Hort Innovation

Final Report

Extension Activities for the Australian Potato Industry – Literature Review and Survey

Project leader:

Peter Philip

Delivery partner:

Ag Aims Pty Ltd

Project code:

PT16000

Project:

Extension Activities for the Australian Potato Industry – Literature Review and Survey – PT16000

Disclaimer:

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This project has been funded by Hort Innovation, using the fresh potato and processed potato research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

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General project overview

Project PT16000 was commissioned by Hort Innovation to complete a literature search and identify information and research on potato seed handling and quality. A report on the findings of the literature report was submitted to Hort Innovation. This report identified many key elements discussed in a wide range of papers, guidelines and research from researchers, industry leaders and particularly university research and extension groups across Europe, North America and South America.

A survey for Australian growers was developed to focus on the key elements identified in the literature review that addressed seed handling and quality.

Face to face interviews were used applying a standard script which validated cohort comparison in the survey results. The survey method was effective with growers freely sharing their time and contributing in confidence. Surveys were also distributed personally to growers for them to complete and return in a postage paid envelope. Limited responses were achieved using this channel. Electronic grower surveying was also used to cover more fragmented industry sections.

The submitted report details the findings of the survey and identifies opportunities including areas of potential extension. The report is at the national level and maintains grower confidentiality.

Summary

Hort Innovation Project PT 16000 reviews the Australian Potato Industry Seed Handling and Seed Quality.

A literature review was completed looking at latest trends and research in Seed Quality. A survey was then completed across the Australian potato supply chain to investigate opportunities to drive sustainable, economic industry improvement.

The Australian Potato industry is geographically diverse, supplying fresh market and processing potatoes. Variety and climate impacts supply continuity and quality. Supply chain customers were surveyed to understand their key success elements that impact the supply chain. Relationships, grower economical sustainability and communication were pivotal to support consumer safety and deliver no surprise quality, with in full on time supply.

The Potato Industry Supply chain is long, 5 to 6 years. Seed quality and handling is business critical for the chain success. Certification, management of quality and physical seed management including cold storage were found to be well controlled compared to research data.

Key elements identified for driving a stronger, efficient and sustainable supply chain are:

Physiological Age Control

Improve understanding of physiological age, timely control of crop maturity, handling and storage. Adopt technology measuring, logging Physiological age (P Age) parameters, field climate, stress, storage temperature and storage environment (CO^2, O^2).

Communication

Increased cross chain communication, in season updates, long term vision to drive best estimate of demand, supply continuity, variety security. This will drive chain efficiency, reduce waste and achieve improved supply performance. Seed certification documentation to carry supplementary seed specification data on P Age factors.

Planting Density, Seed Unit Density, Seed Planting Potential

Accurate seed piece size with stem potential to drive accurate stem density. Improve logistics and handling efficiencies by optimizing seed units per ton, industry sharing of a better chain profit. Optimize cut seed to reduce waste and cuts per ton. Use of Physiological age plus nutrition to drive seed tuber set.

Scalability, District Seed Brand Integrity

Identify strategies to build seed grower profitability though scalability initiatives, co-operation, contracted shared services and storage. Communication, extension, development of district grower groups seeking improvement through best practice to score card, quantifying sustainability and district performance.

Achievements

MS190 is the final Milestone and signifies the completion of Project PT16000. The objective of this milestone (Milestone MS190) is to have signoff of the project PT16000 report by Hort Innovation.

The final report, appendix is submitted for review as per the milestone step (MS110) and is to be reviewed at a joint meeting of the Fresh Potato and Processing Potato SIAP on 26 June, 2018.

Recommendations for future projects or extension of this project PT16000 are included in the presentation. This includes extension of the Project PT16000 summarized findings and opportunities detailed in the project report. The approval of MS190 indicates sign off the report by Hort Innovation.

Outputs

A report on the Literature review (refer Appendix 1

A report on the literature review investigating potato seed quality and handling and its impact on potato production was completed (see appendix 1). From this review a survey was designed to examine the status of the Australian potato industry.

A report on the Survey of the Australian potato industry investigating findings of the Literature review is completed. A Final report and recommendations (MS190) is submitted to Hort Innovation is submitted to Hort Innovation and for presentation to a joint meeting of the SIAP of the Fresh and Processing Potato Industry

A proposal is prepared to frame up suggested extension and additional research into the management of:

- elements of potato seed quality and handling management
- Storage conditions and degree day data logging and use of smart phone technology
- Lean management process and communication.
- Physiological Age training and control process

Refereed scientific publications

No scientific publications.

Outcomes

A report and recommendations has been completed (refer MS190) on the Australian Potato Industry survey looking at the quality and handling of potato seed. This report identifies opportunities and presents recommendations. This report will be summarized in a presentation to the SIAP team.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

Issues and risks

No issues or risks identified.

Other information

As part of the project process a short survey was completed on the end customers of the Australian Potato Industry supply chain. This survey was completed to identify key elements as considered by the chain.

Appendices

Appendix 1 Literature Search Report Potato Handling and Seed Quality

HORT INNOVATION PROJECT PT16000

APPENDIX 1
A REPORT ON THE LITERATURE REVIEW INVESTIGATING POTATO SEED QUALITY AND HANDLING AND ITS IMPACT ON POTATO PRODUCTION

Hort Innovation

Researched and prepared by

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AgAims

EXTENSION ACTIVITIES FOR THE AUSTRALIAN POTATO INDUSTRY – LITERATURE REVIEW AND SURVEY 2016/2017 PT16000

THE IMPACT OF POTATO SEED QUALITY AND HANDLING ON POTATO SEED PRODUCTION, PROCESSING AND FRESH MARET PRODUCTION

Hort Innovation Strategic levy investment | POTATO – FRESH FUND | Hort Innovation Strategic levy investment | POTATO – PROCESSING FUND

The strategic levy investment project Extension Activities for the Australian Potato Industry – Literature Review and Survey 2016/2017 (PT16000) is part of the Hort Innovation Potato – Fresh Fund and Potato – Processing Fund.

Funding

This project has been funded by Hort Innovation, using the Potato - Fresh Fund and Potato -Processing Fund research and development levy and contributions from the Australian Government. Hort Innovation is the grower owned, not-for-profit research and development corporation for Australian horticulture.

Notes on Research Team

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[2]Peter O'Brien is an independent consultant and principal of AgAims. Peter has extensive experience in the potato industry across Australia and SE Asia. This experience includes working for a multinational processor in a global role including working in variety development, seed and supply management. The roles included the efficiency of supply across regions and the green field development of processing potato supply in developing markets through China and SE Asia. Peter has tertiary qualifications in Agriculture.
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1.0 CONTENTS

I.1 LIST OF TABLES AND KEY LEARNINGS

I.2 LIST OF FIGURES

2.0 INTRODUCTION

Potatoes in Australia is an important horticulture crop delivering 1.15 Million tons[1] from over 29,000 Hectares. Potato seed for this crop is vegetative, produced from tissue culture generated mini tubers and then multiplied up through 3 to 5 generations to support the planting of the crop. The seed production system is designed to produce seed free from diseases, virus and of sound quality. Poor quality seed can significantly impact the yield and quality of the final commercial crop used in processing or the fresh market and as a result, the grower's margin.

Genetics of potato varieties is critical in delivering commercial crop fit for the purpose that it is grown for. Varieties are accessed from breeding houses and are grown under Plant Breeders Rights where the characteristics of the varieties drive competitive advantage for the producer.

Genetic characteristics include dormancy which drives storage and shelf life for potato seed and commercial crop. This natural dormancy can also affect the fecundity of the seed and its performance in delivering crop quality and yield.

The Australian potato industry is very competitive with yield and efficiency essential to drive grower return. Seed cost is seen as a significant production cost. Potato growers therefore try to minimize the seed cost to manage cost of production and grower margin.

Fresh and processing potato production relies on genetic expression of the variety potential. This genetic potential's foundation relies on potato seed, its fecundity, quality, nutrition, harvest process and storage. Commercial crop production is directly impacted by seed size, health, nutrition and physiological seed age. Physiological seed age is expressed as the dormancy of seed and relates to the balance of complex sugars, starches and simple sugars driven by the endogenous growth regulating enzymes and proteins.

Physiological age is unique to each variety coming from the variety's genetic expression.

Potato crop storage, the supermarket shelf life and seed storage, is genetic expression of physiological age stability. This genetic potential of the individual potato tuber is directly impacted by its environment including the growing, harvest and storage of the crop.

Commercial potato production relies on optimum emergence, even stem count and crop physiological age. Should potato seed be young it can lead to single stem plants (apical dominance issue) with reduced tubers per plant. Should the seed be too aged then the expression is seen as multiple stems, high levels of tuber set and early senescence of the crop (often with the plant not bulking the crop).

Timing of growing of potato crops across Australia for both seed, processing and fresh market is targeted to achieve optimum productivity from sunlight, climate, temperature, and avoidance of stress events and frost. Australian potato supply is driven by this geographic diversity and strategic cropping matrix buffered by the use of various storage options. Storage includes both controlled environment shed storage and deferred harvest (ground) storage. This extends and stabilizes market supply. Cost of production and logistics directly drives the expression of the matrix of supply.

[1] Source Australian Bureau of Statistics report 71210DO004_201415 Agricultural Commodities, Australia–2014-15 March 2016

Seed potato supply to crop plant timing relies on geographic spread of seed and crop production demand. Seed is grown in areas of low disease and virus risk but allows the harvest and correct ageing (physiological age) through conditioning and storage. This delivers viable vigorous seed for even emergence and stem numbers.

Potato seed quality, size and physiological age therefore has a direct impact on the productivity, yield and quality. Seed quality and physiological age management optimizes achieving the genetic potential of the crop.

Potato seed quality directly impacts the sustainability and economic viability of the grower's potato crop.

This project is aimed at reviewing Australian potato seed and handling best practice through a literature review, identifying potential opportunities.

The project will develop a summary of findings and recommendations to provide growers with an understanding of potential practices. Using extension and communication the growers will be informed on potential improved sustainable best practice that can be adopted in their enterprise.

3.0 OBJECTIVES METHODLOGY

3.1 PT 16000 PROJECT SUMMARY

The project is aimed at reviewing Australian potato seed and handling practice, review research and best practice to identify and document potential opportunities to improve Australian seed quality and handling practices. The project will deliver a summary of findings and recommendations to provide growers with an understanding of practices and thereby adopt and develop improved sustainable best practice for their enterprise. This will help seed growers deliver the Goldilocks quality factor required for potato crop success.

