 1999).

Production of dimethylnaphthalene

Dimethylnaphthalene is a naturally occurring volatile chemical produced by potato tubers. Previous studies have suggested that the chemical plays some role in dormancy in potato tubers, with concentration decreasing at the end of the dormant period. The chemical can also be applied to tubers to extend the duration of the dormancy period, and is available commercially (1-4 Sight) as a sprout suppressant. The observed changes in dimethylnaphthalene concentration produced by potatoes during storage may make this chemical a useful marker of physiological age.

Concentration of dimethylnaphthalene in tuber samples was determined using solvent extraction and GCMS applications. A sample of 10 tubers was used for each

extraction of dimethylnaphthalene. Analyses of dimethylnaphthalene were performed using an HP5890 GCMS in selected ion monitoring (SIM) mode with a non-polar stationary phase HP1 coil. Each sample was extracted in 20 ml hexane containing 70 mg l^{-1} dodecane as an internal standard. Helium was used for the mobile phase at 5 psi.

GCMS-SIM conditions were as follows:

GC:
Oven 60-120°C, ramped at 10°C min^{-1}
Injection at 250°C
Detector at 2890°C

SIM:
m/z dodecane = 99.1
Multiplier at 2200 V
Solvent delay of 2.4 min

Electrolyte leakage

Studies with true seed in other crops has shown that loss of seed viability can be related to a decline in the ability of cells to retain cytoplasmic solutes. The increase in leakage of ionic materials such as sugars and amino acids is thus related to aging of the seeds, with higher levels of leakage occurring in older seeds. A similar relationship between electrolyte leakage and seed performance has been suggested for potato tubers (De Weerd et al, 1995), suggesting that a measure of electrolyte leakage could be used to predict tuber physiological age and therefore seed vigour.

Electrolyte leakage measurement was based on the method of De Weerd et al (1995). Cores were taken from the basal end of 10 tubers per sample using a 7 mm diameter cork borer. Cores were cut into 2mm thick discs and rinsed three times in distilled deionised water. A sub sample of 30 discs was then placed in a vial containing 60 ml of distilled deionised water. Electrolyte leakage was determined by measuring the conductivity of the vial solution using a conductivity meter. Conductivity readings commenced 2 minutes after placing the discs in the water and were initially taken at 2 minute intervals, increasing to 5, 10 and 20 minute intervals over a total period of 120 minutes. The solutions were stirred frequently throughout the reading period. After completing the readings, the total electrolyte pool was determined after a freeze (-20°C, 1 day) and heat to boiling treatment of samples. The rate of electrolyte leakage was expressed as a percentage of the total electrolyte pool of the discs.

Sucrose phosphate synthase activity

The metabolism of carbohydrates in the potato tubers is critical to the sprouting process. Changes in concentration of soluble carbohydrates in tubers have been reported during storage, along with changes in the activities of key regulatory enzymes such as sucrose phosphate synthase. This enzymes was selected for assessment as a potential marker of tuber physiological condition.

Sucrose-6-P synthase extraction and assay were done following the procedure of Sowokinos et al (1985). Potato tissue (25 g) was homogenised in 25 ml buffer and centrifuged at 18000g for 15 min at 4°C. The buffer consisted of a solution of 10% $NaHSO_3$ and 50 mM Tris-phosphate buffer (pH 7.5, 1:4 v/v) containing 10 mM GSH and 1 mM EDTA. Extracts were dialyzed against Tris-phosphate buffer containing 10 mM $NaHSO_3$. Reaction mixtures (0.25 ml) contained 100 mM Tris-phosphate buffer (pH 7.3), 20 mM fructose-6-P, 10 mM UDPglucose, 50 mM NaF, and diluted enzyme containing between 0.02 and 0.2 units of enzyme. Boiled enzyme blanks and sucrose standards (0.5 µmol) were run with each assay. After incubation at 37°C for 1 h, 0.25 ml of 5 N NaOH was added to each reachion, which was then placed into a boiling water bath for 10 min to destroy unreached fructose-6-P. The concentration of sucrose-6-P was determined by the thiobarbituric method. All analyses were performed in triplicate.

Comparison of five Russet Burbank lines

Seed tubers of five Russet Burbank lines (denoted units 1, 2, 3, 4 and 5) representing accessions of the cultivar currently grown commercially in Tasmania were sourced from the Department of Primary Industries, Water and Environment. The tubers were all grown at the Tewkesbury Research Station, cured for 10 days after lifting and stored at 4°C until the trial commenced. The assessment of physiological age indicators commenced 33 weeks after harvest. Twenty five tubers in the 100g size category (±20g) from each unit were sampled for comparisons between units. Ten tubers from each treatment were randomly selected for measurement of sprouting index, ten tubers were planted in 10L pots in the glasshouse for examination of growth pattern and tuber production, and five tubers from each treatment were used for determination of physiological properties of the tubers.

No significant differences in number of stems per plant and number of tubers produced per plant were recorded in pot grown plants from the five units. The differences in sprout number and maximum sprout length recorded in the sprouting index testing could not be used to predict stem number or tuber number although the trend in both stem and tuber number suggested that high sprout number in the sprouting test may be reflected in slightly higher stem and tuber number in plants.

	Sprout number	Max. sprout length	Stem number	Tuber number
Unit 1	4.7a	156.7a	3.6a	12.5a
Unit 2	3.8ab	203.6b	3a	11.6a
Unit 3	3.3b	173.1ab	2.9a	10.2a
Unit 4	3.6b	191.1ab	3.2a	11.4a
Unit 5	3.6b	186.7ab	2.9a	11.1a

Table 1 Sprout number and maximum sprout length from sprouting index test. Stem number and tuber number from pot grown plants. Letters denote significant differences at the 5% level

No significant differences between tuber samples from the five units were found in electrolyte leakage, sucrose phosphate synthase activity and dimethylnaphthalene concentration. Large variations between replicate in both electrolyte leakage and sucrose phosphate synthase activity was recorded. DMN concentration extracted from peels was low and did not vary significantly between treatments.

	Electrolyte leakage	SPS activity	DMN concentration
Unit 1	13.0%	65.2	0.05
Unit 2	14.1%	92.4	0.02
Unit 3	11.7%	53.7	0.06
Unit 4	12.7%	77.1	0.02
Unit 5	13.9%	63.9	0.02

Table 2 Electrolyte leakage (% of total electrolyte concentration), sucrose phosphate synthase activity (units per 10 g fresh weight), and dimethlynaphthalene concentration (mg per kg fresh weight peel).

As no significant differences in stem number and tuber number in pot grown plants were recorded between the five units of Russet Burbank were recorded, it was not surprising that the various potential indicators of physiological age did not vary between the units. The variability within samples was quite large, however, and further examination of the indicators in seed lots with a greater range of physiological ages/conditions is required.

Assessment of 13 Russet Burbank seed lots

A trial was conducted in 1999/2000 to assess the effect of production location on physiological aging in seed tubers. Plant material was sourced from seven different production locations from North West, North East, Midlands and Southern Tasmania. Further details of the trial are described in the next section of the report (Effect of seed production location, page 18). Tuber samples from each seed lot were taken for assessment of sprouting index, dimethylnaphthalene concentration, electrolyte leakage, and sucrose phosphate synthase activity. In addition, a number of physical characteristics of tuber samples (periderm thickness, number of eyes, distribution of eyes) were recorded as potential indicators of seed performance. Seed was not grown out in pots or the field in this trial, so relationships between sprouting index data and indicators of physiological age were undertaken.

Significant differences in sprout vigour were recorded between seed lots.

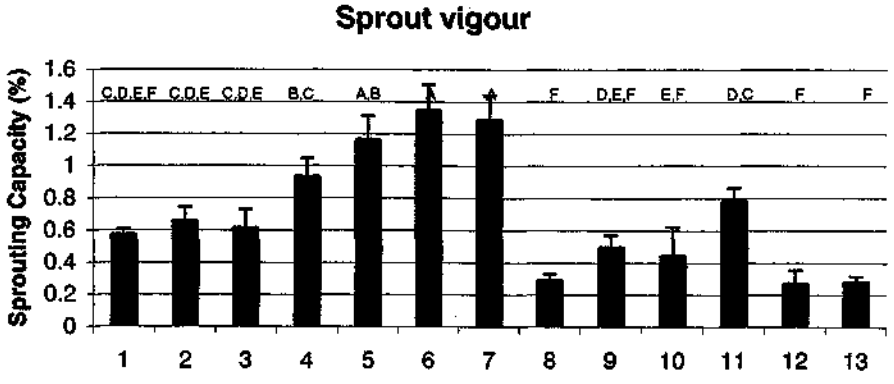

Figure 1 Sprouting capacity (sprout weight as a percentage of seed tuber weight) in thirteen Russet Burbank seed lots. Letters at the top of the graph denote significant differences at the 5% level.

Electrolyte leakage was high in the low vigour seed lots 8 to 13, but did not vary significantly between remaining seed lots. Significant differences in sucrose phosphate synthase activity were detected between seed lots but these differences

were not closely correlated with sprouting vigour. DMN concentration did not vary significantly between seed lots.

Seed lot	1	2	3	4	5	6	7	8	9	10	11	12	13
Electrolyte leakage	11	15	17	14	14	11	14	17	18.0	19	16	18	19
SPS activity	58	69	84	58	69	61	84	66	57	81	53	62	56
DMN concentration	0	0	0	0.1	0	0	0	0.1	0	0.1	0	0.1	0.1

Table 3 Electrolyte leakage (% of total electrolyte concentration), sucrose phosphate synthase activity (units per 10 g fresh weight), and dimethlynaphthalene concentration (mg per kg fresh weight peel).

No relationships were detected between tuber physical properties and sprouting vigour. An example of the variability between seed lots in number of eyes per tuber is shown in Figure 2.

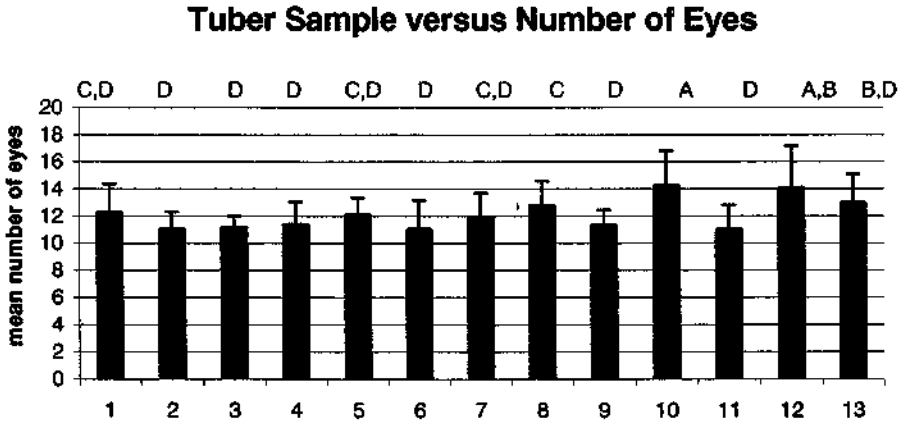

Figure 2 Number of eyes per tuber in each seed lot. Letters denote significant differences at the 5% level.

Further analyses of potential indicators of physiological age were undertaken on seed lots used in field trials in 2000/2001. In each case, no clear relationships between the measured parameters and the performance of the seed lots was detected. Assessment of sprouting index (sprouting pattern under controlled conditions) was concluded to be the only indicator capable of being used to roughly predict seed lot performance. It became clear during the project that the conditions under which the tubers are planted (for example, soil water content and soil temperature) have a major impact on seed performance, so measures of seed physiological condition taken before planting can only explain part of the control of sprouting. Further information on the factors controlling physiological aging is required before more comprehensive assessment of physiological age markers can be made.

Factors influencing Physiological Age

Introduction

The effects of duration and temperature of storage on tuber physiological age have been reported in the literature and are used in the prediction of physiological age based on thermal time or accumulated day degrees. 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. 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. If, for example, significant differences in the rate of aging occur between tubers grown in clay soils and sandy soils, then the accumulated day degrees required to reach a particular sprouting stage (physiological age) will differ. This difference may then be taken in to account when predicting likely sprouting pattern in tubers from different soil types. Information was gathered over the duration of this project on factors other than storage temperature and duration that may influence tuber physiological age. Research involved assessment of sprouting index of tuber samples and assessment of field growth of a selected number of potato seed lots.

Effect of tuber size and genetic type

Laboratory and glasshouse experiments commenced in October 1998. The approach taken in this trial was to examine tubers of identical physiological age (as measured by day degree accumulation model) but of different sizes and different type within the one cultivar. Seed tubers of five Russet Burbank lines (denoted units 1, 2, 3, 4 and 5) representing accessions of the cultivar currently grown commercially in Tasmania were sourced from the Department of Primary Industries, Water and Environment. The tubers were all grown at the Tewkesbury Research Station, cured for 10 days after lifting and stored at 4°C until the trial commenced. The assessment of sprouting index commenced 33 weeks after harvest. Twenty five tubers in the 100g size category (±20g) from each unit were sampled for comparisons between units, while 25 tubers of unit 5 in the size categories 50g, 100g and 200g were selected to examine the effects of size on sprouting pattern. Ten tubers from each treatment were randomly selected for measurement of sprouting index, ten tubers were planted in 10L pots in the glasshouse for examination of growth pattern and tuber production, and five tubers from each treatment were used in the development of methods for examining physiological properties of the tubers.

The sprouting index was determined by placing tubers in moist sand in a controlled environment at 20°C, 95%RH and darkness for thirty days, then measuring sprout number, sprout length, sprout weight and sprout position. These conditions favour rapid sprout development and allow an estimation of the level of apical dominance and the vigour of the sprouts.