The outcomes of the project for delivery to growers in the Australian potato industry

- A summary of a literature review on seed handling (post-harvest handling, storage and seed piece treatments), physiological age of seed, seed piece size and whole v's cut seed and its effect on final crop outcomes
- Review of current Australian seed quality and handling practices based upon data sampling that is representative and scalable for the whole Australian industry
- Identification of opportunities to improve Australian potato seed quality and handling practices
- Publish the project findings with a grower orientated summary and recommendations

3.2 LITERATURE SURVEY

A literature survey was completed looking for quality scientific research into seed quality and handling. Reference material reviews also include potato industry bulletins and publications.

From this literature survey, a report was completed summarizing the findings and citing references to the literature source. Using this report a grower survey was developed to investigate the potential gap between Australian seed handling practices and international practices. From this gap analysis, opportunities and advantaged practices were identified and consolidated into a report.

3.3 GROWER SURVEY

A grower survey was then developed to investigate Australian potato seed quality and handling practices. This survey was actioned through a mix of methods including face to face surveying at the grower's location.

Analysis of grower production volume was completed as part of the survey to ensure that the survey was scalable, effectively capturing a cross section of the Australian potato industry including potato seed production, fresh and processing potato production.

The survey ensures grower confidentiality. The data recorded and subsequent reports are managed to preserve this confidentiality, reporting at the Australian industry level.

The survey report was then workshopped with a group of potato industry leaders to validate the findings as being practical and grower orientated.

3.4 PROJECT REPORT

Report Outcomes

The project report will communicate findings of the project to growers and stakeholders of the Australian potato industry. The format and report length will enable growers to identify the findings in such a way that they can consider adoption in practical commercial terms for their enterprise.

The following key outcomes are

- Improved grower understanding of seed quality and its impact on productivity, profitability and sustainability particularly
    - seed quality
    - seed handling
    - seed physiological age
    - seed piece size
    - impact of cut seed v's whole round seed.
- Tools to allow growers to adopt and maintain best practice seed management
- Improved productivity and sustainability of potato production through development of global best practice

Project Report and Grower Adoption

The project report will integrate the findings of the literature review and summary with the grower survey and identified gaps and potential opportunities. Advantaged practices will be highlighted for the Australian potato industry.

The project report will focus on principles and concepts for grower consideration and their subsequent development of their best practice but will be of a general nature. The project report will have limited financial analysis or detailed solutions at the individual grower level. Before adoption of project findings, the growers must consider the viability of change to their individual enterprise and production systems.

Further Research Opportunities

The project report will identify opportunities for further research and investigation guidelines that can then lead to ongoing value for the HIA investment in this project.

4.0 LITERATURE REVIEW - A REVIEW ON SEED HANDLING AND QUALITY

4.1 LITERATURE REVIEW OVERVIEW

The literature review was actioned by searching sources for technical information and research papers on potato seed quality and handling. Each paper reviewed was assessed and qualified to ensure that its information was valid for inclusion in the review.

Qualification of research papers considered the date of publication, status of publication medium, focus of material on critical reference terms. The research papers needed to be based on scientific principles, impartial and avoid potential commercial bias.

Review reporting will summarize findings, cite the sources and first author and date and is listed in section 6.0 Works Cited of this report.

Reporting will be focused on fit to the Australian potato industry, growing conditions and the terms of reference of the project. As this report is not confidential any material provided in confidence from industry sources will be reported in general nature so as to maintain confidential privilege.

Figure 1. Traditional stem cutting of the potato crop haulm to promote skin set in South America (FAO Potato Post Harvest Production) (Meyhuay, 2001)

4.2 LITERATURE REVIEW RESULTS

Results of the literature review are outlined in the following sections as a precis relating to key review topics. As potato seed quality is a complex of these elements, research papers often report observations and conclusions that cover several topics. The report summary discusses the interrelation of topics and their hierarchy to deliver best grower understanding of seed quality and sustainable productivity practice and opportunity.

The review shows how over time, researchers have tackled the question of potato productivity and manipulation of tuber size distribution. In 1990 Stuik (Struik, 1990), a researcher from Wageningen University, Netherlands, summed this up when he reported that many diverse and interacting mechanisms regulated tuber-size. While plant density was easier to control stem number was less easily controlled. Tubers on the same stem differ in timing, rate and duration of growth. Tubers of a seed crop will therefor vary in chronological age, maturity and physiological age (**Figure 14**).

In this literature review, some papers from 1940-50's discussed tuber dormancy and its impact on potato production. Hemberg (Hemberg, 1949) looked at growth inhibiting substances and auxins of the potato in relationship to dormancy. As technology and science has evolved, depth of investigation accelerated and so the complexity of potato dormancy better understood. Its biochemical pathways and controls were more accurately measured.

Brown (Brown, 2005) completed a report and a three (3) year study on processing potatoes in Tasmania. The HAL Project (PT0212) aimed to identify the major contributors to potato seed physiological quality. This work concluded crop performance prediction from seed crop management factors was limited as was seed crop storage performance. There is need to understand interaction of physiological status of seed and the planting environment. Brown's work gave a good understanding of various performance attributes and this work is cited through the specific sections following.

Of note is a publication, ***Commercial Potato Production in North America,*** (Bohl W. , 2010) ***The potato Association of America Handbook (second revision).*** This is a comprehensive general reference on potato growing with an extensive list of contributors from the potato research and extension community of North America.

http *potatoassociation.org/wp-content/uploads/.../A_ProductionHandbook_Final_000.pdf*

4.2.1 SEED POST HARVEST HANDLING AND STORAGE

Knowles (Knowles, 2014) of Washington State University published lecture notes[2] on potato storage that discussed the importance of tuber physiological maturity, skin maturity and the impact of storage on physiological age.

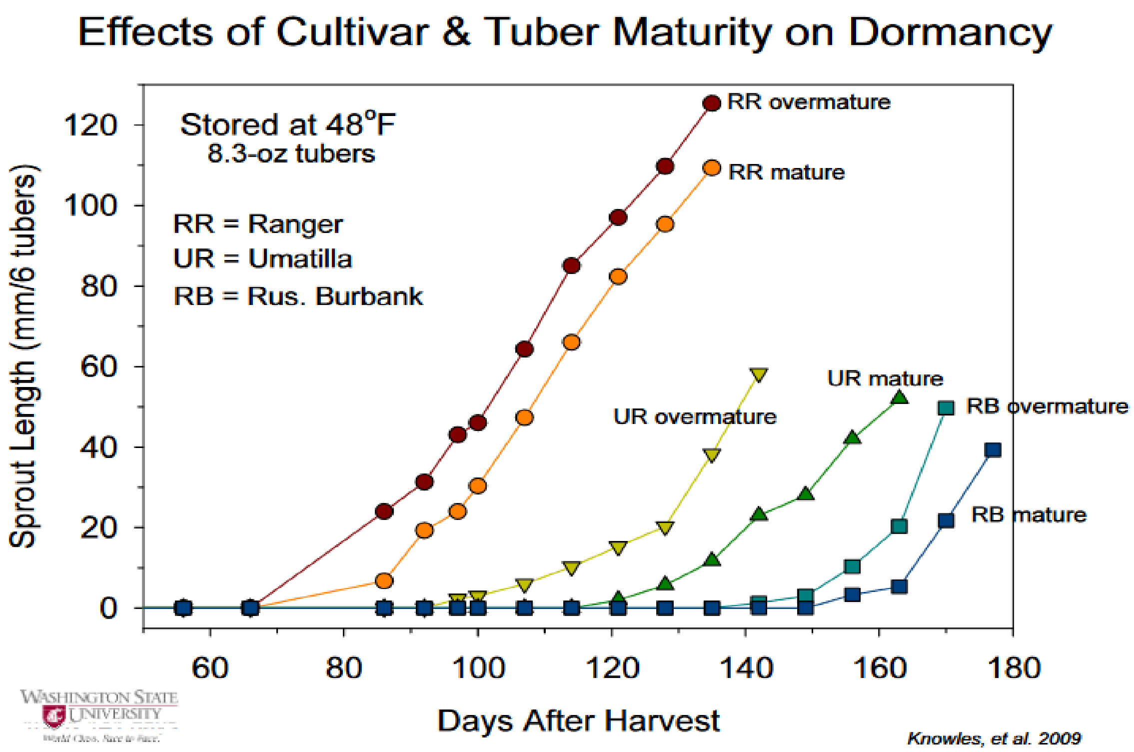


Figure 2. Effect of Cultivar and Tuber Maturity on Dormancy (Knowles, 2014)

[2] http://web.cals.uidaho.edu/potatoscience/files/2014/04/Potato-Science-Lecture-23-4-17-14.pdf

In the lecture note, Knowles shows that variety impacts physiological maturity and physiological age. In above Russet Ranger (RR) demonstrates a shorter dormancy than Russet Burbank (RB), indicated by sprout length on the vertical axis. The lecture notes also discuss the importance of damage management and bruise management during the harvest and storage process.

Preston, a contributor to the handbook "Commercial Potato Production in North America" (Bohl W. , 2010) discusses on Page 78 of this handbook, the impact of harvest and handling in the development of bruise and damage. Potato quality and stability in storage can be affected.

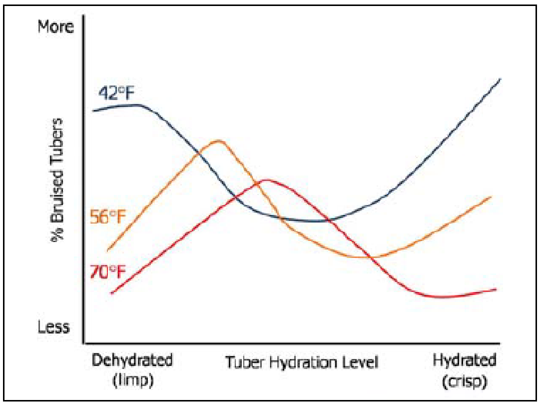


Figure 23. Tuber temperature and hydration levels have an impact on black spot and shatter bruise susceptibility. Dehydrated tubers are most susceptible to black spot while hydrated tubers are susceptible to shatter bruises. Generally, soil temperatures should be between 45 and 65°F at harvest time.

(Adapted from: Smittle, D.A., et al. 1974. Harvesting Potatoes with Minimum Damage. Am. Potato J. 51: 153-164.)

Figure 3. Tuber temperature and Hydration impact on bruise and damage susceptibility (Bohl W 2010)

Al-Mughrabi (Al-Mughrabi, 2016) in a document prepared for The Canadian Horticultural Council in 2016 identifies temperature, humidity and air movement as critical management parameters for storage of seed potatoes. Harvesting of warm tubers should be avoided. Stored seed potato tuber temperature change should be gradual, for example reduction of tuber temperature (1°C every 1-2 days). Optimum temperature for holding seed tubers is at **3-4°C**. Humidity is best maintained at **92-98 %** and regular ventilation (systems minimum of 20 cfm/Ton) to ensure control of carbon dioxide and storage temperature profile. When handling potatoes, tuber temperature should be greater than 7.2°C to help avoid tuber damage.

Studies into storage of potatoes by Sanford (Sanford, 2006) in Wisconsin identified that use of variable speed fans in cool storage facilities had better efficiency using **68% less power**. Quality with variable speed fan storage was advantaged compared to constant speed. Variable speed fans had significantly less tuber weight loss, 4.03% shrinkage compared to 4.55% tuber weight loss with conventional fans.

Rhoades (Rhoades, 1988) reported the history of potato storage in Peru. This identified storage to control light and temperature in various structures from rustic Andean barns to more developed specialized stores. These stores often did not have cooling and relied on design and climate. Farmer management of storage, sale or consumption of potatoes was driven by financial return. The fundamental principles of potato storage are universal.

Seed and its quality in storage is a declining paradigm, from maturity through harvest handling and storage.

Knowles sums this up in various reports and Washington State University lecture notes[3] (Knowles, 2014).

[3] *web.cals.uidaho.edu/potatoscience/files/2014/.../Potato-Science-Lecture-23-4-17-14.p*

Figure 4. Illustration adapted from Andean carved gourd showing the Andean people's understanding of the potato's agricultural calendar from breaking the field to storage and sale of the harvest (Rhoades, 1988)

Some of the key factors that impact how steep the downward slope is are

- **Variety traits** influence tolerance to disease, nutrition efficiency and physiological ageing
- **Crop growing environment** including soil, irrigation and climate, pest and diseases, nutrition, stress and time (days after planting (DAP))
- **Skin set** and genetic trait of skin tenacity
- Infield **temperature and time** from maturity to harvest
- **Bruising and damage** from harvest through grading, cutting and planting
- **Storage** condition and management

Bruise and damage can lead to break down or change in physiological age. Skinning and poor suberization of damage (healing) can lead to rapid weight loss and increased propensity to bruise and damage. Bruise and damage will lead to accelerated physiological ageing.

Knowles (Knowles, 2014) states that bruise should not be greater than three (3) to four (4) percent. The harvest process was identified as the greatest contributor to tuber bruise and damage (50 to 70% of total bruise and damage). The damage and bruise healing process increase respiration and accelerates physiological age.

Control of storage temperature and humidity influences weight loss and slows decline of quality and physiological age change but it never stops the change. See Figure **7** Section 3.2.2

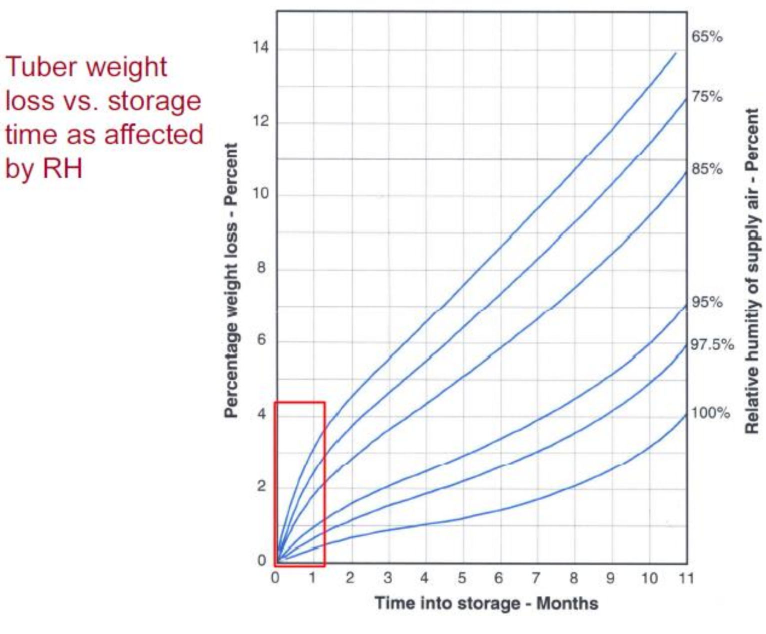
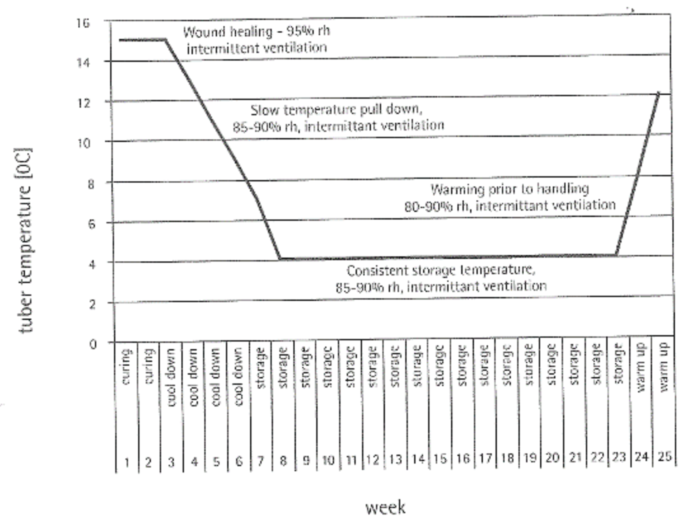


Figure 5. Impact of Relative humidity in storage on percentage weight loss over time **(Knowles, 2014)**

Seed storage modelling for Australia was discussed by Bleasing[4] (Bleasing, 2004) in a HAL funded report, "Seed Potatoes and Best Practice" in 2004.

Note

Optimum storage temperature varies with variety and purpose of potato (fresh, processing, seed)



This report explores the risk management and mitigation of quality issues in seed storage and handling in a practical applied management style.

The report looks at handling and curing of seed and the importance of cooling strategy in storage.

Bleasing's report gives growers and store managers examples and templates to build better seed management systems and risk management.

Figure 6. Principles and Modelling of Curing, Storage and warming up of seed potatoes, an example (Bleasing, 2004)

Knowles talks to this in more detail with an example of Russet Burbank seed storage temperature (Knowles, 2014) and the relative difference of storing fresh market or processing (French fry).

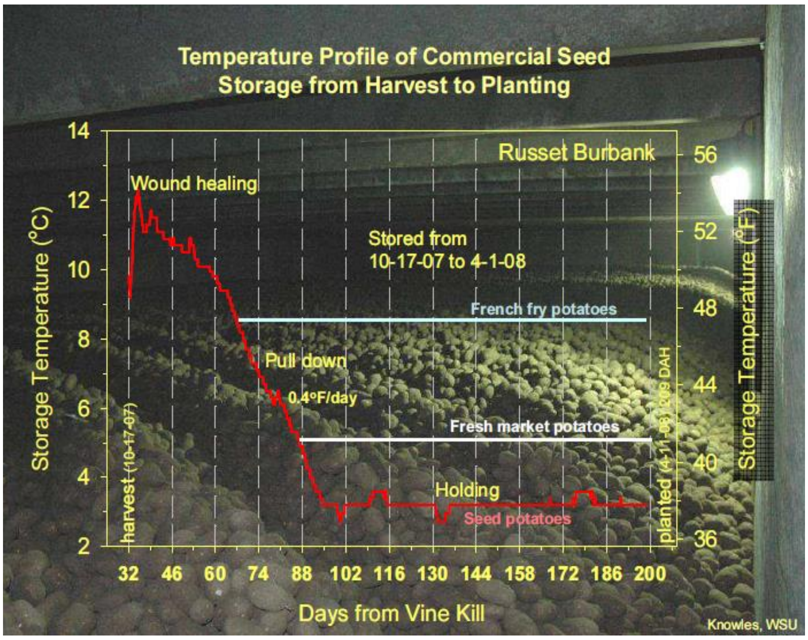


Figure 7. Temperature Profile of a Commercial Seed Storage comparing Seed Temperature to Limits of Processing and Fresh Market Storage **(Knowles, 2014)**

[4] https://ausveg.com.au/infoveg/infoveg-search/seed-potatoes-a-best-practice-handling-and-storage-guide-for-growers-and-store-operators/.)

Potato store management is critical to maintain the quality and performance of seed potatoes. The Potato Council (UK) (a division of Agriculture Horticulture Development Board)[5] published a comprehensive store management guide written by Cunnington and Pringle (Cunnington, 2008). This report addresses general storage of fresh and storage potatoes. Some of the quality issues, diseases, condensation management and storage management can be adapted to seed potato storage.

The report also addresses safety in the store for the store operator. Ethylene is used as a sprout suppressant but care should be taken with its impact on respiration rate and development of carbon dioxide.

The variety and potato market use impacts storage temperature and length of potential storage.

Temperature depends on use, variety and storage duration.
Examples:

Hermes	9-12°C
Lady Rosetta	8-10°C
Saturna	8-10°C
Maris Piper	7-11°C
Markies	8-10°C
Pentland Dell	8.5-10°C
Russet Burbank	6.5-8.5°C

- The lower end of the scale is appropriate for 6-9 month storage; the higher end should be used for shorter durations

Figure 8. Examples of Suggested European Varieties Optimum Temperature Ranges (Cunnington, 2008)

Studies by Oliveira (Oliveira, 2014) on the South Island of New Zealand however identified varieties Bondi and Fraser seed did not respond to cold storage and cold storage cost would not return value for cost regards physiological age and stem count. This reflects variance in variety but also the potential seed crop growing conditions influencing stability of physiological age.

4.2.2 PHYSIOLOGICAL AGE OF SEED

Tuber dormancy is defined as the absence of visible bud growth (Suttle, 2007).

Physiological age is a period of time during which the tuber is dormant as the tuber progress from maturity to active vegetative growth. The period of dormancy, environmental stress factors and tuber maturity at harvest impacts the development and activity of buds and the number of stems each bud produces. Cool storage and reduced tuber temperature can slow physiological ageing but does not stop it.