Significant differences between treatments in the number of sprouts emerging from tubers were observed. Total sprout number per tuber ranged from 4.3 for unit 2 to 8.2

for unit 5. Large tubers (200g class for unit 5) had a greater number of sprouts than medium or small tubers. Many of the sprouts emerging were less than 2mm in length, so a comparison between treatments of number of sprouts >2mm in length may give a better reflection of the sprouting capacity of the tubers. Differences between treatments in number of sprouts >2mm in length are not as large as in total sprout number, but significant differences were still measured. Unit 1 had a significantly higher sprout number than the other units, while larger tubers had the highest number than small tubers. It is interesting to note that while unit 2 had the lowest total sprout number, 95% of the sprouts present on the tuber were >2mm in length. This compares with approximately 50% of sprouts >2mm in units 4 and 5. This may reflect a difference in vigour between the treatments. The results for sprout number measurements are shown below.

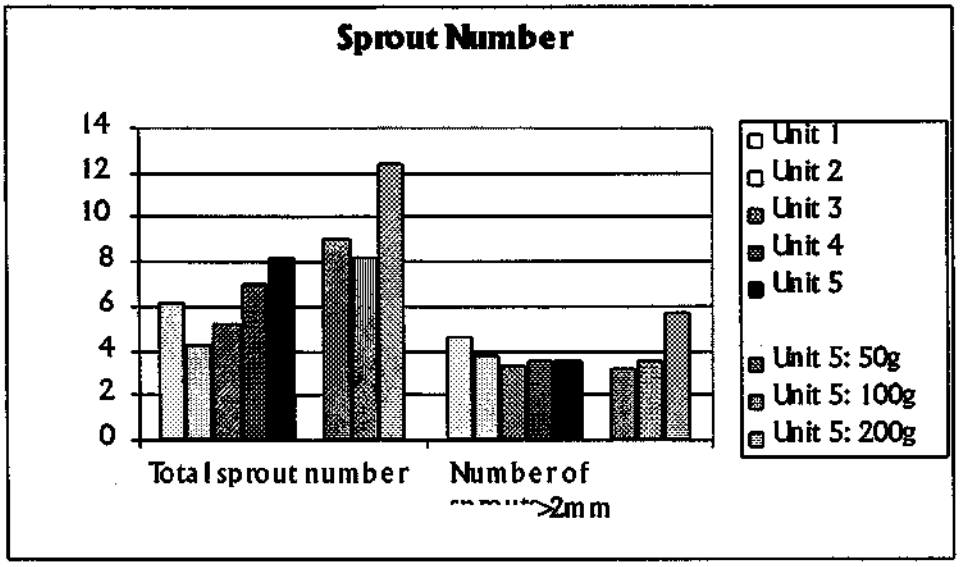

Figure 3 Sprout number in Russet Burbank seed lots (Units).

Significant differences in sprout length between treatments were recorded. Unit 2, which had a high percentage of sprouts over 2mm in length, had the highest mean sprout length and also mean sprout length for sprouts >2mm. Tuber size effects were similar to those noted for sprout number, with larger tubers having longer sprouts. The only significant differences between treatments in length of the longest sprout was between units 1 and 2, and between small and large sized tubers in unit 5. Thus the dominant sprouts in each case tended to be of similar lengths, but the length of non-dominant sprouts vary significantly between units. The sprout length results are shown below.

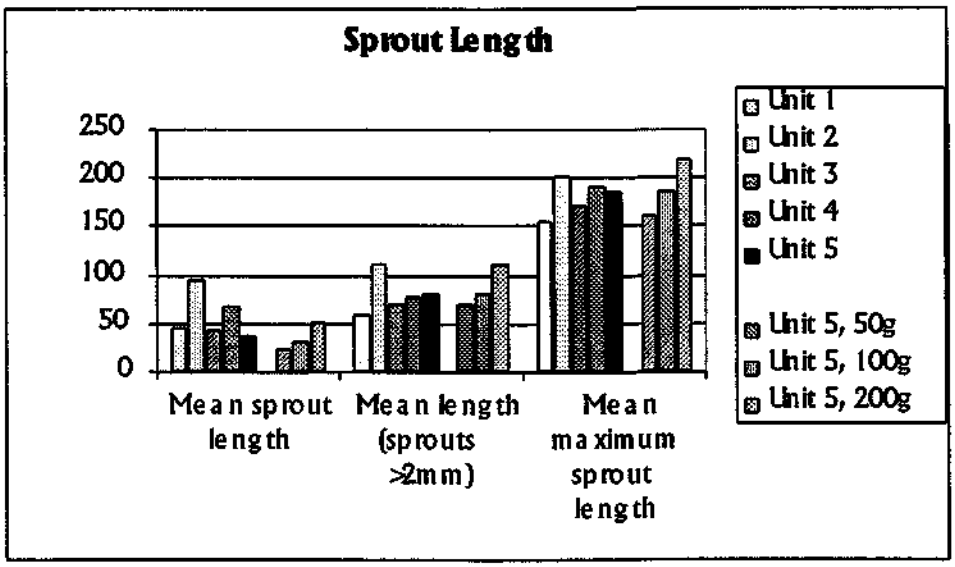

Figure 4 Sprout length in Russet Burbank seed lots (Units).

Sprout weight was more uniform between treatments than the other measured parameters. The major difference in sprout weight was between unit 1 and the other units in mean weight of sprouts >2mm in length. Unit 2 had a similar mean sprout weight to units 3, 4 and 5, suggesting that the sprouts produced by unit 2 tubers were thinner as they were significantly longer than sprouts in the other treatments. This is consistent with observed sprouting responses for physiologically old tubers, where longer and thinner sprouts tend to be produced by older tubers. These results suggest that differences in physiological condition exist between the treatments even though they are of identical physiological age according to measurements using the day degree model.

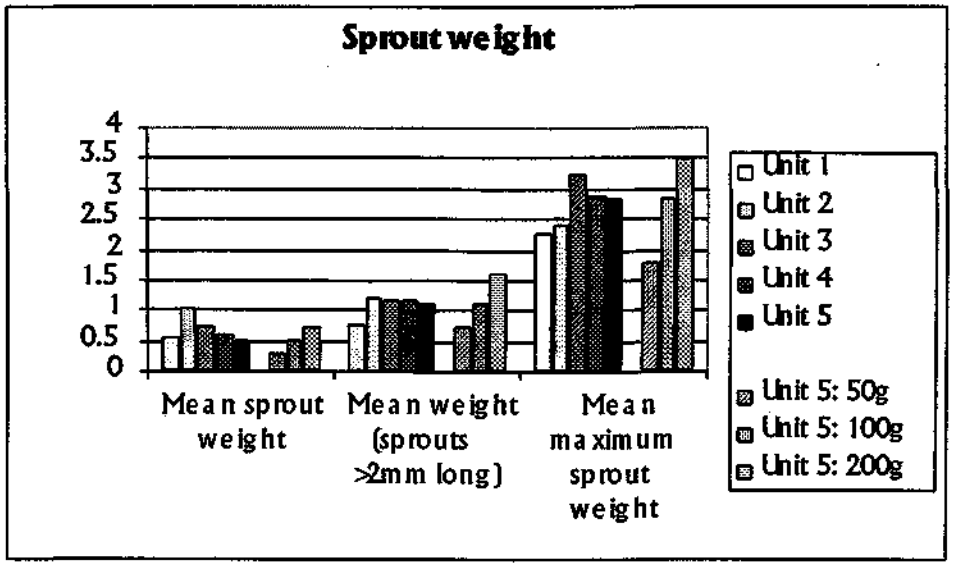

Figure 5 Sprout weight in Russet Burbank seed lots (Units).

The position of the dominant sprout, measured by denoting the apical sprout as 1, varied from position 3 in unit 2 to position 7 in unit 5. Tuber size had a significant influence on position of the dominant sprout, with the sprout being located further from the apical position with increasing tuber size. There was no significant

difference in location of the dominant sprout when calculated either on the basis of sprout length or sprout weight. The data on sprout position is shown below.

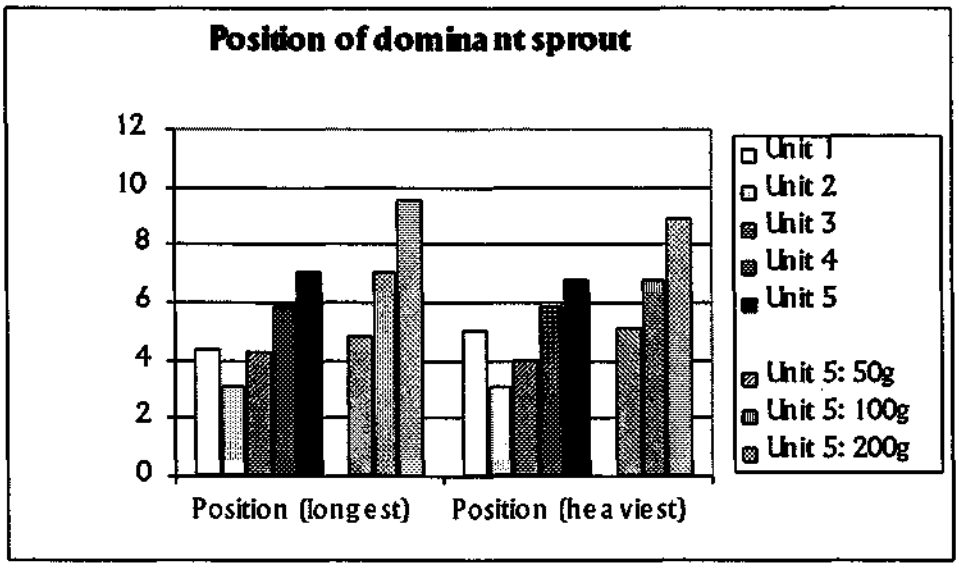

Figure 6 Position of the longest sprout in Russet Burbank seed lots (Units).

The data recorded in this trial demonstrate the effect of tuber size on the sprouting pattern obtained from seed potatoes, and also suggest that the five clones of Russet Burbank grown in Tasmania may have small differences in sprouting pattern. All clones were grown at the one location under identical crop management practices, and the differences in sprouting pattern recorded in this trial must therefore represent a genetic difference or seed lot variability due to site factors (small differences in soil type or other field factors across the seed production location) or seed history (differences in management or handling of the seed in the previous generation). All treatments were of the same physiological age according to the accumulated day degree model, so clearly time and temperature in storage can only account for a portion of the variability in physiological age (sprouting pattern) between seed lots. Small differences in time to emergence were recorded in pot trials using these seed lots, confirming the results of the sprouting index test. No significant difference in stem number or tuber number from the plants was recorded, suggesting the differences in rate of physiological aging between Russet Burbank clones in Tasmania is unlikely to contribute to variability in seed performance in the field.

Effect of seed tuber production location

The environment in which seed crops are grown and the management practices used on the crops are factors that potentially may influence the rate of physiological aging after harvest. A trial was conducted in 1999/2000 to assess the effect of production location on physiological aging in seed tubers. Plant material was sourced from seven different production locations from North West, North East, Midlands and Southern Tasmania. A total of thirteen seed lots were collected from the seven locations. The approximate date of haulm senescence and the date of harvest of each seed lot was recorded. The time of haulm senescence varied from 03/03/2000 to 29/03/2000, while time of harvest varied from 30/03/2000 to 27/04/2000. Six of the seed lots were

obtained from a research trial conducted at Burnie, and differed in treatments imposed during growth of the crop.

Seed lot number	Production region	Date of haulm senescence	Date of tuber harvest
1	Ulverstone	12/03/00	14/04/00
2	Rianna	04/03/00	07/04/00
3	Oatlands	15/03/00	28/04/00
4	Rianna	03/03/00	30/03/00
5	Derwent	10/03/00	10/04/00
6	North East	29/03/00	27/04/00
7	Cressy	19/03/00	17/04/00
8	Burnie	11/03/00	17/04/00
9	Burnie	11/03/00	17/04/00
10	Burnie	11/03/00	17/04/00
11	Burnie	11/03/00	17/04/00
12	Burnie	11/03/00	17/04/00
13	Burnie	11/03/00	17/04/00

Table 3 Details of seed lots used in the trial

Approximately 8kg samples were collected for all seed lots. The tuber samples were collected at harvest, which was generally 3 – 4 weeks after haulm senescence. Tubers in the seed lots were graded according to weight and 50 healthy, spherical to ovoid shaped tubers within the weight range were selected from each seed lot. Of these 50 tubers, 20 were allocated for sprouting capacity assessment and the remaining 30 were used for morphological, anatomical and dormancy assessment. The tuber samples were labelled and stored at 4°C or 10°C until required. Two storage temperatures were chosen in order to test tubers at two physiological ages from each seed lot. Sprouting capacity was determined for each seed lot 20 weeks after the date of haulm senescence. 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.

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. No significant differences between seed lots in duration of dormancy were recorded.

The tuber sprouting capacity at 10°C (total sprout weight as a percentage of tuber weight) varied from 0.25 to 1.35 – in other words the most vigorous seed lots produced 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 were similar to those of tubers stored at 10°C, but as expected the tubers held at the higher temperature displayed higher sprouting capacity. The sprouting capacity data are displayed in the following graphs (insufficient tubers

were available for 10°C storage from seed lots 9 and 10, resulting in the missing data in the second figure).

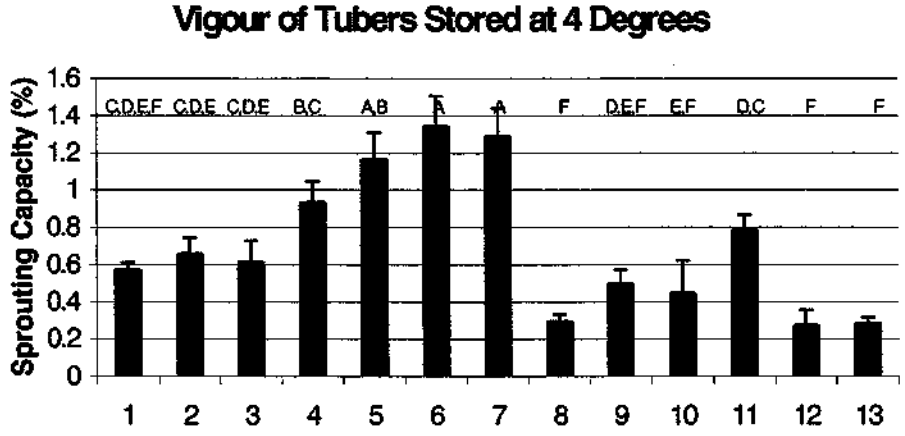

Figure 7 Sprouting capacity (sprout weight as a percentage of seed tuber weight)

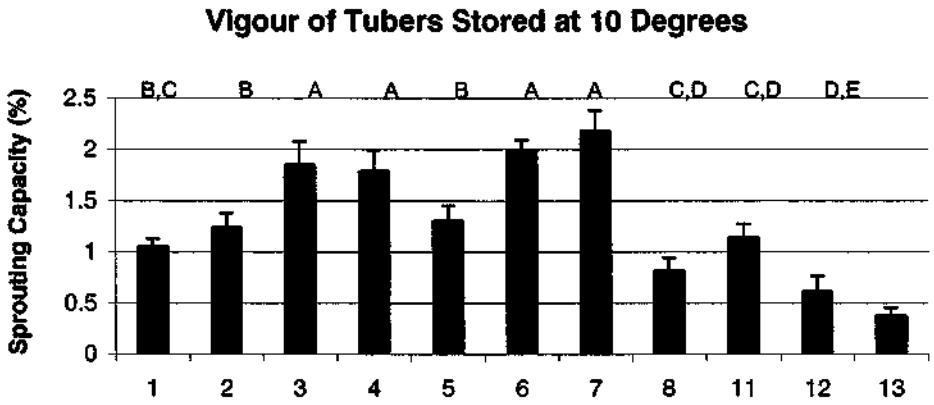

Figure 8 Sprouting capacity (sprout weight as a percentage of seed tuber weight)

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 (krasnozem). While the range of seed lots is limited, the data suggests that tubers from seed crops grown on sandy soils age faster than tubers produced in clay soils. Seed lots 8 to 13 originated from a trial site where the crop was planted late (end of December 1999) and forced to senesce early through withholding irrigation. This seed was apically dominant (producing one or few sprouts from the rose or apical end of the tuber), suggesting that it 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 left to die off naturally 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 killed early displayed the characteristic ageing cycle (dormancy, single sprout/apical dominance phase, multi-sprout stage, sprout branching stage, little tuber stage).

The results of this trial demonstrate that major differences in seed lot performance (sprout vigour and sprout number) may be due to seed crop production conditions. While further work remains to identify critical climatic and crop management factors, the results clearly identify seed production factors as contributors to physiological aging.

Field performance of different seed lots

Field trials were conducted in 2000/2001 to assess differences between seed lots in crop yield and tuber size distribution. Three Russet Burbank seed lots were selected for the trial; the seed lots were selected based on industry advice and were predicted to cover a range of physiological ages from the youngest seed planted commercially to physiologically old seed. The seed lots were planted at two locations and at two planting dates at one of the locations. The trials aimed to record the variability in crop performance that can be expected from using different commercially available seed lots.

Seed was supplied by industry partners and was stored under commercial cold store (4°C) conditions prior to use. The seed lots were denoted A (standard physiological age), B (physiologically old) and C (physiologically young). Seed was warmed to air temperature for two weeks then cut into approximately 50g sets and cured for five days before planting. The trial was hand planted at a density of 6.5 sets per square metre (190mm within row spacing) with three replicate plots per treatment. Four row plots of 6m length were used, with the middle five metres of the two central rows used as harvest plots and the remaining plants acting as buffers. The trials were planted at Forthside Vegetable Research Station (NW Tasmania, krasnozem soil) and at a private property near Cressy (Northern Midlands of Tasmania, sandy duplex soil). All three seed lots were planted at Forthside on 30 October 2000. Seed lot A was planted at Cressy on 1 November 2000 and seed lots A and C at Forthside on 22 November 2000. A basal fertiliser (1400 kg/ha 11:13:19 N:P:K at Forthside, 1234 kg/ha 9:12:17 at Cressy) was banded under the seed pieces at planting. Rows were mounded after crop emergence. All trials were harvested at commercial maturity. Plot yields and tuber size distributions were recorded at harvest. Stem emergence rates and stem numbers were recorded during crop development.

No significant differences in time of emergence were recorded between the seed lots. There were significant differences in stem number per seed piece between the three seed lots and between locations and planting dates (see figure below). Seed lot C, selected by industry personnel as being physiologically young, produced a significantly higher stem number at FVRS and at both planting date compared to the other seed lots. Seed lot B, considered by industry to be physiologically young, produced more stems than seed lot A (average aged seed lot for Tasmanian processing industry). Fewer stems per seed piece were recorded at the later planting date at FVRS compared with the earlier planting date. Significant differences in stem number were also recorded between the FVRS and Cressy sites despite the fact that planting dates were only 2 days apart. These results suggest that planting environment had a major impact on the sprouting response of seed tubers. The number of sprouts produced per seed piece in a crop can therefore not be predicted purely on the physiological age of the seed, but varies with both physiological age and planting

environment. The difference in stem number between the two planting dates at FVRS clearly demonstrate this point as seed planted at the second date would be expected to be physiologically older than at the first planting date, but displayed the sprouting habit of younger seed in producing fewer stems.

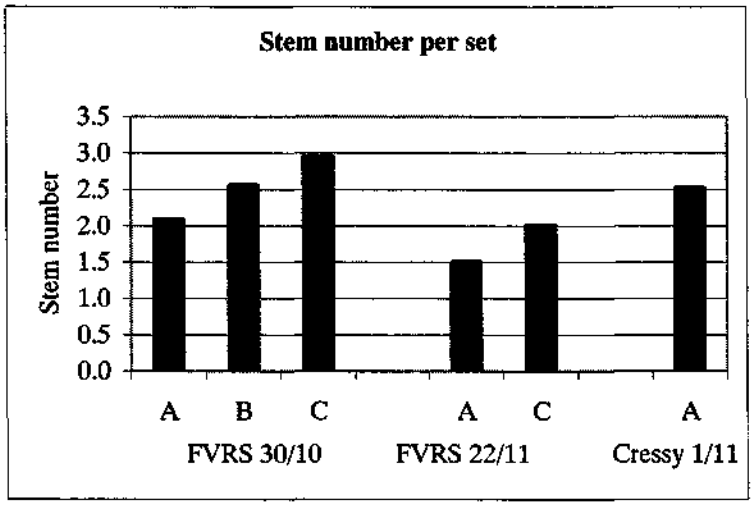

Figure 9 Stem number per plant for seed lots A ('standard' age), B ('old') and C ('young') planted at Forthside Vegetable Research Station (FVRS) on 30/10/00 and 22/11/00, and at Cressy on 1/11/00.

Significant differences between seed lots in both tuber number and yield were recorded. Seed lot C produced the most tubers and highest yields, while seed lot B performed very poorly. Rhizoctonia infection in seed lot B contributed to the poor performance of the crop. Severe waterlogging during harvest at the Cressy site resulted in high disease levels in seed lot C plots, so tuber number and yield data was not recorded. Seed lot A plots were harvested prior to the onset of rain and are therefore included in the figure below. There was a strong correlation between stem number and tuber number for the seed lot A and C data from FVRS and Cressy, with high tuber numbers being associated with high stem numbers. Treatment yields were 60.6 t/ha, 31.8 t/ha, and 64.63 t/ha for seed lots A, B and C (FVRS 30/10), 46.2 t/ha and 55.3 t/ha for seed lots A and C (FVRS 22/11) and 84.5 t/ha for seed lot A at Cressy. The relationship between stem number and yield was not as strong as that between stem number and tuber number, with site and planting date appearing to have a strong influence on yield. This finding is consistent with previous reports where yield is associated with length of growing season and photosynthetic activity of the crop, while tuber number is linked to stem number and conditions at tuber set.

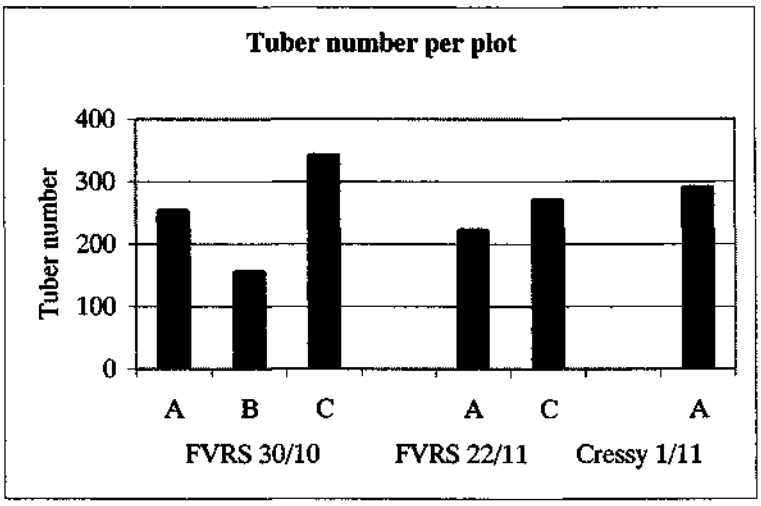

Figure 10 Tuber number per plot (10 m row length) for seed lots A ('standard' age), B ('old') and C ('young') planted at Forthside Vegetable Research Station (FVRS) on 30/10/00 and 22/11/00, and at Cressy on 1/11/00.

The difference in tuber number between seed lots was also reflected in the tuber size distributions. The graph below shows the tuber size distributions for the three seed lots planted on 30/10 at FVRS. Seed lot A had a greater proportion of tubers in the larger size grades (tubers with smallest diameter greater than 60mm) than seed lot C. The total number of tubers in the whole seed size classes (30-50mm and 50-60mm) was higher for seed lot C than for seed lot A. Tuber number in seed lot B was low and the distribution was quite variable, with a high proportion of small tubers and also a significant number of very large tubers.

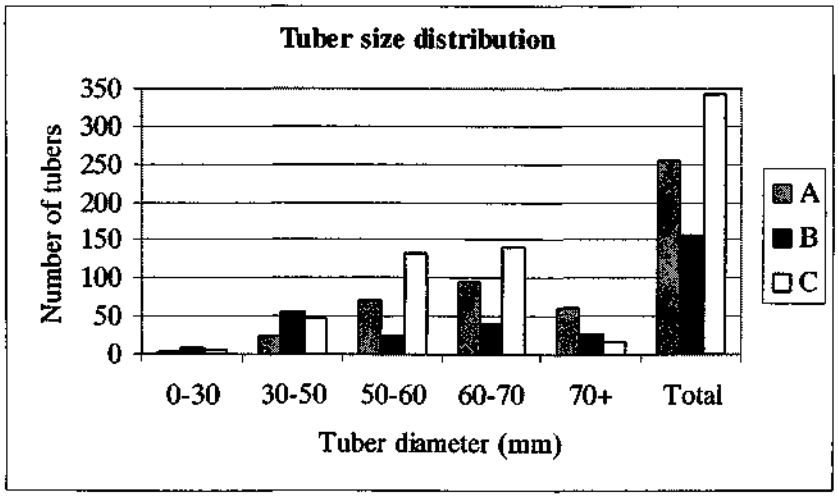

Figure 11 Tuber number in size classes per plot for seed lots A ('standard' age), B ('old') and C ('young') planted at Forthside Vegetable Research Station (FVRS) on 30/10/00.

The differences between seed lots in stem number, tuber number, yield and tuber size distribution highlight the importance of physiological age or seed tuber physiological quality as a determinant of potato crop performance. While disease status may partially explain the poor performance of seed lot B, the significant differences between seed lots A and C reflect the scale of variation in crop performance that is

due to differences in physiological condition of commercial seed lots. The results also demonstrate that there is an important interaction between the physiological condition of the tuber when planted and the environment in which the tuber is planted. The potential of the tuber to produce a given number of stems of certain vigour is associated with the physiological condition of the tuber, but the expression of that potential may be modified by planting environment. It is therefore likely that seed may behave as 'physiologically young' (low stem number, relatively high stem vigour) under some conditions but as 'physiologically old' under other conditions. The prediction of seed lot performance is therefore problematic; not only does the duration and temperature of storage influence the physiological condition of the tuber, but the conditions under which the tuber was produced and the conditions under which the tuber is planted also have major effects on crop performance.

Treatments to manipulate stem and tuber number

Introduction

The results presented in the earlier sections of this report clearly demonstrate the difficult in predicting performance of seed potato tubers. No useful markers or indicators of physiological age have been identified, and prediction based on production, storage and planting conditions is restricted by the limited information on the interactions between these factors. As further research is still required to enable valid assessment of seed lot physiological quality, development of strategies to manage stem number and tuber size distribution is an alternative method to improve seed potato production. Research in this project focussed principally on the pre-planting application of S-carvone, a reversible sprouting inhibitor, on stem number and tuber size distribution, but preliminary research was also conducted on a number of treatments applied at tuber initiation stage in the crop to increase tuber number and tuber set.