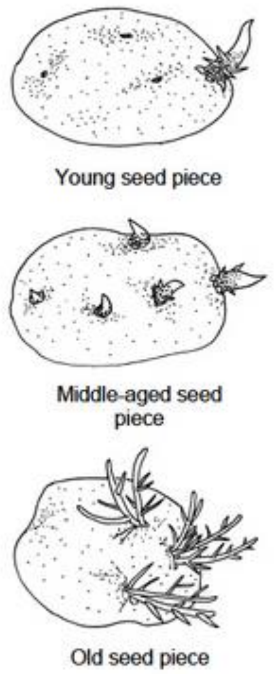
Johnson (Johnson, 1997, 2015) summarized physiological age of seed in an extension bulletin. Johnson characterized seed into **Young Seed, Middle Age Seed and Old Seed** and related the bud activity and stem development to these groups.

Bleasing (Bleasing, 2004) and Crump (Crump, 2009) both show Johnson's diagrams as they explain potato tuber's physiological age indicators adapting this descriptive style.

Johnson in Bulletin #2412 **(Johnson, 1997, 2015)** discusses cutting seed and how it can lead to increased physiological age. Some varieties like Atlantic and Kennebec are more suited to pre-cutting as they can be slower in curing.

[5] https://potatoes.ahdb.org.uk/sites/default/files/publication_upload/Store%20Managers%20Guide%20Updated%2011.05.12.pdf

Soil temperature and conditions can also slow emergence and cause uneven establishment. Physiological age of seed can help offset this. Correct seed age gives strong sprouts and faster emergence leading to better crop establishment.



Dormant Seed
Potato seed does not sprout and is still in resting phase

Young Seed
Demonstrates strong apical dominace and plant only produces a few stems, leading to low tuber set, larger and few tubers

Middle Aged Seed
No clear apical dominance with multiple sprouts leading to multiple steam and high tuber set

Old Seed
Weak sprouts, can be branched and appear hairy leading to lack of vigour, weak plants, high tuber sets with lack of vigour to bulk tubers to size

Figure 9. Visual Indicators of the stage of Potato Seed Physiological Age **(Johnson, 1997, 2015)**

The key reason for cool storage of potato seed is to condition seed, allow curing of damage and skin set and to slow the process of physiological age. By reducing temperature of the seed, respiration is slowed and the tuber biochemical processes are also slowed. Knowles (Knowles, 2014) in his lecture notes calls up work from Kleinkopf and Olsen that shows how temperature and variety influences physiological ageing. Russet Burbank dormancy decreases by 30 days for a variation of 3°C from 150 days at 5.5°C (42°F) to 120 days at 8.9°C (48°F) (refer Figure **10**).

Effects of Storage Temperature & Cultivar on Length of Dormancy

	Approximate Length of Dormancy (days)		
Cultivar	**42°F**	**45°F**	**48°F**
Russet Burbank	150	135	120
Ranger Russet	75	60	50
Summit Russet	150	125	100
Umatilla Russet	140	120	80

Kleinkopf & Olsen (2003) In Potato Production Systems, Univ. of Idaho

Figure 10. Effects of Storage Temperature and Variety (Cultivar) on length of Dormancy **(Knowles, 2014)**

Jackson (Jackson, 1997 (2)) completed plant spacing trials in Queensland Australia. As part of this work he published a summary from the trial work that focused on the influence of physiological age. A trial was planted using the same seed source in winter and then in spring. The winter trial seed demonstrated apical dominance and closer spacing improved yield, the seed was younger in physiological age. The spring trial planted latter, the seed had achieved more physiological age, demonstrated multiple stems with wider spacings delivering advantaged yield and returns. Jackson concluded that physiological age was a major consideration in selecting plant spacing regardless of variety.

Suttle (Suttle J. , 2004) in 2004 reported in the Journal of American Potato Research that Abscisic Acid (ABA) was the primary growth regulator that controlled potato dormancy. Suttle (Suttle J. , 2009) also reported a study in 2009 on dormancy pathways in mini tubers. This identified that Ethylene levels while important to initiate dormancy did not influence maintaining of dormancy and did not impact release of a tuber from dormancy. It was important to understand dormancy control so a genetic solution for dormancy could be developed. Suttle (Suttle J. , 2008) in 2008 identified that synthetic Cytokinin (CK) was more effective in breaking dormancy than natural Cytokinin and presented short thick buds that resisted breakage during seed handling compared to other bud stimulators that presented elongated buds.

Rodríguez (Rodríguez, 2010) of Columbia University Bogota summarizes the dormancy process of potatoes and how plant hormones particularly ABA, control dormancy. As ABA declines with time CK's, Indoleacetic acid (IAA) and Auxins increase along affecting bud activity and sprouting. Complex sugars, starches, transition to simple sugars around the bud sites driving bud growth. A critical change in the tuber is the movement of sugars to the bud. Variety genetics is fundamental in time of dormancy change for example the variety Cirillo which has little or no dormancy.

Crump (Crump, 2009) discussed how physiological age affected the productivity of potatoes. Young seed had slower emergence and later harvest compared to old seed that emerged earlier but senesced early. This trend in crop performance impacts yield and tuber size therefor quality and return to grower (Figure 11)

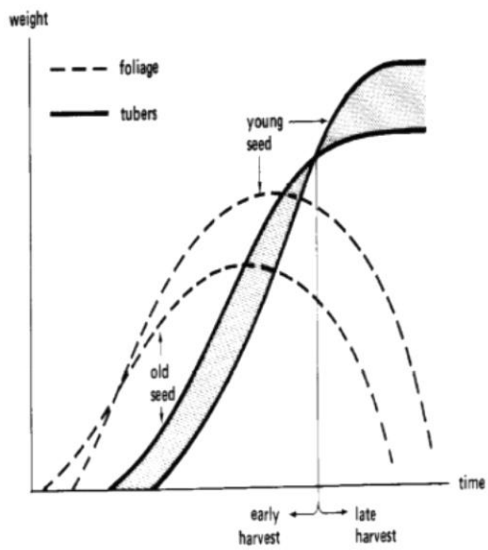


Figure 1 Growth of foliage and tubers from young and old seed; old seed has yields with early harvest v's young seed has yields with late harvest *(Wiersema 1985)*

Figure 11. Impact of Physiological Age on weight of foliage and tubers against time **(Crump, 2009)**

Blauer (Blauer, 2013) discusses the impact of manipulating physiological age in five (5) potato varieties that are insensitive to heat manipulation. Treating cut seed with varying rates Gibberellic Acid was assessed. Rate of GA and yield response was variable to variety with higher rates of GA causing yield decrease.

Brown (Brown, 2005) in the HIA project PT02012 looked at key aspects of seed crop management and storage that influence physiological quality. For Russet Burbank chemical testing, butanol testing, chemical maturity (sugars) testing (see Figure 12), of physiological maturity in this project proved unreliable.

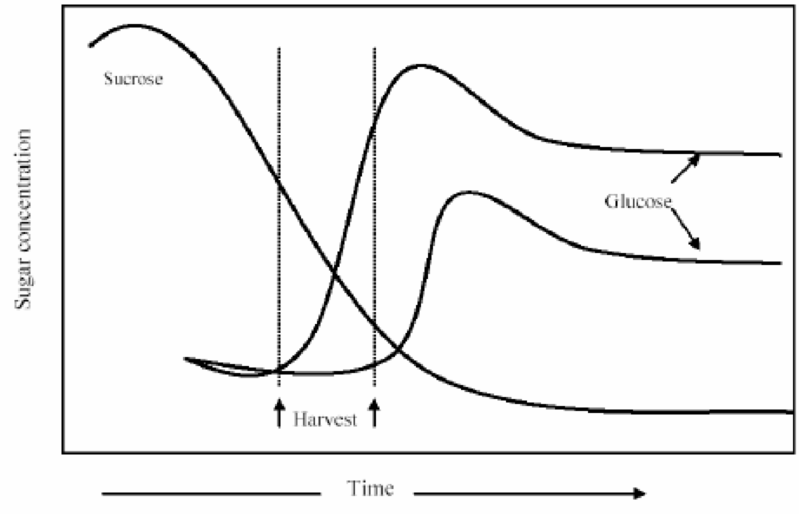


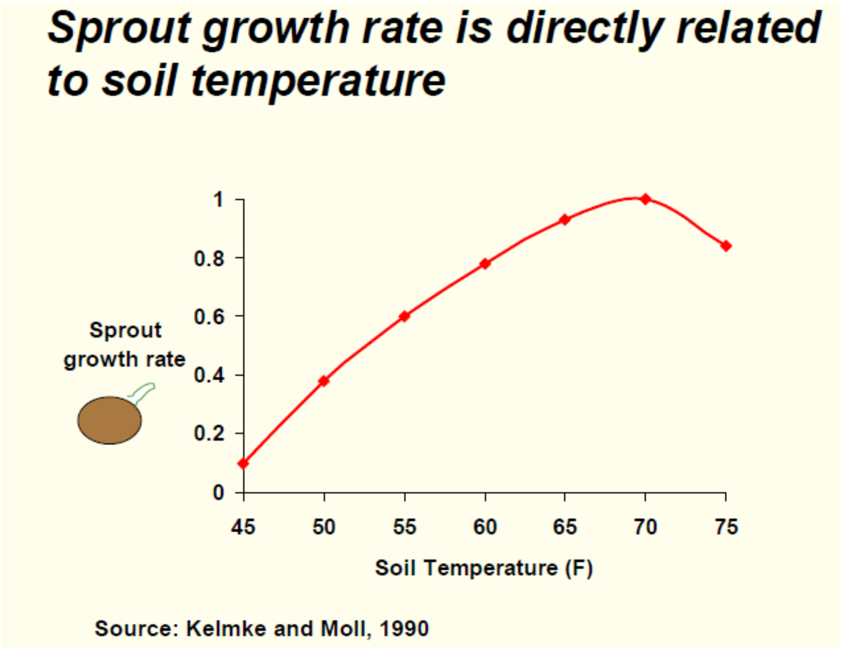
Figure 1. Changes in sugar concentrations in tubers during tuber growth and after harvest. Tubers at the first harvest point are immature (high sucrose levels) and will accumulate higher glucose levels during storage than tubers harvested at the later date when chemically mature. (Source: Pritchard,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

Brown reported that pysiological age is generally regarded as the major factor in influencing stem number per plant, speed and eveness of emergence.

Brown concluded that physiological status was unlikely to be useful in predicting seed performance. Seed crop management and storage duration do affect seed performance through changes in seed physiological age.

Figure 12. Changes in Sugar concentrations in tubers during tuber growth and after harvest (Brown, 2005)

Crop planting environmental interaction, particularly soil temperature and moisture, with physiological seed state have an overriding effect. Seed crop production practices that impact seed tuber quality is seed crop senescence and harvest. Thornton (Thornton, 2014) shows the effect of soil temperature on sprout development (see figure 13) which supports Brown's comments.