Preliminary investigation of effects of carvone

Carvone, the active ingredient in the potato sprout inhibitor formulation 'Talent®', has been shown to be an effective sprout suppressant that does not permanently inhibit the tuber from sprouting. While the formulation is currently not financially viable as an alternative to CIPC for sprout control, it does appear to have potential in the seed potato industry as a reversible sprout suppressant. Earlier trials investigating the efficacy of carvone as a sprout suppressant have indicated that treatment can result in the reduction in apical dominance in tubers (strong sprout development from the rose end of the potato in physiologically young tubers). The treatment may thus be used as a form of chemical desprouting, promoting multiple sprout development in physiologically young tubers. These tubers may develop into vigorous multi-stemmed plants with the potential to yield high numbers of small sized seed tubers. This effect would be particularly desirable for the production of whole seed. This trial was a preliminary investigation to assess the potential of carvone to complement or replace treatments such as manual desprouting, high density planting and physiologically aging seed.

The efficacies of carvone (Talent®) and DMN (1-4 Sight®), in regards to suppression of apical dominance and thereby maximising the yield of small, round seed, were trialed using 'Russet Burbank'. Commercial seed potatoes of varieties Russet Burbank and Shepody were kindly donated by Tasmanian potato processing companies. The seed had been stored at 4°C following harvest and was transferred to three temperature controlled shipping containers for sprout inhibitor treatments in early October. Carvone and DMN were applied with a 'swingfogger' once bud initials were evident at potato eyes. The tubers were treated on 30th November with 600 mls/tonne S-Carvone (commercial formulation 'Talent®', supplied through BV Luxan, Netherlands), 20 mls/tonne 1-4-DMN ('1-4 Sight®') or left untreated as controls. Sprout suppressant chemicals were applied directly into the refrigerated containers with vents closed, but with air continuing to circulate. Control seed was

treated in an identical manner, although no chemical was applied. The containers were opened back to air circulation after 24 hrs. The seed was cut on the 13th December and planted on the 22nd of December following 10 days curing at ambient temperatures.

Seed was cut into approximately 50g pieces according to standard industry practice. Small seed tubers were cut for planting as whole seed. Seed from the three treatments were planted at the TAFE farm near Burnie, North-western Tasmania using 36 m beds with a 19 cm seed spacing in split plot double rows, replicated over four beds. Seed pieces or whole seed tubers were planted at a standard commercial planting density of 6.5 propagules per m^2. 'Russet Burbank' seed were planted as whole seed and as cut piece treatments (both with approximate weight of 50-70 g). 'Shepody' treatments were planted as cut seed only. The trial was constructed in a split plot design replicated four times over four double rows. Each replicate of the six cut seed treatments consisted of 5 m of double row with buffer plants between treatments. The three whole seed treatments were planted in 2 m replicates.

Three weeks after planting the number of shoots produced by each of ten seed pieces from each replicated block was determined, as was the height of the highest haulm – taken as an indicator of early growth rate and emergence. In order to maximise yields of small round seed, plants were dehaulmed after 3 months growth and a sub-sample of plants from each treatment was hand harvested, weighed and counted. Irrigation was withdrawn from the crop 20 days prior to haulm removal.

Examination of the tubers two weeks after treatment revealed that carvone had removed all developing sprouts and appeared to have stimulated new sprout development from all eyes on the tubers, with multiple sprouts evident in most eyes. Suppression of growth was evident following DMN treatment but no difference in sprout number or position was observed between control and DMN treated tubers. Tuber samples will be taken for assessment of physiological condition (discussed earlier in the report) on the day of planting.

Despite the sprout suppressing properties of S-carvone and DMN, early establishment of plants did not appear to be affected by these treatments. No significant effect was found in terms of the number of missing plants, although more misses occurred in cut-seed treatments. No differences were found between 'Russet Burbank' treatments in terms of emergence rate (expressed as the mean height of the highest haulm two weeks following emergence of 50% of seed). However, S-carvone did slightly delay emergence of 'Shepody' seed pieces. 'Russet Burbank' cut and uncut seed exhibited increased primary haulm numbers as a result of S-carvone treatments, with larger increases in round seed. No such increase was observed following exposure of seed to DMN. Neither treatment was able to increase primary haulm numbers of 'Shepody' plants. A summary of the results relating to plant establishment are given in the table below.

Seed Type	Treatment	Misses (%)	Emergence Rate	Mean Primary Haulm No.
'Russet' round seed	Control	0	18.3 ± 0.8	2.56 ± 0.20
	S-Carvone	1	18.3 ± 0.7	3.00 ± 0.24
	DMN	0	16.6 ± 0.9	2.13 ± 0.15
'Russet' cut seed	Control	0	13.1 ± 0.7	2.45 ± 0.16
	S-Carvone	4	14.6 ± 0.8	2.73 ± 0.15
	DMN	2	12.3 ± 0.6	2.55 ± 0.16
'Shepody' cut seed	Control	5	14.1 ± 0.6	2.28 ± 0.20
	S-Carvone	1	10.4 ± 0.5	2.25 ± 0.16
	DMN	4	12.2 ± 0.5	2.23 ± 0.17

Table 4 Summary of establishment data. Emergence rate is expressed as the mean height of the highest haulm two weeks following emergence of 50% of seed. Emergence rate and mean primary haulm numbers are given ± standard error.

Plots were harvested in early March. The short growing season produced a maximum proportion of tubers in the target size range for whole seed (30-60 mm diameter at narrowest point). Neither S-carvone nor DMN produced satisfactory results when applied to 'Shepody'. Both treatments produced a decline in total yield and thereby reduced yields in the 30-60 mm size grade. This result may have been due to the already aged state of the seed used. This cultivar is normally planted somewhat earlier, and the seed appeared to have been grown in a sandy soil (anecdotal evidence suggests that this type of soil may result in older seed). The results of S-carvone treatment to 'Russet Burbank' appeared promising. Slight yield increases were obtained when applied to whole seed. However, substantial increases in both total yield and whole seed tuber yields were obtained from cut seed. The result of DMN application on 'Russet Burbank' seed was also satisfactory for whole seed, however, yield increases for cut-seed were well below that achieved using S-carvone. Under the conditions which this trial was conducted 'Russet Burbank' whole seed performed considerably better than cut seed.

Seed Type	Treatment	Total Yield (t/ha)	30-60 mm Yield (t/ha)
'Russet' round seed	Control	34.8	32.0
	S-Carvone	36.1	33.6
	DMN	36.8	33.9
'Russet' cut seed	Control	28.7	26.4
	S-Carvone	36.3	33.8
	DMN	31.1	28.7
'Shepody' cut seed	Control	41.4	37.4
	S-Carvone	33.7	31.4
	DMN	27.2	25.4

Table 5 Crop yield data.

While treatment of the Russet Burbank seed with carvone increased the yield of round seed in this trial, the efficacy of the treatment required further testing across a range of

seed lots and planting environments. In addition, the beneficial effect of carvone in this trial may be a result of the short growing season, with the treatment slightly retarding crop development and therefore resulting in a more uniform tuber size at harvest. It is possible that growth of the crop over a longer season would result in rapid development of a proportion of the tubers in the crop, leading to the broader size range recorded in the control plants. Investigation of changes in tuber size distribution in carvone treated and control plants is therefore warranted to address this point.

Efficacy of carvone

Initial field trials examining the effects of the reversible sprout suppressants S-carvone and 1,4-dimethylnaphthalene (DMN) on tuber number and size distribution were completed in the 1999/2000 season. 'Russet Burbank' cut and uncut seed exhibited increased primary haulm numbers as a result of S-carvone treatments, with significant increases in round seed yield. No such increase was observed following exposure of seed to DMN. More extensive trialing of the S-carvone treatment was therefore undertaken in the 2000/2001 season. Results from controlled environment and laboratory assessments of physiological ageing were also taken into consideration when planning the field trials. The field trials included three seed potato seedlots of varying physiological age, with or without S-carvone application, planted at two different dates and at two different locations. In addition, S-carvone treatment was applied to three fresh market and one crisping potato cultivar. The effect of carvone treatment on tuber size distribution over the later stages of crop development was investigated in the trial.

The first component of the trial was designed to test the effects of carvone application applied to three Russet Burbank seed lots of varying physiological age, one crisping cultivar (Atlantic) and three fresh market cultivars (Goldstar, Royal Blue, Victoria). Seed was supplied by industry partners and was stored under commercial cold store (4°C) conditions prior to use. The Russet Burbank seed lots were denoted A (standard physiological age), B (physiologically old) and C (physiologically young). The remaining seed lots were denoted D (Atlantic), E (Goldstar), F (Victoria) and G (Royal Blue). Control and carvone treatments plants were recorded with a numeric suffix, so that A1 represented control plants of seed lot A and A2 represented carvone treated plants of seed lot A.

The seed was stored at 4°C following harvest and transferred to two temperature controlled shipping containers for sprout inhibitor treatments in early September. Carvone was applied with a 'swingfogger' once bud initials were evident at potato eyes. The tubers were treated with 600 mls/tonne S-Carvone (commercial formulation 'Talent®', supplied through BV Luxan, Netherlands) or left untreated as controls. Carvone was applied directly into the refrigerated containers with vents closed, but with air continuing to circulate. Control seed was treated in an identical manner, although no chemical was applied. The containers were opened back to air circulation after 24 hrs.

The trial was hand planted at a density of 6.5 sets per square metre (190mm within row spacing) with three replicate plots per treatment. Four row plots of 6m length

were used, with the middle five metres of the two central rows used as harvest plots and the remaining plants acting as buffers. The trials were planted at Forthside Vegetable Research Station (NW Tasmania, krasnozem soil) and at a private property near Cressy (Northern Midlands of Tasmania, sandy duplex soil). The three Russet Burbank seed lots and Atlantic seed lot were planted at Forthside on 30 October 2000. Seed lots A, E, F and G were planted at Cressy on 1 November 2000. Seed lots A and C were planted at Forthside on 22 November 2000. A basal fertiliser (1400 kg/ha 11:13:19 N:P:K at Forthside, 1234 kg/ha 9:12:17 at Cressy) was predrilled and was present as a band under the seed pieces at planting. Rows were mounded after crop emergence. All trials were harvested at commercial maturity. Plot yields and tuber size distributions were recorded at harvest. Stem emergence rates and stem numbers were recorded during crop development.

There were no significant differences in time of emergence and percentage emergence between carvone treated and untreated plants at the first planting date at FVRS. No misses were detected in the trial site, resulting in 100% emergence one month after sowing. The emergence of carvone treated plants appeared to be delayed slightly in comparison to untreated control plants, but this trend was not statistically significant. A higher level of replication would be required to detect any effect of the carvone treatment on emergence time given the small magnitude of the effect if it is present. Significant differences in percentage emergence existed between seed lots, with seed lot D (Atlantic) and seed lot C (Russet Burbank, physiologically 'young') having a higher perecentage emergence than seed lots A and B 18 days after planting.

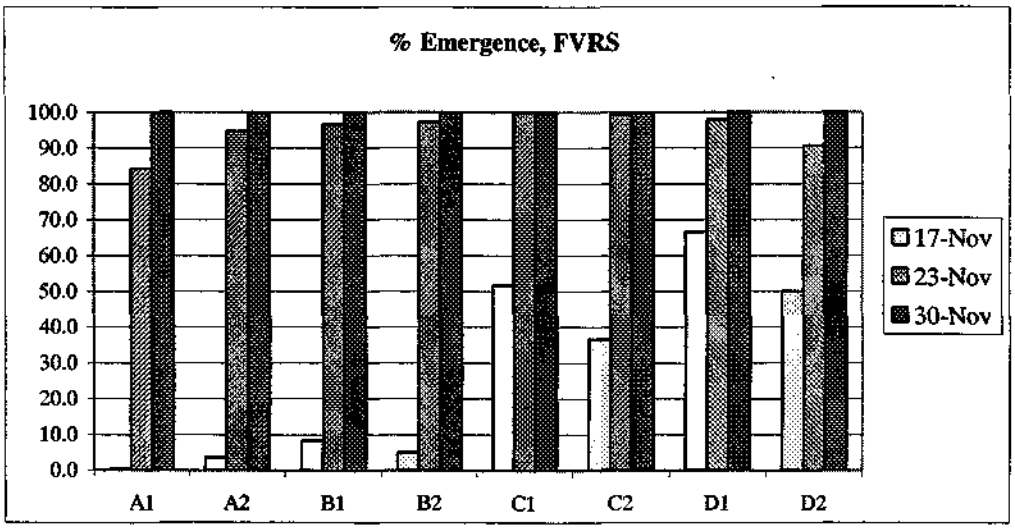

Figure 12 Plant emergence of seed lots at FVRS, planted 30/10/00.

Carvone application had a significant, detrimental effect on emergence of the three fresh market cultivars included in the trial at Cressy. In all cases the percentage emergence was significantly reduced and the time to emergence was increased. The effect was most obvious in seed lot G (Royal Blue) where on 40% of carvone treated seed produced shoots compared with 100% of untreated seed. The fresh market cultivars were in a more advanced stage of sprouting (sprouts greater than 1cm long on most tubers) prior to carvone treatment, so it is likely that removal of the developing sprouts slowed emergence relative to the controls. If axillary sprouts were in the eyes of treated tubers were absent or few in number then a reduced emergence

percentage would be expected. The number of sprout initials present in the eyes of cultivars must by considered prior to carvone application as the treatment may eliminate potential sprouts and thus prevent plant development. Based on the emergence results in this trial, it is recommended that carvone treatment of physiologically old tubers or tubers with advanced sprout development not be undertaken, particularly in cultivars with few sprout initials in each eye. Further research is required to refine the optimum tuber age and stage of development for carvone application in seed potatoes.

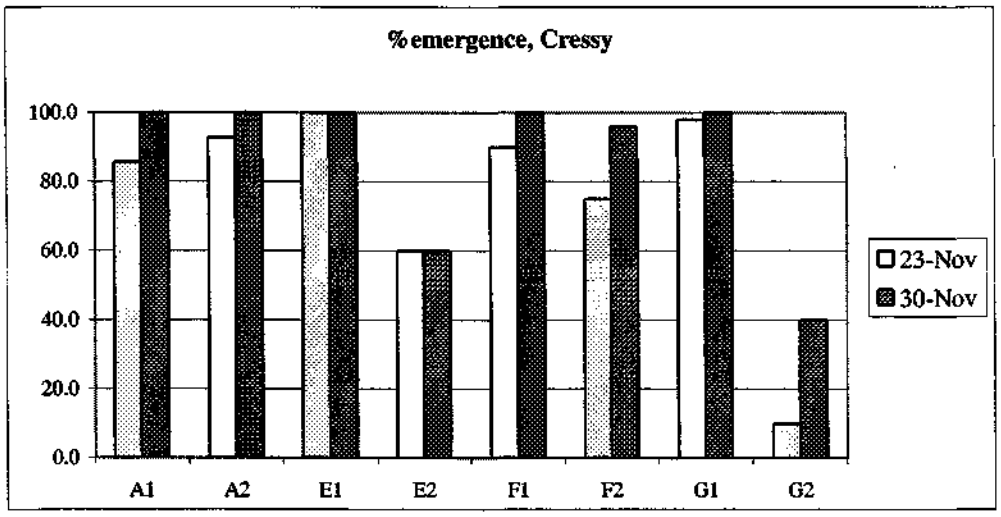

Figure 13 Plant emergence of seed lots at Cressy, planted 1/11/00.

An assessment of plant vigour was undertaken at the FVRS site 31 days after planting of the trial. Stem number and average stem height were recorded for all treatments. The number of stems produced in the carvone treated plants was consistently higher than control plants across all seed lots. The increase in stem number was, however, quite small, averaging approximately one quarter of a stem higher in treated than control plants. There was a corresponding decrease in stem height in carvone treated plants in comparison to control plants in all except seed lot A. Significantly higher stem heights in seed lots C and D compared to A and B may reflect the earlier emergence of these seed lots.

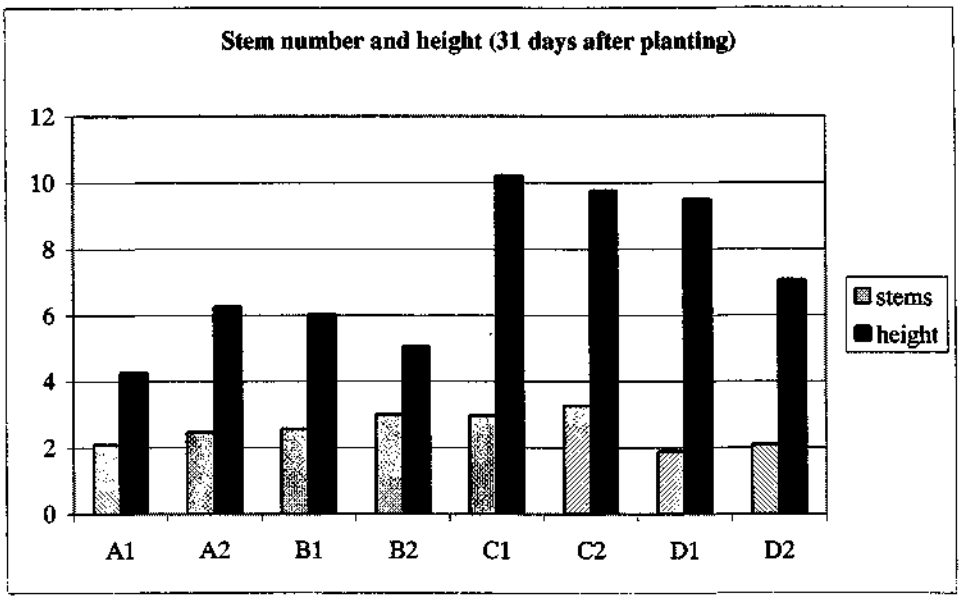

Figure 14 Plant vigour of control (1) and carvone treated (2) seed lots of Russet Burbank (A,B,C) and Atlantic (D).

Carvone application resulted in a significant increase in stem number in 6 of the treatments, and resulted in a higher number of stems than control plants in all treatments. The increase in stem numbers was small, in the order of 0.25 to 0.5 stems per plant for most treatments. This increase would correspond to an extra 1.6 to 3.25 stems per square metre at the planting density used in the trial.

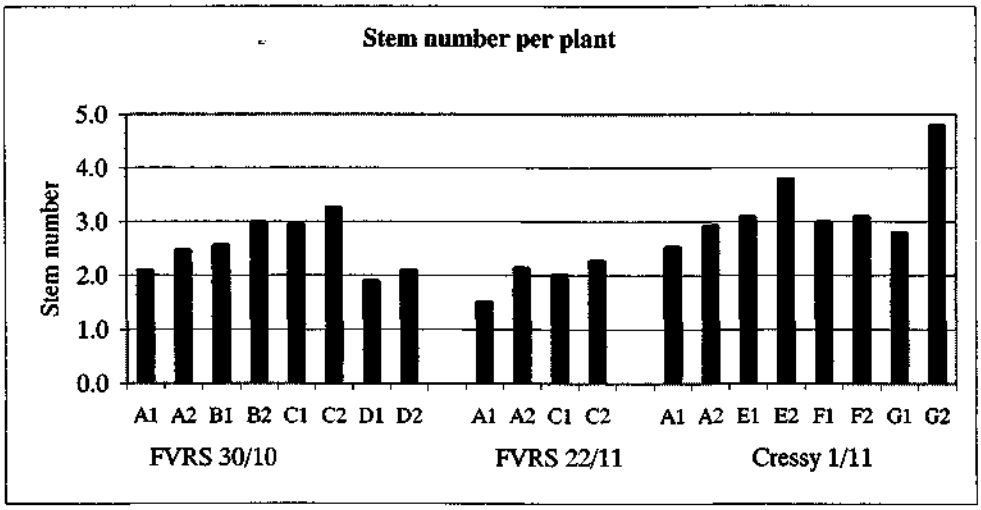

Figure 15 Stem number of control (1) and carvone treated (2) seed lots of Russet Burbank (A,B,C), Atlantic (D), (Goldstar (E), Victoria (F) and Royal Blue (G). Trials were planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00, and at Cressy on 1/11/'00.

The number of tubers produced per plot was higher in carvone than control treated plants in 5 of the 8 harvested treatment comparisons. A number of plots at the Cressy site were not able to be harvested due to waterlogging during harvest and resultant development of tuber rots.

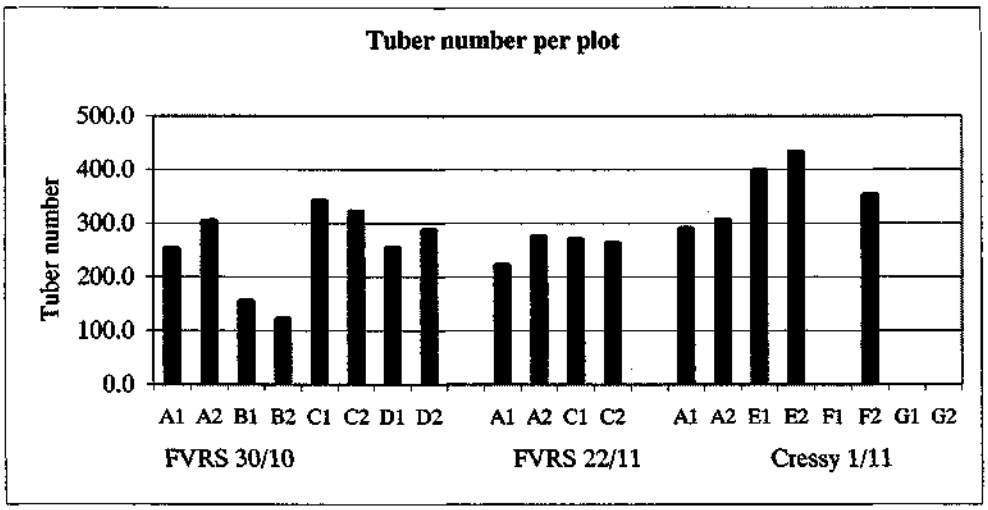

Figure 16 Tuber number per plot (2 rows x 5m) of control (1) and carvone treated (2) seed lots of Russet Burbank (A,B,C), Atlantic (D), (Goldstar (E), Victoria (F) and Royal Blue (G). Trials were planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00, and at Cressy on 1/11/'00.

The differences in total tuber yield between carvone treated and untreated were not statistically significant for the majority of seed lots across planting dates and locations. A significant decrease in yield was recorded for seed lot B at FVRS and for seed lot A at Cressy. Significantly higher yields were recorded in carvone treated plants of seed lot D at FVRS and seed lot A at FVRS. The variability in yield data suggest that carvone is unlikely to have a major impact on the overall crop yield.

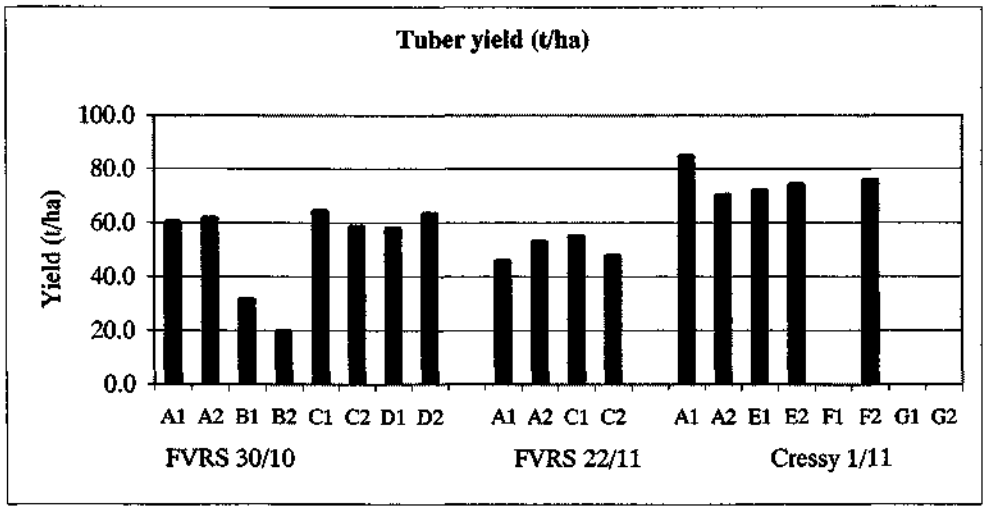

Figure 17 Tuber yield of control (1) and carvone treated (2) seed lots of Russet Burbank (A,B,C), Atlantic (D), (Goldstar (E), Victoria (F) and Royal Blue (G). Trials were planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00, and at Cressy on 1/11/'00.

A positive relationship between stem number and tuber number was recorded in the Russet Burbank seed lot A treatment but not seed lot C. Increased stem numbers per plot resulted in increased tuber numbers in seed lot A and for seed lot C across planting dates but not between carvone treated and control, as can be seen in figures 18 and 19.

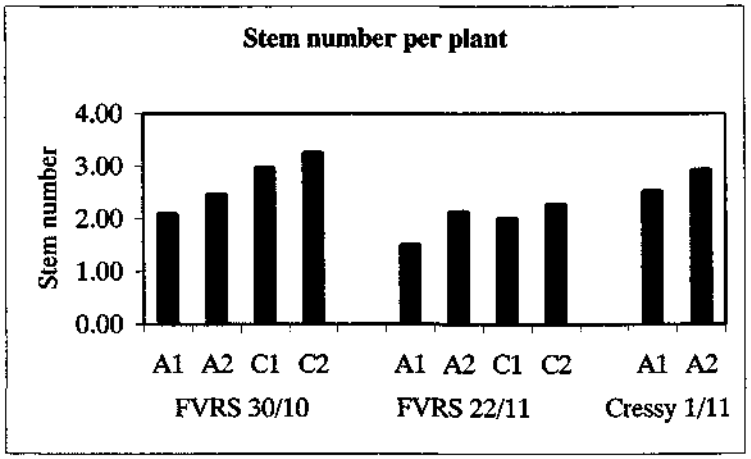

Figure 18 Stem number per plant of control (1) and carvone treated (2) seed lots of Russet Burbank (A, C), planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00, and at Cressy on 1/11/'00.