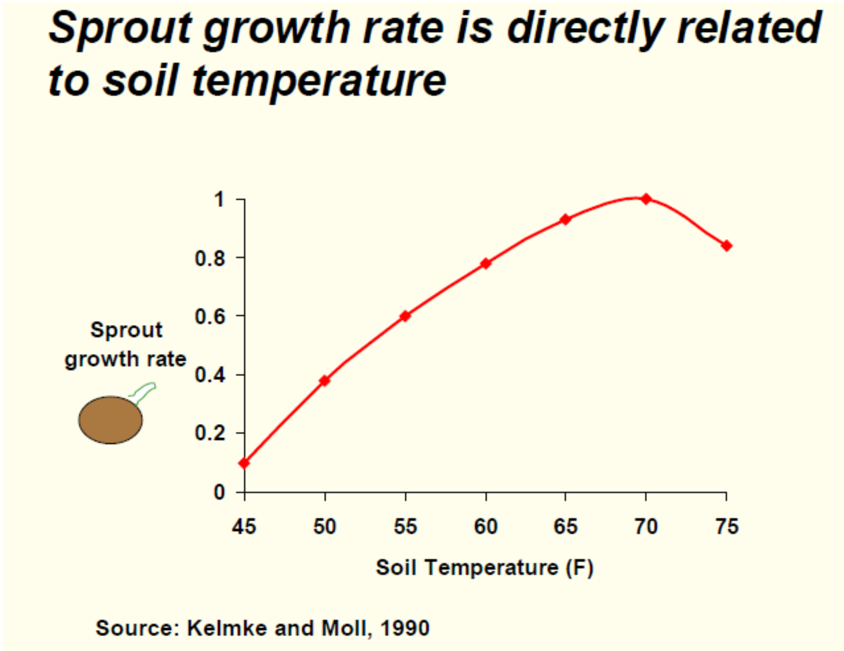


Figure 13. Soil temperature impact on sprout growth (Thornton, 2014)

Thornton (Thornton, 2014) presentation notes show the growth stages of the potato. Tubers initiate over a period of time which can affect maturity and physiological age at time of harvest. (**Figure 14**). Depth of tuber set can vary which can also affect physiological age.

Variability of physiological age exists in a parcel of seed, driven by environment, growth and tuber development on a potato plant. Variability of physiological age occurs across the seed crop. Development timing and tuber development is shown in Thornton's (Thornton, 2014) paper. Figure 14 illustrates this with growth stage III and growth stage IV showing tuber initiation and development. This can lead to variation in maturity and solids (specific gravity) that may impact physiological age.

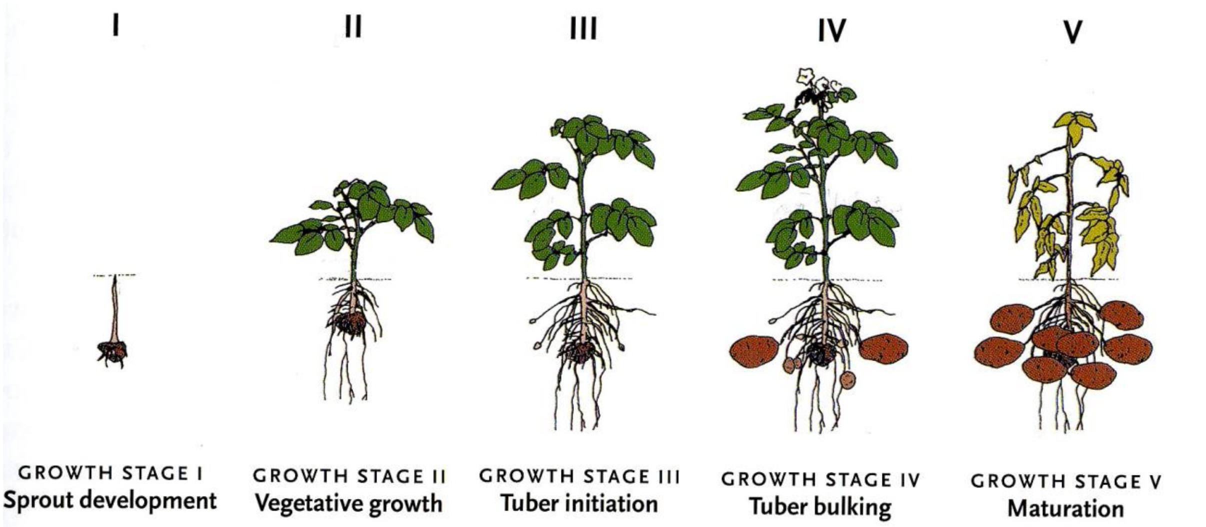
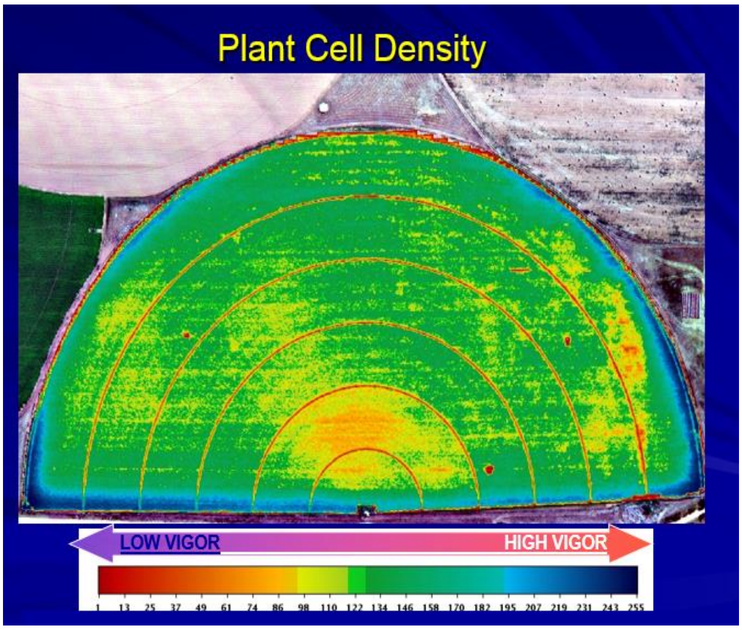


Figure 14. Growth Stages of the Potato showing tuber development timing and position **(Thornton, 2014)**

In broad acre potato seed production, soil type, paddock topography, plant density and plant vigour will vary across the seed growing area. Pest and disease, irrigation application also varies across the planted area. The crop emergence and canopy density vary with the vigour. This impacts maturity, response to haulm kill.



Sentek Australia demonstrate (Buss, 2017) variability in plant density and subsequent irrigation demand and required management using multispectral photography. This shows up variations in vigour and therefore potential variation in physiological age at harvest. An example of this shown in .

More recent studies on physiological changes in potatoes published 2009 were completed by Delaplace (Delaplace, 2009). The article concluded that comparison of previous works was not easy due to their varied methods. The ageing process of potatoes varied from other seed. No useable indicator of physiological age was identified.

Figure 15. Variation of Cell Density across irrigated potatoes (Buss, 2017)

De Stefano-Beltran (De Stefano-Beltran, 2006) investigated ABA in potato tuber dormancy and forced dormancy break. De Stefano-Beltran confirms potato dormancy depends on both the genotype (variety) and environmental conditions during growth and storage. By using dormancy terminating agent bromoethane (BE) rapid and synchronous sprouting of dormant potatoes was induced. (Note bromoethane is reported as a carcinogen and this was used in controlled laboratory research. It is unsuitable for commercial use)). De Stefano-Beltran confirmed that observed changes in ABA during tuber dormancy progression (physiological ageing) are a result of a dynamic equilibrium of ABA biosynthesis and degradation that increasingly favours catabolism (break down) as dormancy progresses.

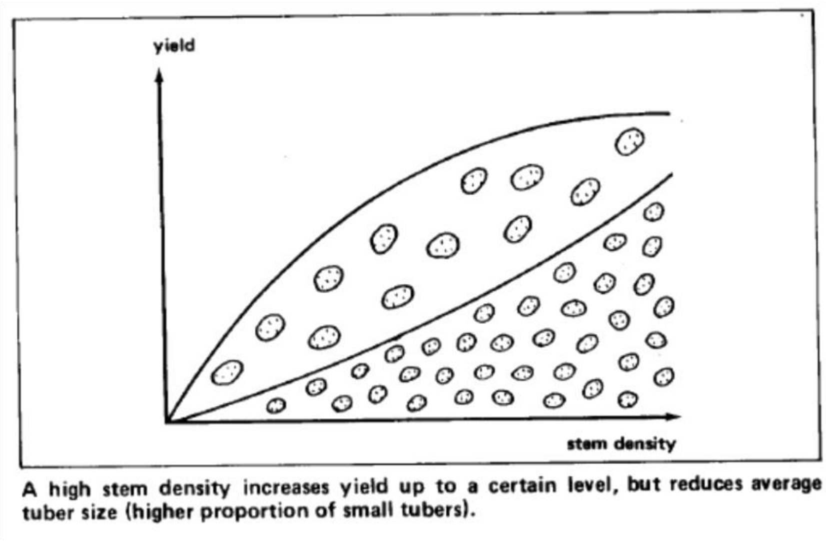
Suttle (Suttle J. , 2012) completed work looking at the effect of azole type P450 inhibitors including diniconazole and paclobutrazol on ABA. Paclobutrazol (Cultar) is registered for reducing internodal shoot length by inhibiting biosynthesis of gibberellins in plants. The work showed although ABA content was reduced it is not a prerequisite for dormancy exit and on set of tuber sprouting.

4.2.3 SEED PIECE SIZE AND WHOLE V'S CUT SEED

4.2.3.1 SEED PIECE SIZE

Seeding rate is a critical decision that growers control that drives plant density and cost of production. Australian growers purchase seed by the Ton and seed value (price) is expressed as dollars per ton. Planting of the seed takes weight and distributes it as seed or seed pieces across an area of production. The question is, what weight delivers the targeted plant density and what have researchers found about seed weight (size) and productivity.

Efficient and sustainable potato production starts with a target of plant density and stem density for the crop use to yield marketable tubers of a desired size and quality for the production location and resources.



Seed potato crops will drive for higher tuber counts per square metre (less tuber weight and size) than French fry production.

Planting rate also is driven by the variety's genetic characteristics and canopy development to suit the climate and grower input efficiency.

Wiersma (Wiersema, 1987) identified that stem density not plant density is the critical measure.

Figure 16. Wiersma demonstration of effect of stem density on yield and tuber size (Wiersema, 1987)

A stem acts as an individual plant and therefore drives tuber density.