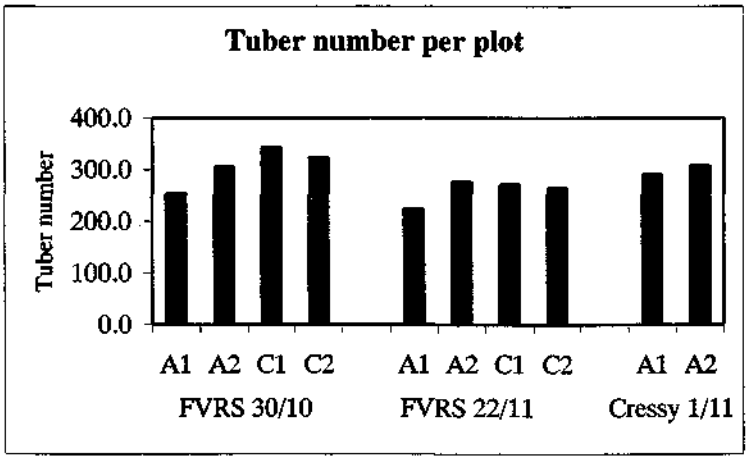

Figure 19 Tuber number per plot (2 rows x 5m) of control (1) and carvone treated (2) seed lots of Russet Burbank (A, C), planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00, and at Cressy on 1/11/'00.

The effect of carvone treatment on tuber size distribution reflects the combination of effects on tuber number and overall yield. When carvone increased tuber number, the proportion of tubers in the smaller diameter size classes was increased. The yield of tubers in the round seed classes (30-50 mm and 50-60 mm diameter) was increased in most carvone treated seed lots. The effect was, however, much smaller than the differences between seed lots. The physiological status of seed lots at planting has a much greater potential to influence tuber size distribution than the carvone treatment applied in this study.

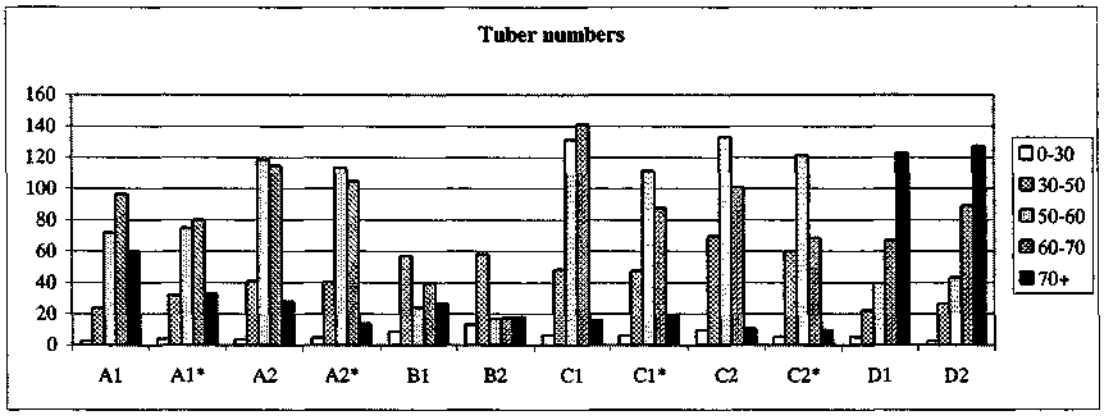

Figure 20 Tuber size distribution of control (1) and carvone treated (2) seed lots of Russet Burbank (A, B, C) and Atlantic (D), planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00 (*).

The differences between seed lots and between carvone treated and untreated plants in total tuber number and tuber number in the 30-60 mm diameter size class is shown in Figure 21. The corresponds tuber yield figures are shown graphically in Figure 22.

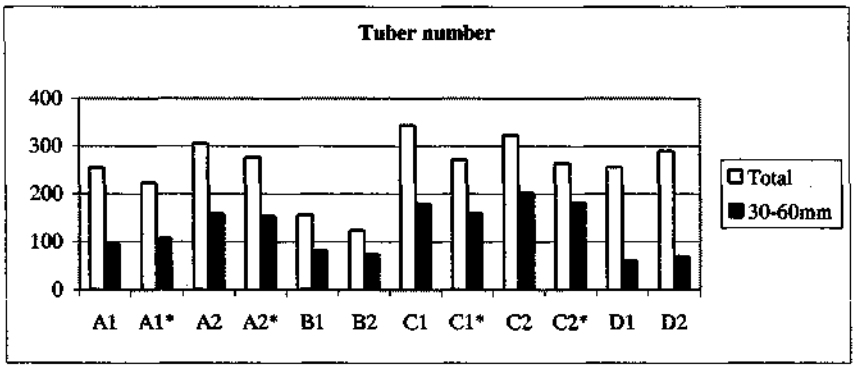

Figure 21 Tuber number per plot of control (1) and carvone treated (2) seed lots of Russet Burbank (A, B, C) and Atlantic (D), planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00 (*).

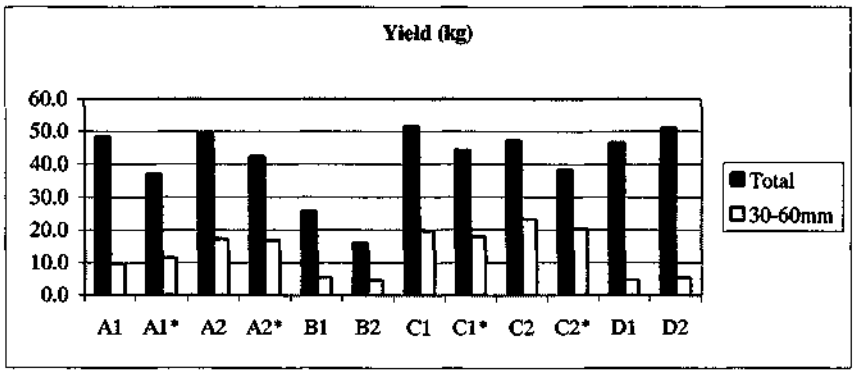

Figure 22 Tuber yield per plot of control (1) and carvone treated (2) seed lots of Russet Burbank (A, B, C) and Atlantic (D), planted at Forthside Vegetable Research Station (FVRS) on 30/10/'00 and 22/11/'00 (*).

While carvone has significantly increased round seed number in seed lots A and C, the differences between seed lots is much greater than the difference due to carvone. The effect of carvone was to increase tuber number in the round seed class, but the effect

varied between seed lots. The lack of predictability in response to carvone application severely limits the potential commercial application of the treatment.

The second component of the 2000/2001 field trial was designed to enable measurement of changes in tuber size distribution in carvone treated and control plants during crop development. Tubers of seed lot A were used in this trial and were treated as described above. The trial was planted at FVRS on 30 October 2000 and consisted of four treatments each replicated three times. The treatments were control plants (no carvone application) planted at low density (6.5 plants per square metre, 190 mm within row spacing) and high density (12 plants per square metre, 102.5 mm within row spacing), and carvone treated plants at low and high density.

Plants were harvested on 23/1/'01 (H1), 12/2/'01 (H2), 26/2/'01 (H3) and 14/3/'01 (H4). The final harvest date corresponded to standard harvest time for the crop and was approximately 10 days after haulm senescence. Average tuber weight increased over the four harvest dates for control and carvone treated plants at low density, but did not vary between harvest dates 2, 3 and 4 for the high density treatments. Carvone treated plants produced higher numbers of tubers than control plants. The higher number of plants in the high density treatments resulted in higher tuber numbers per plot than for the low density plantings.

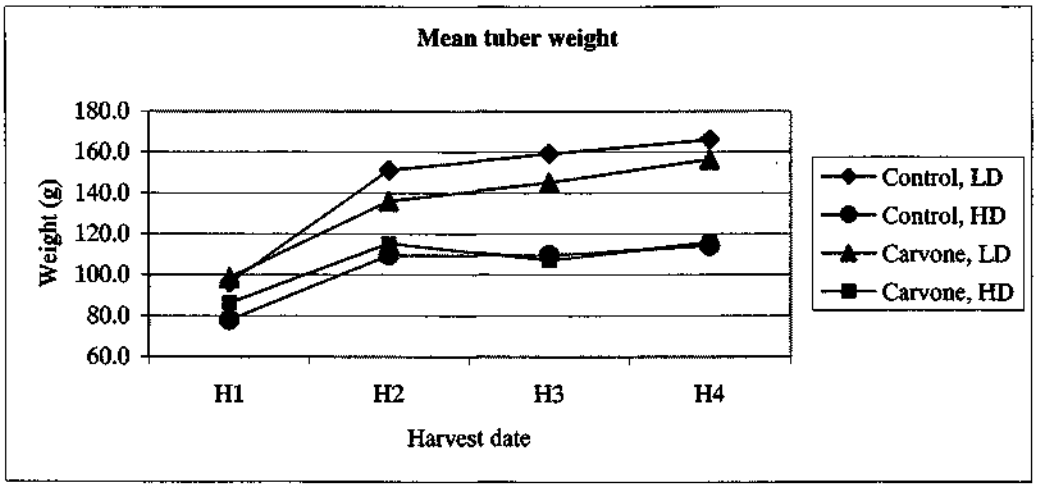

Figure 23 Mean tuber weight

Mean tuber diameter displayed a similar trend to tuber weight, but with increased over harvest date occurring at both planting densities. Carvone treated plants produced significantly lower mean tuber diameters than control plants over all harvest dates in the low density plantings and in all but the final harvest date at high density planting.

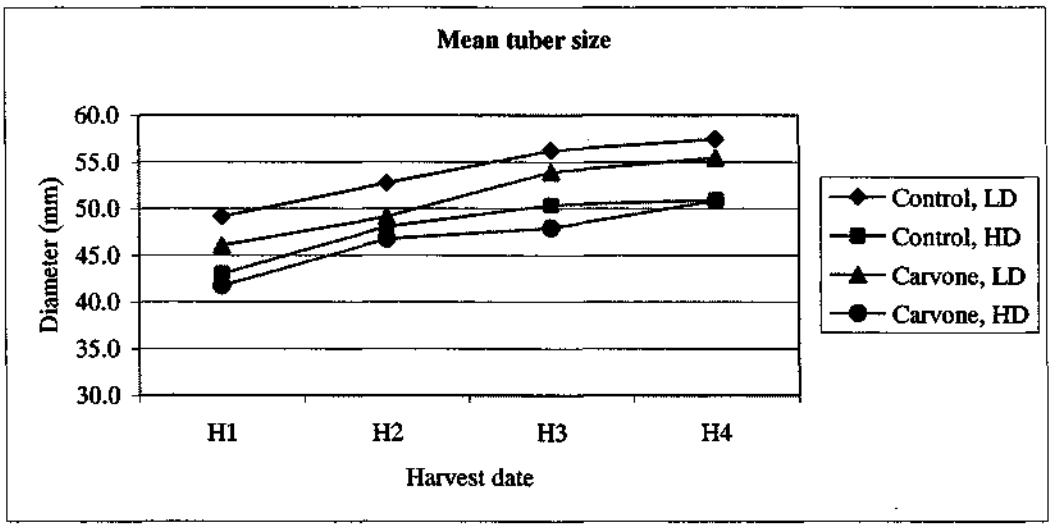

Figure 24 Sprouting capacity (sprout weight as a percentage of seed tuber weight)

The conclusion drawn from the time of harvest trial was that the effect of carvone application on tuber size distribution persists through the duration of crop development. Analysis of variability around mean tuber weight and diameter indicated that carvone application produced a higher degree of tuber size uniformity (a higher proportion of tubers in the mid size range) than untreated plants, where a small proportion of very large tubers skewed the size distribution.

The final component of the trial at FVRS was a preliminary examination of the effects of three treatments applied at the tuber initiation stage of crop development. Carvone treated and untreated seed lot A cut seed pieces were planted at FVRS on 30 October as described above. The trial area consisted of four replicate plots of carvone treated and untreated plants. The three treatments applied at tuber initiation (13 December 2000) were physical pinching out of shoot tips, application of the growth retardant paclobutrazol ('Cultar', 500 mg/l ai) and application of a copper based fungicide ('Cuprox', 10g/l). These treatments were selected based on their potential to reduce shoot growth rate and therefore potentially allow partitioning of a greater proportion of resources below ground to promote tuber initiation and tuber set. The paclobutrazol application was repeated in a commercial seed potato crop near Scottsdale in North East Tasmania. Three replicate 3 metre double row plots were treated with Cultar or left as untreated controls on 15 December 2000. Tuber number, yield and size distribution were recorded at harvest.

Application of the growth retardant Cultar or pinching out of shoot tips at the time of tuber initiation increased the number of tubers harvested per plant. The increase in tuber number resulting from Cultar application was in the order of 20% at both trial locations. Application of copper based fungicide did not improved tuber number. The application rate did not produce any detectable decrease in shoot growth rate and it was concluded that the rate used was too low to induce the mild phytotoxic effect desired.

	Control	Cultar (not treated with carvone)	Pinched	Copper	Control	Cultar (Carvone treated)	Copper
Tuber number							
0-30	0	0	5	13	2	0	3
30-50	21	27	30	65	42	33	30
50-60	54	82	62	99	86	111	118
60-70	114	121	116	59	101	123	93
70+	54	52	55	2	19	27	17
Total	243	282	268	238	250	294	261
Tuber Yield (kg per 5 m double row)							
0-30	0.0	0.0	0.0	0.1	0.0	0.0	0.0
30-50	1.1	1.6	1.8	4.4	2.1	1.9	2.1
50-60	5.9	9.4	7.4	15.0	10.5	14.4	15.7
60-70	20.6	23.2	21.7	13.1	21.7	24.5	20.3
70+	17.2	16.7	18.9	0.6	6.3	8.0	5.5
Total	44.7	50.8	49.8	33.2	40.5	48.7	43.6

Table 5 Forthside trial

	Tuber number (2m double rows)		Yield (kg per 2 m double row)	
	Cultar	Control	Cultar	Control
0-30	15.7	18.3	0.14	0.10
30-50	116.7	83.7	5.83	4.52
50-60	115.3	77.7	12.97	8.58
60-70	29.3	36.3	5.38	6.37
70+	0.7	2.0	0.18	0.55
Total	277.7	218.0	24.50	20.12

Table 6 Scottsdale trial

Manipulation of tuber size distribution during crop growth appears to be feasible using growth retarding treatments at the time of tuber initiation. Cultar appears promising as a crop growth regulator and further research into application rates and economic feasibility is warranted. The application rate used in this study may have been higher than required as retardation of shoot growth persisted over the remaining period of crop development. If a significant increase in tuber number can be obtained at a lower application rate then the treatment is may be commercially feasible. Further investigation of other treatments designed to slow shoot growth at the critical stage of tuber initiation and tuber set may yield more cost effective strategies for improving yield of round seed.