Tuber density needs to reflect environmental potential, nutrition and inputs to deliver tuber size of best commercial value and quality. Doubling stem density above the environment and variety potential will not result in doubling yield. (refer **Error! Reference source not found.**). The crop production is limited by the least available r esource, Liebig's law applies.

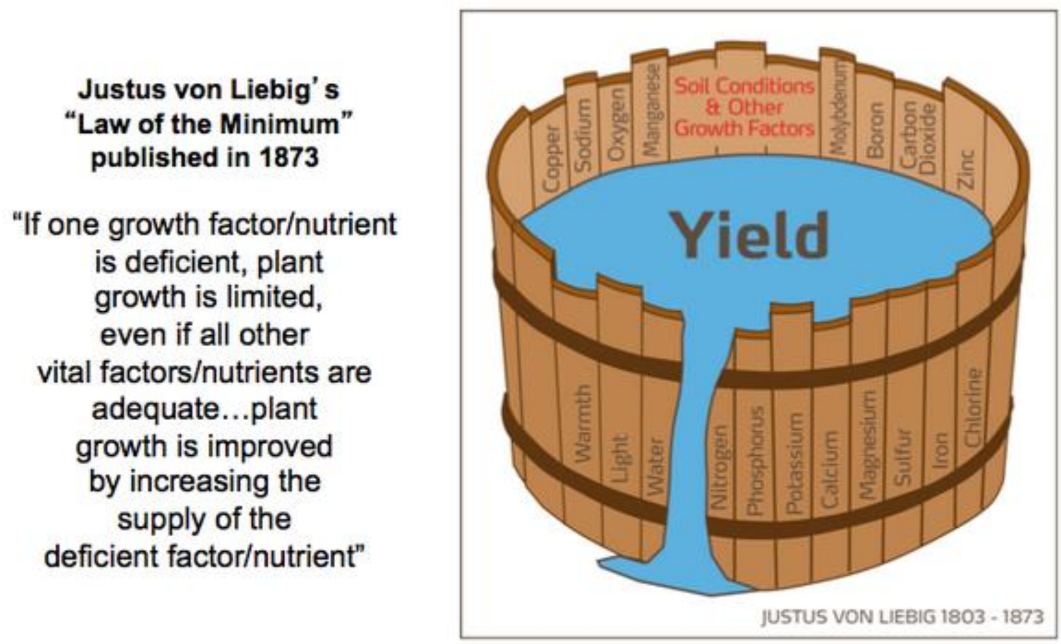


Figure 17. Liebig's law of the minimum is often shown as Liebig's Barrel with the shortest stave limiting the barrels capacity (Kemnovation, 2017)

By increasing the number of tubers per area (driven by stem density), for a given environment and available grower input, this may result in the crop exceeding available resources. The potato crop grows tubers to the available resources but tubers may not bulk adequately to meet market demand. This results in the crop value and grower return being compromised. Timely maturity may also be impacted.

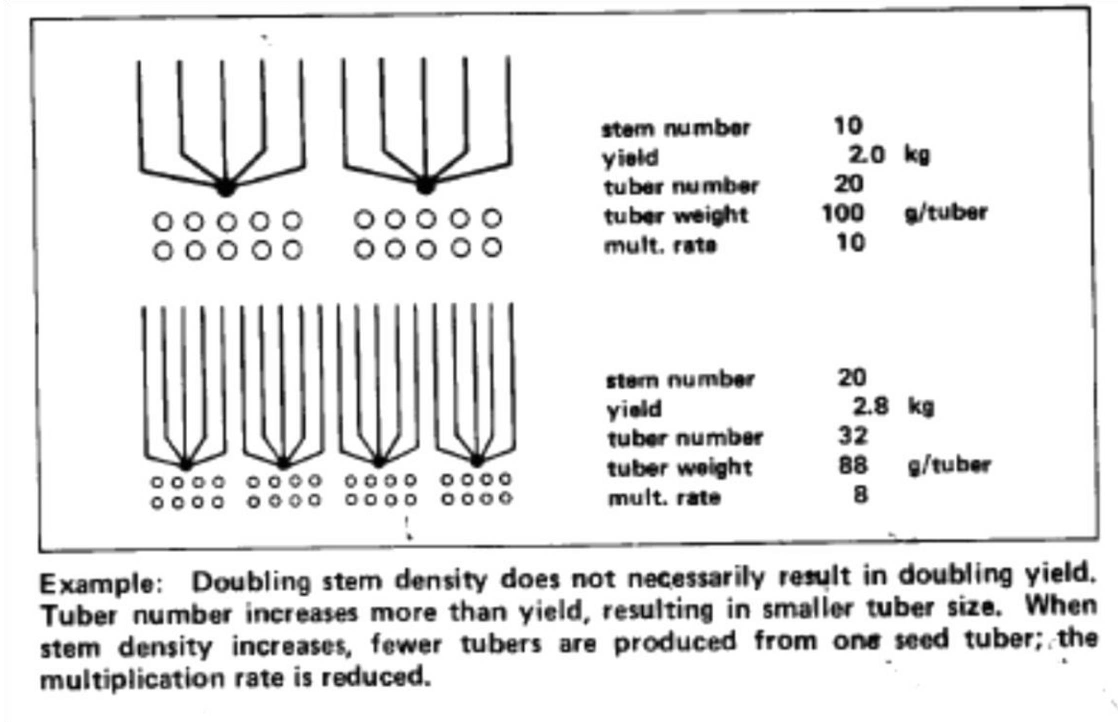


Figure 18. Wiersma showing an example of the impact of Stem Count and its relationship on Tuber Number and size (Wiersema, 1987)

Thornton (Thornton, 2014) reported that seed piece weight was critical and there was a high correlation between seed weight and yield. Thornton expressed this as weight per stem reflecting the importance of stem driving yield. The seed piece plays a critical role in crop establishment acting as the primary source of energy for the first 40 days (see Figure 19). Optimum seed weight varies by variety.

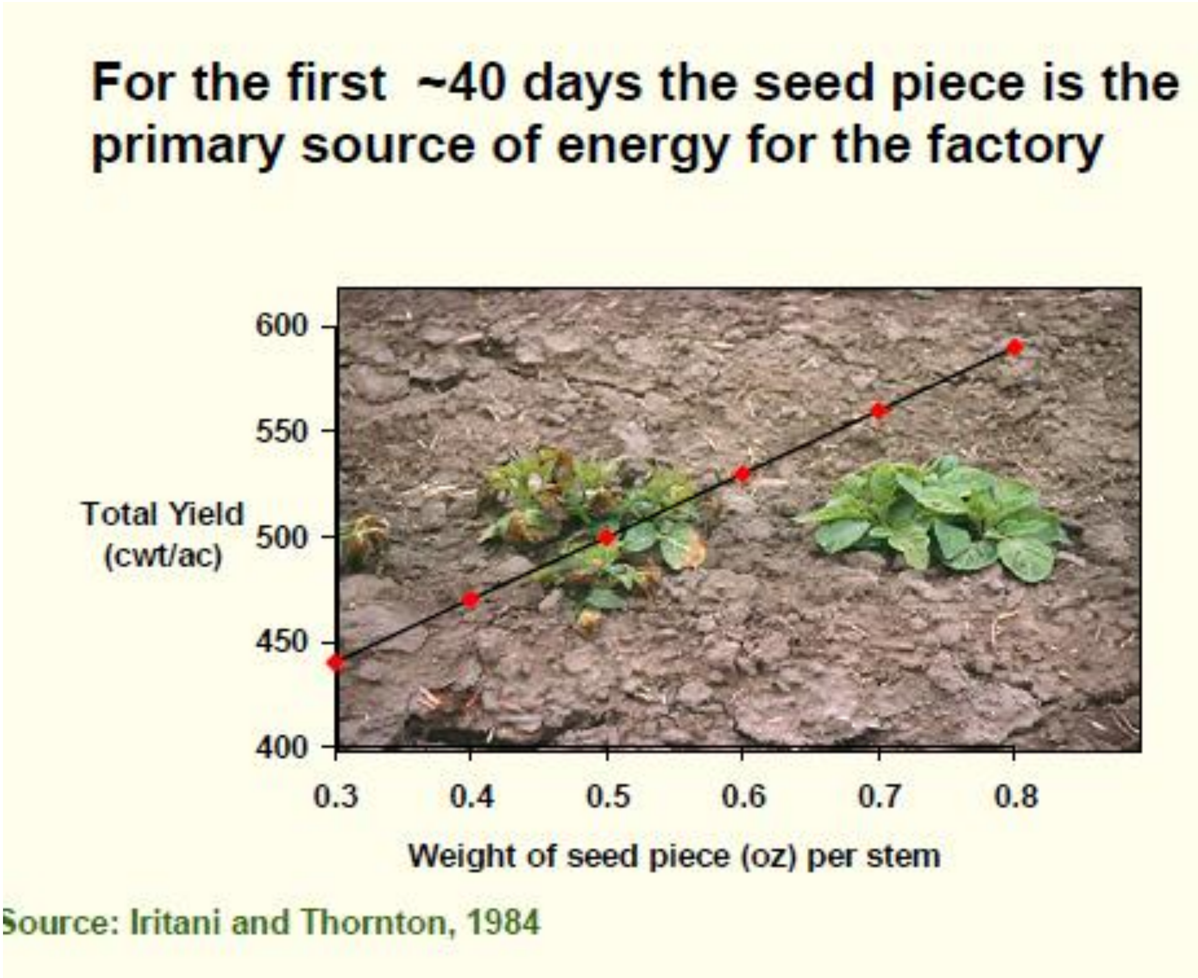


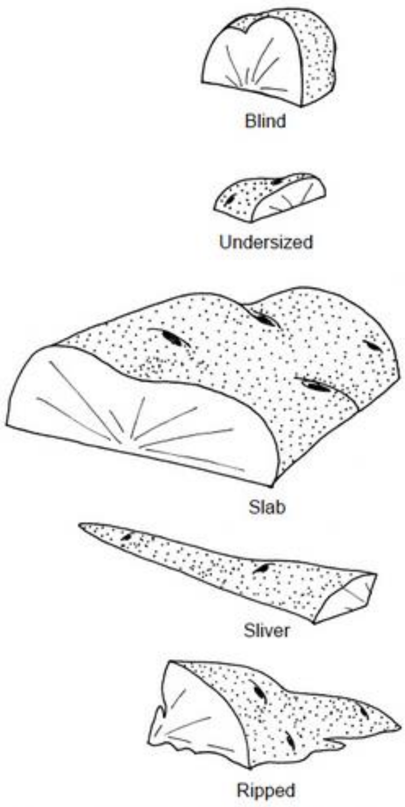
Figure 19. Thornton illustration of relationship of seed piece weight per stem on yield (Thornton, 2014)

Seed piece spacing and row width are critical decisions to develop the optimum stem or plant density to produce best sized tubers for sale. Optimal plant density or stem density is critical to ensure effective canopy coverage that drives fundamental photosynthesis efficiency and sustainable irrigation efficiency.