Summary

Management of seed potato physiological age is a complex issue. The level of knowledge of physiological age and appreciation of the importance of tuber physiological condition or quality on crop performance has been low in Australia. One significant outcome of this project has been an increased awareness of seed physiological condition as an important issue within the seed industry. The project has identified crop growing conditions and the environment in which the seed tuber is planted as important determinants of seed performance. Recognition of these two factors is critical to the industry in understanding variability in seed performance and in differentiation of seed based on likely performance attributes. Much still remains to be learnt about seed physiological age and seed performance, but at the least this project has identified a number of areas worthy of concentrated investigation.

The project was not successful in identifying useful markers of p age. Of the markers examined, sprouting capacity (number and weight of sprouts produced under controlled environment conditions) could be used to distinguish between seed lots with big differences in physiological condition, but was not accurate in predicting sprout number or vigour in field trials with seed lots of similar physiological condition. The weakness in use of all the physiological markers was the strong influence of seed planting environment on sprouting behaviour. Identical seed lots planted under two different environments may display different sprouting behaviour. For this reason, markers of physiological age are not likely to be of much benefit to industry until more is known about the interactions between seed physiological condition and planting environment in determining seed performance during crop establishment.

Seed crop production conditions were identified as a significant contributor to seed performance. The conditions under which a seed crop is grown will influence the sprouting behaviour (number and position of sprouts likely to develop after different periods of storage) and the vigour of the seed lot. While only preliminary observations were made in the project on the types of conditions and management practices likely to influence seed physiological quality, the potential to improve the quality of Australian seed potatoes through manipulation of physiological quality during seed production is significant and warrants further investigation. While it is unlikely that sprouting behaviour and vigour will be predictable based on records of crop growth conditions, avoidance of conditions likely to decrease vigour of seed lots will improve performance under most growing conditions.

One aspect of seed crop management that requires further investigation is the effect of haulm killing versus natural senescence on seed physiological condition. In this project it was noted that seed produced from crops left to die off naturally 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 killed early displayed the characteristic ageing cycle (dormancy, single sprout/apical dominance phase, multi-sprout stage, sprout branching stage, little tuber stage). The original research on physiological ageing, done in Europe where seed crops are killed off early, therefore needs to be carefully interpreted in Australia given the range of climatic conditions under which crops are grown and the range of crop management

practices used. More attention may need to be paid to matching seed physiological condition (strongly influenced by seed crop growing conditions) to likely planting conditions instead of concentrating on management of ageing in storage.

Several treatments to manage tuber numbers in seed crops were evaluated in the project. Carvone appeared promising in early trials but the efficacy of the treatment varied significantly between seed lots. There appeared to be a interaction between seed physiological condition and efficacy of carvone treatment. Physiologically old seed, or seed with well developed sprouts or low sprout number per eye, was not suitable for carvone application. The effect of carvone was generally to slightly increase stem number and therefore tuber number, but the size of the increase varied between seed lots. The treatment is likely to be cost effective in some seed lots and not others, and as it is not possible to predict which seed lots will be responsive to the application the treatment is of limited commercial applicability. Further work could be conducted on multiple carvone applications during storage to attempt to increase stem number further than is possible with a single application.

Application of the growth regulator cultar was the most promising treatment for increasing tuber number in seed crops. A single application at time of tuber initiation resulted in a significant increase in trials at two locations and in plots of different plant densities. Further work is required to develop recommendations for rates and timing of application in a wider range of potato cultivars and production environments.

At this stage the best strategy available to users of seed potatoes to manage seed physiological age is to identify a reliable seed supplier whose seed performs well under your own growing conditions and stick with that supplier. It is also worth considering that there are likely to be large differences in performance (vigour and sprout number) between seed lots, so trialing seed from a number of sources (if possible stored under identical conditions) may be a useful strategy to identify the best supplier.

CONFERENCE ABSTRACTS AND PAPERS

During the course of this project, presentations to industry groups have been made at state, national and international events. Yearly reports to industry in Tasmania have been made at the annual ARAC Potato Presentation Days. The project results have also been reported annually in Potatoes Australia and in 2000 in Good Fruit and Vegetable Grower magazine. A presentation was made at the VicSPA seed potato meeting in 2001, Potatoes 2000 in Adelaide, and at the International Potato Congress in India in 1999.

Copies of the Good Fruit and Vegetable Growers article and conference papers from The International Potato Congress and Potatoes 2000 are attached on the following pages.

Potato Physiological Age and managing tuber number in seed crops

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Introduction

Management of tuber number and tuber size in seed and ware crops is an important aspect of potato crop production. For the past three years a research project in Tasmania has examined management of tuber number and size distribution, focussing particularly on seed crop requirements. This article provides a summary of part of the project, the work on potato physiological ageing.

The Concept

The importance of seed tuber physiological age is a well known in the potato industry but surprisingly little is done to manage physiological age in commercial production. It is common knowledge 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 (Table 1). Seed growers therefore prefer to use older seed while growers of processing potato crops aim to use young seed. This sounds good in theory, but how easy is it to get 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 (Figure 1). 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. 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). Management of physiological age under Australian conditions therefore requires some understanding of the importance of these factors on the rate of ageing.

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. Several markers were examined in the project but none were able to accurately indicate the sprouting pattern and vigour of seed.

Sprouting of tubers under standard conditions is a useful indicator of seed condition and was used to demonstrate the importance of growing conditions on seed ageing.

Seed from 13 locations in Tasmania was stored at 4°C for 10 weeks following haulm death and then sprouted in moist sand at 20°C for 4 weeks. The tuber sprouting capacity (total sprout weight as a percentage of tuber weight) varied from 0.25 to 1.35 – in other words the most vigorous seed lots produced over five times the weight of sprouts as the weakest seed lots. There were also big differences between seed lots in the number of sprouts produced per tuber. Seed produced from crops left to die off naturally 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 killed early displayed the characteristic ageing cycle (dormancy, single sprout/apical dominance phase, multi-sprout stage, sprout branching stage, little tuber stage). The original research on physiological ageing, done in Europe where seed crops are killed off early, therefore needs to be carefully interpreted in Australia given the range of climatic conditions under which crops are grown and the range of crop management practices used. More attention may need to be paid to matching seed physiological condition (strongly influenced by seed crop growing conditions) to likely planting conditions instead of concentrating on management of ageing in storage.

Physiological Age and Planting Conditions

Soil temperature and soil moisture content influence the sprouting pattern and vigour of the planted seed tubers. Cooler temperatures or limited water availability at planting tend to produce slow emerging plants with few stems. These plants develop larger, more vigorous haulm and root systems, characteristic of young seed. The influence of planting conditions on sprouting behaviour were demonstrated in a field trial conducted last season; seed was planted at one site on 30th October and 22nd November, and at a second site on 1st November, and resulted in 2.1, 1.5 and 2.5 stems per plant respectively. The seed planted at the first site performed like younger seed at the second planting date compared to the first planting date.

Management of Tuber Number

The density of stems within a crop has a major impact on the number of tubers produced. Management of stem density has generally been achieved by changing plant spacings and, if possible, selecting appropriately aged seed tubers. It is interesting to review previous research on round seed production in Australia to highlight the difficulty in managing seed age – in almost all cases optimum spacings vary between sites and between seed lots at any one site. At this stage the best strategy available to growers to manage seed physiological age is to identify a reliable supplier whose seed performs well under your own growing conditions and stick with that supplier. It is also worth considering that there are likely to be large differences in performance (vigour and sprout number) between seed lots, so trialing seed from a number of sources may be a useful strategy to identify the best supplier.

While this report has concentrated on physiological age, much of the work undertaken in the project has concentrated on managing stem number (and therefore tuber number) by application of the sprout suppressant carvone prior to planting. This treatment has consistently increased tuber numbers by around five percent for Russet Burbank. Application of the growth retardant paclobutrazol at tuber initiation has also been shown to significantly increase tuber set, and other treatments applied at this stage have also given promising results in an observational trial. Further information

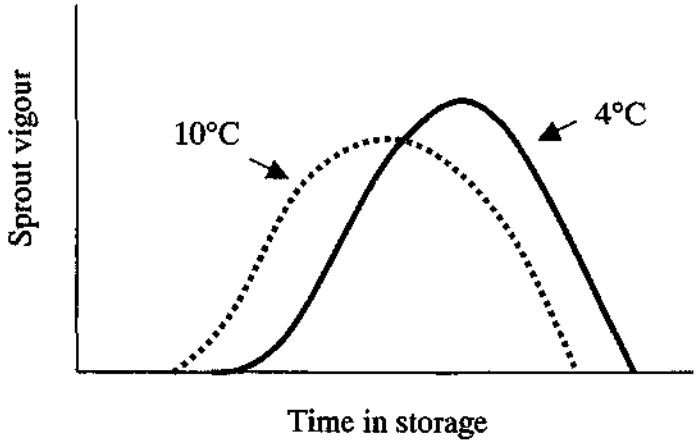
on this work is available from the author and will soon be available in the project final report from Horticulture Australia.

Acknowledgments
Funding support from Horticulture Australia and the potato levy is gratefully acknowledged.

Table 1. Characteristic behaviour of physiologically young and old seed tubers.

Young Seed	Old Seed
Slow emergence	Rapid emergence
Apical dominance	Multiple main stems
Few main stems	Increased stem branching
Vigorous, large plants and root systems	Smaller, weaker plants and root systems
Fewer tubers per plant	Many tubers per plant
Long bulking period	Rapid bulking
Long tuberization period	Relatively uniform tuber set
Large tubers at harvest	Smaller average tuber size
High yields	Lower yields
Delayed senescence	Early senescence

Figure 1. Effect of storage temperature on sprout vigour



Use of S-Carvone and 1,4-Dimethylnaphthalene as Sprouting Inhibitors during Potato Storage

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Abstract
The efficacy of four sprout suppressants was compared to that of chlorpropham (CIPC) on the potato cultivars 'Russet Burbank' and 'Denali'. S-Carvone and 1,4-dimethylnaphthalene (1,4-DMN) were the most successful sprout suppressants trialed under the conditions used. The performance of S-carvone applied at a rate of 600 ml t^{-1} was similar to that of CIPC applied at commercial rates. DMN was as effective as CIPC at a rate of 60 ml t^{-1}. Timing of application and initial head space concentration were critical in regards to efficacy. Better sprout control was achieved when applications began before visible signs of sprouting occurred. The cultivar 'Russet Burbank' was more amenable to sprout suppression by S-carvone and DMN than 'Denali'. No discernible loss of processing quality (fry colour and organoleptic assessment) was observed following treatment with S-carvone or DMN. Unlike CIPC, S-carvone and DMN are fully reversible sprout inhibitors. However, carbohydrate profiles from the periderm and cortex following treatments showed S-carvone and CIPC had similar effects on sucrose and reducing sugar concentrations. Both of these treatments resulted in substantially decreased glucose and sucrose concentrations in the periderm which, in control tubers, increased as sprouting progressed. SEM and macroscopic observations showed that application of S-carvone to young shoots at concentration of 600 ml t^{-1} resulted in physical damage to sprouts. Tubers then appeared to lose apical dominance, with proliferation of lateral and apical auxiliary shoots. Indexing of silver scurf (*Helminthosporium solani*) colonies on the tuber surface following treatments to 'Russet Burbank' and 'Denali' revealed that infections were limited by S-carvone.

Introduction
Over one third of Australian processing potatoes are stored following harvest due to production exceeding processing capacity during the primary harvest period. During storage, tubers are required to be maintained in a similar condition to freshly harvested potatoes, i.e., unsprouted, turgid, and containing low concentrations of reducing sugars. Therefore, potatoes are kept in an environment of high humidity and temperatures of 7 to 10°C. Although lower temperatures may be used to further reduce sprouting, higher reducing sugar concentrations may result. Further control of sprouting is currently achieved in Australia using the herbicides isopropyl N-(3-chlorphenyl) isopropylcarbamate (chlorpropham or CIPC), and isopropyl N-phenyl-carbamate (propham or IPC). (C)IPC prevents cell division and are very effective sprout inhibitors. However, concerns relating to possible health issues and environmental safety of (C)IPC breakdown products and chemical additives in general, have led to the investigation of alternative, naturally occurring sprout inhibitors (however, also see Kerstholt *et al*, 1997). Two compounds which have previously been shown to possess sprout suppressing qualities, S-carvone and 1,4-dimethylnaphthalene (1,4-DMN) (Beveridge *et al*, 1983; Duncan *et al*, 1992;

Oosterhaven *et al*, 1995), were trialed along with the herbicide Imazethapyr and essential oil waste product (d)-fenchone, to test their efficacy in regards to sprout suppression on two Australian potato cultivars. S-Carvone is a monoterpene derived from caraway (*Carum carvi* L.) seed oil, whilst isomers of DMN occur naturally in potato peel. The effect of S-carvone on the apical bud development and tuber sugar content during storage was also investigated.