Johnson (Johnson, 1997, 2015) identified issues of cutting and seed piece size impacting yield performance. It was important to avoid seed pieces of poor shape and seed pieces should be "blocky" 1.75 oz. (50 gm) in size. Eye distribution of the variety must be considered, e.g. "Atlantic" and "Shepody" 2 oz. (57 gm), but Russet Burbank is 2.5 oz. (70 gm) as it has less eyes per tuber.

Potato planters need 70% seed between 1.5 oz to 3 oz (40 to80 gm). Larger seed pieces are associated with higher yields but risk higher bruise (leading to break down) and dehydration with a larger cut surface area and generally have a slower emergence.

Oversized cut seed causes more skips, undersized seed pieces contribute to more doubles or triples (wasted seed and incorrect stem density).



Sizes of potato piece affects early plant vigor

Bohl in 1994 (Bohl W. , 1995) wrote an industry extension paper that discussed the relationship of seed piece weight, physiological age and the conversion of seed tonnes to stem and plant density.

The productivity of the potato crop planting depended on plant spacing, stems produced by the seed. Planting rate (cwt/acre) varied by seed piece size (weight) and the plant spacing (row width by seed piece spacing in the row). Seed 1.5 oz. (40 gm) to 3 oz. (80 gm) are best not cut. Seed greater than 10 oz. (280 gm) should not be used or cut.

Care should be taken with cutting varieties that have few eyes. While cutting seed influenced physiological age, young cut seed may still produce less stems than required.

Bohl cited research work by Iritani (Iritani, 1984) et al that showed seed size influenced yield but this trend diminished when seed pieces were greater than 2.5 oz. (70 gm) and in most cases seed pieces between 1.5 oz. (40 gm) and 2.5 oz. (70 gm) was optimal.

Figure 20. Cut seed can produce unproductive seed pieces with poor crop potential (Johnson, 1997, 2015)

Factors influencing physiological age of seed included, growing conditions of the seed crop, bruising of seed tubers, seed storage temperature and cutting operation. Seed piece spacing should consider physiological age to ensure effective plant density, stem density and plant vigour.

Crump (Crump, 2009) published a technical paper for seed growers that summarized the impact of physiological age on seed potato quality and its productivity. This paper adapted work from Bohl et al to better reflect Australian units of measure. This illustrated potential change in stem density and potential reduction in seed weight per hectare from using a more physiologically aged seed (refer (Crump, 2009).

Table 2 . Effect of seed piece size and physiological age on number of stems per hill and per hectare with four plant spacings.

		Spacing		Seed tonne/Ha	Stems/hill	Stems/Ha
2 oz	(56.7 g)	9 in	(22.86 cm)	3.01	3.1	148303
2 oz aged	(56.7 g)	12 in	(30.48 cm)	2.26	4.1	147107
3 oz	(84.01 g)	12 in	(30.48 cm)	3.39	3.9	139931
3 oz aged	(84.01 g)	15 in	(38.1 cm)	2.76	5.1	146188
4 oz	(113.4 g)	12 in	(30.48 cm)	4.52	4.2	150685
4 oz aged	(113.4 g)	18 in	(45.72 cm)	3.01	6.2	148303

Adapted from Bohl, Nolte, Kleinkopf and Thorton

Figure 21. Effect of Seed Size and Physiological Age on Stem Numbers per Hectare at 4 Row Spacings (Crump, 2009)

One key recommendation from Bohl was to grade seed and calculate the average seed size (weight). Using this and allowing for physiological age calculate your spacing and plant rate (tons per hectare). Aged seed required a lower seeding rate through greater spacing. Older seed pieces generated more stems. By increasing seed piece spacing the stem and crop potential was similar to young seed. Young seed seeding rate required a greater weight of seed per hectare.

Jackson (Jackson, 1997) completed a research project (HAL PT 314) investigating the whole round seed performance compared to cut seed in Queensland, Australia. The study included different varieties, seed size and whole v's cut seed. Both spring and winter plantings were examined. Jackson found that there was no advantage to grading whole round seed while large whole round seed (80-150gm) produced the highest yield. Round seed advantage over cut seed increased in later plantings indicating physiological age was a critical factor in the seed decision matrix. Seed emergence of round seed was advantaged but stem count per seed piece was more influenced by physiological age.

Jackson's work highlighted the economic advantage of using cut seed, reduced planting cost, but this cost benefit was offset largely by round seed's better vigour and yield. Varieties (genetic expression) reacted differently to spacing and seed size. Physiological age influence on seed performance was more significant than cut v's round or variation in spacing.

Jackson (Jackson, 1997 (2)) published a summary from the trial work that focused on the influence of physiological age. A winter and spring planted trial used the same seed source. The winter trial seed demonstrated apical dominance and closer spacing improved yield. The following spring trial where seed had achieved more age demonstrated multiple stems with wider spacings delivering advantaged yield and returns. Jackson concluded that physiological age was a major consideration in selecting plant spacing regardless of variety.

Bohl (Bohl W. H., 2011) reported on seed piece size of three (3) varieties and its impact on yield in a trial where hand cut seed of different size (weight) were planted at different spacings but at a constant weight per hectare. Increasing seed piece size from 42 gm to 85 gm resulted in higher total yield regardless of in row spacing. Economic return for Russet Norkotah fresh pack (tuber size distribution value less seed cost) was higher for 85 gm seed piece compared to 42 gm or 64 gm all at 40 cm spacing. Economic return will depend on cost of seed and selling price of harvested potatoes.

4.2.3.1 CUTTING OF SEED, ITS IMPACT ADVANTAGES AND OPPORTUNITIES

The periderm (skin) of the potato is a complex cellular structure to protect the tuber from pest and diseases and control water retention in the tuber. Damage to the tuber can result in suberisation that then impacts physiological age. Skin set before harvesting of tubers is important to prevent seed break down, rapid weight loss and disruption of physiological age in the seed parcel.

Cutting seed aims to manage seed piece size, reduce cost of planting material and break dormancy. Cutting seed does not increase bud number and assumes that non-apical buds of whole seed will not break dormancy (seed is young in physiological age) if planted uncut.

Lulai (Lulai, 2016) in 2016 completed work looking at the physiological aspects of wound healing and suberization in potatoes. Networking and co-ordination plant growth hormones in regulation of wound healing process is not well understood. This research showed wounds induced cytokinin biosynthesis although transient followed by increased activity of Auxins IAA. Gibberellins activity was not seen. This concluded that cytokinin and IAA were critical in wound periderm activity.

Neilsen (Neilsen, 1989) completed research looking at the impact of variety and seed size on the number of blind seed pieces when cutting seed. This work established that Russet Burbank on average had twice as many eyes as Nooksack. Nooksack cut from smaller seed (28 gm) had 24% blind seed pieces. Nooksack seed cut from larger seed tubers had greater bind seed pieces. Nooksack had a 96% stand when cut from 84 gm to 140 gm seed compared to 74% when cut from larger seed 252 gm to 280 gm.

Sterret (Sterret, 2015) of Virginia State University summarizes the importance of seed quality and physiological age in potato production. The report also identifies that seed size and eye number on seed pieces is critical for effective production.

Strengths	Weakness
• Reduces planting cost of seed per acre • Helps use larger seed • Extend development of new variety • Ages seed reduce apical dominance	• Breaks the periderm • Increases moisture loss • Time and cost input, handling and curing • Large seed (greater 70 mm) still problem in cup planter • Waste and scrap • Vary cutting by variety • Ages seed (excessive physiological age) • Variability in age impact depending tuber size and cutter blade sharpness
Opportunity	**Threats**
• Drives early dormancy break • Reduces apical dominance	• Transmission of diseases, viruses • Blind seed pieces • Damage of seed piece • Small seed pieces • Damage to sprouted seed • Drives excessive seed age

Table 1. Some Strengths, Weaknesses, Opportunities and Threats of Cutting Seed

Crump (Crump, 2009) summed up the equation of stem density in the diagram in Figure 22 below. The grower targets the stem density to fit the environment, grower inputs, and target tuber size to optimize yield and productivity. Cutting of tubers adds an additional complexity to managing this equation. The grower's decision is based on managing seed cost (Jackson, 1997) but this reduction of seed cost may be offset by reduced quality and yield.

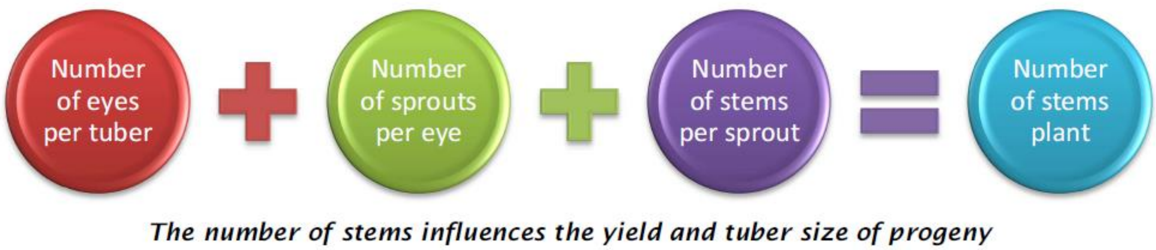


Figure 22. Stem Count per plant as a product of Variety (eyes per tuber), sprouts and stems **(Crump, 2009)**

4.3 LITERATURE REVIEW SUMMARY

The literature survey has identified papers, articles and resource material that talks to the core question of this research project

"How does Seed Quality and Handling Impact Potato Production in Australia"

The following summary identifies the core findings of this literature survey. The Grower Survey will follow how the Australian Potato Industry understand and manage these drivers of seed quality and handling.

This project is a step in the journey to find best practice and build on previous investments in research funded by Horticulture Innovation Australia, to capitalize on this grower investment.

Growth Regulators…….Terminology in seed and future consumer market sensitivity.

In this review we report on research into potatoes that use the term "plant hormones". These are naturally occurring plant generated organic compounds that regulate plant process. The consumer market may have sensitivity to the term "hormone". It is suggested that the industry adopt standard terminology referring to these naturally occurring compounds as growth regulators. The report summary, grower survey and grower reports will adopt this standard terminology.