Materials and Methods

The two cultivars used in this study were 'Russet Burbank' and 'Denali'. 'Russet Burbank' tubers were obtained from Tasmanian crops purchased by McCains Foods Pty Ltd and Simplot Australia Pty Ltd. 'Denali' tubers were supplied by Smiths Snackfoods Company, South Australia.

Studies examining the efficacy of the sprout inhibitors S-carvone (Talent®), 1,4-DMN (1,4 Sight®), imazethapyr (Spinnaker®) and (d)-fenchone were conducted over two years. The initial trial also included CIPC treatments (Tato-Vapo®) at the industry rate of 60 ml t^{-1}. Initial treatments during the first year used refrigerated shipping containers holding commercial potato crates. In the second trial, storage containers were bulk filled, which resulted in increased efficacy, probably as a result of increased head space concentrations. Sprout suppressants were applied to refrigerated containers using a 'swinfogger'. Containers were modified by constructing a false floor in the containers to enable air to circulate evenly around bins. Bulkheads were constructed to allow fogging while container doors were open. Temperature was maintained at 7-8°C throughout the trial, and airflow maintained at 20 m^3 t^{-1} hr^{-1}. Containers were fitted with data loggers that monitored temperature and humidity throughout the 172 day trials. S-Carvone was applied at rates of 300 and 600 ml t^{-1}, 1,4-DMN at a rate of 60 ml t^{-1}, (d)-fenchone at 600 ml t^{-1} and imazethapyr at 60 ml t^{-1}.

Container head space concentrations were determined using a Dragar gas detection test kit. Relative efficacy of sprouting inhibitors was calculated using a sprouting index based on the observed lengths of sprouts. Fry colour was tested by selecting 50 tubers of 'Russet Burbank' and 'Denali', which were, respectively, sent to the Simplot processing plant in Ulverstone, Tasmania, and the Smiths Snackfood Company factory in Tynong, Victoria. Fries were graded according to respective company standards. Organoleptic assessments of S-carvone and CIPC treated potatoes were also conducted on the fries produced.

Degree of sprouting was assessed at the end of the trial using 50 tubers sampled at random from each bin. The length of the longest sprout was measured and recorded as one of the following categories:

1 - not sprouted
2 - less than 3 mm
3 - 3-10 mm
4 - 10-20 mm
5 - greater than 20 mm

The index was calculated using the mid-point values of these categories and the frequency of tubers in the five categories, e.g.:

Sprouting index = (A*0)+(B*1.5)+(C*6.6)+(D*15)+(E*40) where A-E were the proportion of the tubers in the categories 1-5.

Apical buds of tubers treated with CIPC and S-carvone were examined at weekly intervals by making an impression of the bud with dental polymer. An impression of the bud was then caste using West System 504 resin. Models were examined under an environmental scanning electron microscope to monitor morphological changes in the bud. Later, macroscopic changes and measurements were assessed using a light microscope. Sugar analyses were conducted on 8 mm cores and periderm samples from three tubers treated with CIPC and S-carvone at weekly intervals. Extractions of sucrose, glucose and fructose were performed according to Lambrechts *et al.* (1994). Ethanol-soluble carbohydrates were assayed using methods based on the stoichiometric reduction of NADP to NADPH as a result of oxidation of glucose-6-P dehydrogenase (Bergmeyer & Bernt, 1974; Bergmeyer *et al*, 1974; Bernt & Bergmeyer, 1974). Tubers were examined at the end of the storage trial to detect the presence of the storage disease *Helminthosporium solani* (silver scurf). Disease was recorded in terms of presence and severity. Tubers were graded as 0 (no visible infection), 1 (<5% surface area infected), and 2 (>5% surface area infected).

A 10 kg sample was taken from each bin for residue analysis at the end of the trial. Residue analyses for S-carvone and DMN were performed using an HP5890 GCMS in selected ion monitoring (SIM) mode with a non-polar stationary phase HP1 coil. Each sample was extracted in 20 ml hexane containing 70 mg l^{-1} dodecane as an internal standard. Helium was used for the mobile phase at 5 psi. GCMS-SIM conditions were as follows:

GC:
Oven 60-120°C, ramped at 10°C min^{-1}
Injection at 250°C
Detector at 2890°C
SIM:
m/z dodecane = 99.1
m/z S-carvone = 82
Multiplier at 2200 V
Solvent delay of 2.4 min

Results and Discussion

The initial trial compared the efficacy of CIPC, S-carvone, and (d)-fenchone (Table 1). The performance of S-carvone applied at a rate of 600 ml t^{-1} was similar to CIPC applied at a rate of 60 ml t^{-1}. Efficacy of carvone at this concentration was much greater than at 300 ml t^{-1}. Fenchone, applied at a rate of 600 ml t^{-1}, did not satisfactorily suppress sprouting in the potatoes used for this trial, although damage to sprout primordia was observed. In the following year sprout suppressing abilities of S-carvone, 1,4-DMN, and imazethapyr were compared (Table 2). The results showed that efficacy of S-carvone and 1,4-DMN was cultivar dependant, with 'Russet Burbank' proving to be more amenable than 'Denali' to sprout suppression by these chemicals. When applied at a rate of 60 ml t^{-1}, 1,4-DMN was at least as effective as, if not better than, S-carvone in controlling potato sprouting in storage when potatoes

were stored in bins. Two refrigerated containers were bulk filled with 'Russet Burbank' and treated with 300 and 600 ml t^{-1} of S-carvone during this second trial. This method of treatment substantially increased efficacy of S-carvone at the lower application rate. Imazethapyr proved to be ineffective as a long-term sprout inhibitor during this trial, although during the initial 8 weeks successful suppression of sprouting was observed.

Container	Treatment	Sprouting Index
1	CIPC 60 ml t^{-1}	7.53
2	CIPC 60 ml t^{-1}	3.4
3	S-Carvone 300 ml t^{-1}	2.54
4	S-Carvone 300 ml t^{-1}	1.87
5	S-Carvone 600 ml t^{-1}	1.25
6	S-Carvone 600 ml t^{-1}	1.35
7	(d)-Fenchone 600 ml t^{-1}	40+

Table 1: Relative sprouting indices of 'Russet Burbank' and 'Denali' tubers treated with sprout suppressants after 172 days in storage during initial trial.

Container	Treatment	Sprouting Index
1	'Denali' S-Carvone 600 ml t^{-1}	7.53
2	'Russet Burbank' S-Carvone 600 ml t^{-1}	3.4
3	'Denali' 1,4-DMN 60 ml t^{-1}	2.54
4	'Russet Burbank' 1,4-DMN 60 ml t^{-1}	1.87
5	'Russet Burbank' S-Carvone 600 ml t^{-1}	1.25
6	'Russet Burbank' S-Carvone 300 ml t^{-1}	1.35
7	Imazethapyr 60 ml t^{-1}	40+

Table 2: Relative sprouting indices of 'Russet Burbank' and 'Denali' tubers treated with sprout suppressants after 172 days in storage during second trial.

Bulk filling of containers 4 and 5 appeared to increase the efficacy of S-carvone treatments. Successful sprout inhibition at 300 ml t^{-1} was achieved using this method. This result agrees with previous studies (Hartmans and Buitilaar, 1993), which also found that repetitive small doses of S-carvone are less effective than few large doses. This was found to be a result of increased head space concentrations, which lead to more efficient accumulation of S-carvone in the sprouts. Head space measurements showed a dramatic fall within three days of application, reducing from 70-80 $\mu g\ l^{-1}$ to 7-12 $\mu g\ l^{-1}$.

S-Carvone was found to physically damage sprouts in this study. However, suppression of sprouting can also be accomplished without visible effects (Oosterhaven, 1995). SEM examination of tuber sprouts showed that S-carvone caused extensive damage to sprout primordia. As a result, sprouting, when it did occur, was from axillary and lateral buds only.

Examination of carbohydrate changes in the storage tissue and periderm revealed that S-carvone treatment caused a similar response to CIPC-treated tubers. Cortex tissue

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S-CARVONE; A SPROUT GROWTH REGULATOR FOR SEED POTATOES?

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INTRODUCTION

A research project being conducted by the Tasmanian Institute of Agricultural Research is examining new pre-planting chemical treatments to increase tuber numbers and decrease average tuber size in seed potato crops. S-carvone, the active ingredient in the potato sprout inhibitor formulation 'Talent®', has been shown to be an effective sprout suppressant that does not permanently inhibit the tuber from sprouting. While the formulation is currently not financially viable as an alternative to CIPC for sprout control, it does appear to have potential in the seed potato industry as a reversible sprout suppressant. Earlier trials investigating the efficacy of s-carvone as a sprout suppressant have indicated that treatment can result in the reduction in apical dominance in tubers (strong sprout development from the rose end of the potato in physiologically young tubers). The treatment may thus be used as a form of chemical desprouting, promoting multiple sprout development in physiologically young tubers. These tubers may develop into vigorous multi-stemmed plants with the potential to yield high numbers of small sized seed tubers. This effect would be particularly desirable for the production of whole seed. The potential of s-carvone to complement or replace treatments such as manual desprouting, high density planting and physiologically aging seed requires further investigation.

METHODS

The efficacies of s-carvone (Talent®) and DMN (1-4 Sight®), in regards to suppression of apical dominance and thereby maximising the yield of small, round seed, were trialled using 'Russet Burbank' whole seed (30–60mm) and cut seed. Sprout suppressant chemicals were applied directly into the seed stores (refrigerated containers) with vents closed, but with air continuing to circulate. Control seed was treated in an identical manner, although no chemical was applied.

Three weeks following chemical treatments, potatoes were removed from refrigerated containers for chitting. Seed was cut into approximately 50g pieces according to standard industry practice. Seed from the three treatments were planted at the TAFE farm near Burnie, North-western Tasmania using 36 m beds with a 30 cm seed spacing in split plot double rows, replicated over four beds. Three weeks after planting the number of shoots produced by each of ten seed pieces from each

replicated block was determined, as was the height of the highest haulm – taken as an indicator of early growth rate and emergence. In order to maximise yields of small round seed, plants were dehaulmed after 3 months growth and a sub-sample of plants from each treatment was hand harvested, weighed and counted.

RESULTS AND DISCUSSION

The total number of tubers set on plants was significantly higher in s-carvone treated plants than in DMN and control (untreated) plants (Table 1). S-carvone treatment also resulted in a greater number of stems per plant and a greater stem height at three weeks after planting, indicating earlier emergence or increased vigour at emergence. The mean tuber weight in the s-carvone treatment was lower than the control treatment and this may be related to the higher number of tubers on each plant.

Table 1. Effects of S-carvone and DMN treatments

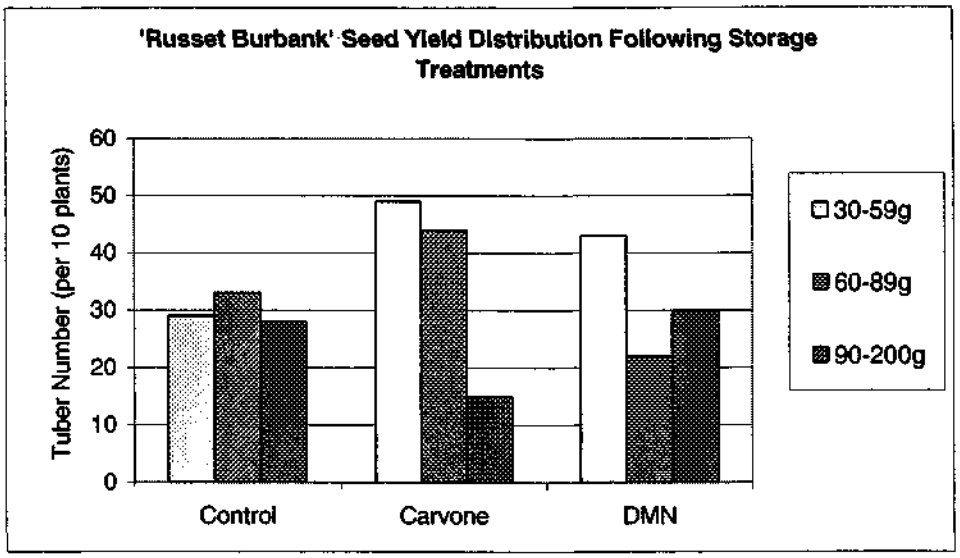
	Control	S-carvone	DMN
Tuber number per plant	8.50	10.25	8.88
Mean tuber weight	77.9	66.6	79.3
Mean stem number	2.54	2.73	2.55
Emergence height	12.9	14.6	12.2

The effects of s-carvone were more pronounced when cut seed was treated compared to whole seed.

Table 2. Yield comparisons for treated cut and round seed

Seed Type	Treatment	Total Yield (t/ha)	30-60 mm Yield (t/ha)
'Russet' round seed	Control	34.8	32.0
	S-Carvone	36.1	33.6
	DMN	36.8	33.9
'Russet' cut seed	Control	28.7	26.4
	S-Carvone	36.3	33.8
	DMN	31.1	28.7

S-carvone application resulted in increased uniformity in tuber size, with fewer large tubers per plant and the highest yields of tubers in whole seed weight classes. DMN application did not increase the uniformity of tuber size distribution compared with the control treatment.



The results of this trial indicate that s-carvone application prior to planting can increase the number of stems per seed piece and the number of tubers per plant in 'Russet Burbank'. The altered pattern of sprouting also resulted in increased tuber size uniformity, with a greater proportion of tubers suitable for use as whole seed being produced. More extensive trial work on the application of s-carvone to manipulate seed crop yields and tuber sizes is being conducted this season. Registration of s-carvone for use in seed potato production will be considered following the trial work.

ACKNOWLEDGEMENTS

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