4.3.1 Summary Seed Post Harvest Handling and Storage

Seed quality declines from the point of harvest. Effective post-harvest handling and storage is about managing this decline so as to deliver quality seed that will yield a profitable potato crop being seed, fresh or processing market.

Seed handling and storage directly impacts physiological age and cold storage will slow tuber ageing but does not stop tuber ageing. Storage is aimed to preserve seed so when delivered, it is of acceptable quality and fecundity for timely planting of the next crop.

Field conditions at harvest, particularly soil temperature and moisture, tuber turgidity and temperature directly impact propensity to damage and bruise. Handling and harvest process should minimize bruise and damage from impact and crushing. Tuber field heat should be reduced quickly but at a speed to avoid temperature shock or tuber dehydration. (note **Error! Reference source not found.**)

Storage cost is an adaptive cost of production. Sustainability and cost effectiveness relies on best management practice and adoption of automated systems using variable speed fans.

Storage humidity and air quality should be closely managed to ensure quality is maintained and the respiration rate of the seed tuber is slowed but adequate to maintain seed quality.

Storage temperature for fresh market crop and processing crop is higher than that of potato seed. Seed held at fresh market or processing crop temperature will age faster and have a shorter storage life. Potatoes held at seed temperature may be subject to cold sweetening if processed.

4.3.2 Summary Physiological Age

Physiological age is the process of change of potato bud from dormant status to active vegetative growth.

Physiological age biochemical process is still not clearly understood. ABA is a key plant growth regulator and as the balance of ABA, cytokinin and auxins changes so the buds of the potato become active. Sugars and sugar movement to the buds then drives bud development and elongation.

Chronological age and physiological age can vary. Physiological age is impacted by the crop environment, stress, maturity and variety.

Physiological age of seed potatoes can vary by

- variety (genotype) dormancy potential, its length
- the field ….across the crop field (stress, inputs, soil)
- the plant across the plant (depth and time of tuber initiation)
- the tuber across the tuber itself (apical dominance)

Handling and wounding can directly impact rate of physical age and dormancy decline. Wound healing drives cell activity respiration and dehydration accelerating biochemical activity and changing growth regulators and sugar balance

- the bruise, internal cell damage,
- the wounded periderm (skin) breach of the tuber including
- cutting of the seed, healing and suberization of cut surfaces

Stress and environmental factors can accelerate dormancy decline. Field conditions particularly temperature and tuber temperature change biochemical balance and sugars that increases physiological age.

Cold storage of seed potatoes slows the biochemical activity and reduces respiration. It does not stop physiological age. Storage temperature variation and fluctuation by even 3°c can reduce stable seed storage.

Crop potato storage temperature is significantly higher than seed potato storage. Storage of seed with crop potatoes is not compatible. Seed extracted from crop storage will have shorter dormancy. Varieties vary in their optimum storage temperature.

Temperature varies vertically in a potato seed stack with the top of the stack often up to 2°C warmer.

Storage environment including carbon dioxide/oxygen levels and humidity impact seed quality need to be well managed with adequate air changes. Rate of respiration impacts air quality. Cut or damaged seed has a significantly higher respiration rate and requires higher rate of ventilation. Stress from air quality can accelerate changes in sugars and reduce potential storage life. This results in accelerating dormancy break and increased physiological age.

There is currently no accurate method to quantify, measure physiological age and chronological time to bud activity. Best method is to assess environment and stress and then taking samples from storage and hold at warm temperatures to observe time to sprout and degree of apical dominance.

Chiting of tubers can increase physiological age but is impractical in commercial potato production.

Cutting of tubers reduces risk of apical dominance and will increase seed piece physiological age.

Researchers have identified key control agents in tuber dormancy but the mechanism and genetic trait control is not fully understood. Environment and stress impact the biochemical process of the tuber and have a significant impact on physiological age and propensity to apical dominance. Research development is now looking at genetic based traits.

The complexity of levers in physiological age and dormancy control must be better understood to better target genetic trait selection. A summary of interrelating factors that drive seed dormancy is shown in Figure 23.**Error! Reference source not found.**

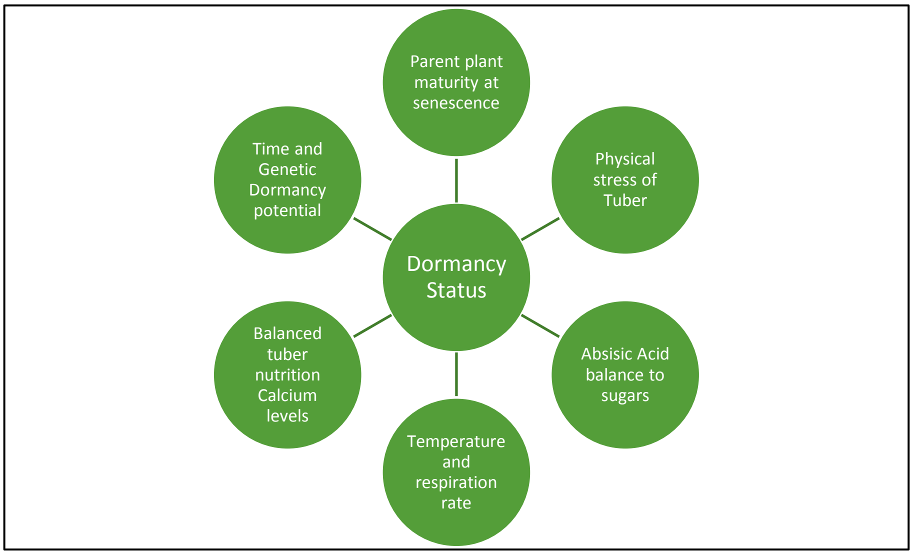


Figure 23. Some key elements affecting Physiological Age and Dormancy Status of the Potato (Philp, 2017)

The inter-relationship of growth regulators in the plant is complex. The levels of each compound and the balance of other plant compounds such as starches, complex and simple sugars influence the plant activity. To help growers understand this progression over the crops life cycle.

Calcium is critical in the potato tuber skin as it is essential for effective biochemical communication at a cellular level.

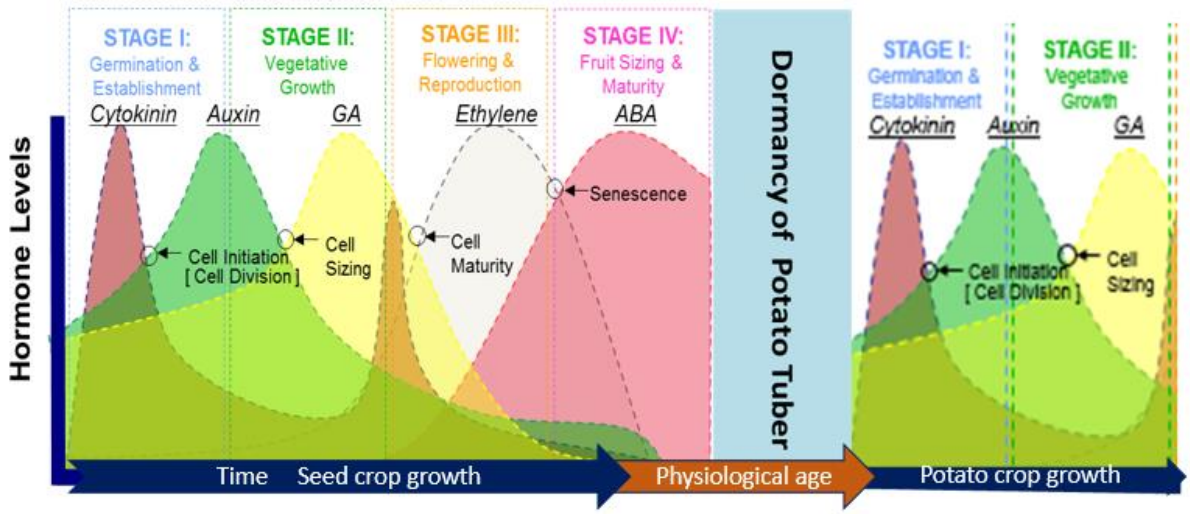


Figure 24. Diagrammatic model of the function and relationship of growth regulators in plants over the plant life cycle (Cavallaro, 2010)

Various compounds have been tested to terminate dormancy. Gibberellins did not reliably achieve dormancy break but are important in stem elongation. Movement of sugars and sugar structure in the tuber in proximity to the bud supports bud activity.

4.3.3 Summary Seed Size and Seed Cutting

Size of seed directly impacts yield and emergence performance. Optimum seed size or seed piece size depends on variety.

Round seed delivered advantaged yield and better economic return than cut seed. Variables that drove economic return is seed spacing to optimize stem density.

Stem number per area is the fundamental crop density measure. Genetic (variety) trait drives potential tuber set per stem. Stem number is driven by physiological age with young seed having more single stems and showing greater apical dominance.

Principle driver of cutting seed is economic, reduce seed cost, facilitate use of larger seed potatoes that have lower price.

Cutting of young seed improves stem numbers which is generated by increasing physiological age of seed through tissue damage, suberization and stress. Cutting of middle age seed will not increase stem numbers. Do not cut old seed as increased physiological will limit potential maturity and bulking.

Cutting of seed does not increase eye density per area or stem potential (not considering influence of ageing of cut seed).

Cutting of seed has risk associated with the breaching of the periderm (skin) of the seed including

- production of waste, ineffective seed pieces (small or irregular shape) impacting yield
- transmission of diseases, virus
- Increased risk of seed piece break down, dehydration, weight loss
- Increased cost in handling storage, seed treatments, complexity in cool store management
- Increased lead time to plant and risk of planting environment driving seed piece

Optimum seed piece size varies with variety and buds per potato. Optimum seed piece size range is 1.5oz. (40 gm) to 2.5oz. (70 gm) but this was variable by study. Variety and its genetically driven eye number influenced optimum size.

Potato planter accuracy was influenced by potato seed size, smaller seed causing double ups, larger seed causing misses. Cut seed still had physical size issue and the diameter of seed limited flow.

Cut seed size depended on decision of physiological age. There is no precise measure of physiological age.

Conclusion and critical message
Crop yield and performance is driven by stem count per area and seed size. Stem count is driven by physiological seed age.

Table 2. Key Learning Crop Yield driven by stem count and seed size

5.0 GROWER SURVEY DESIGN

5.1 GROWER SURVEY DESIGN OVERVIEW

The grower survey will be a mix of face to face interviews supported by other delivery methods. Information will be captured through a set of targeted questions that address the core elements of the project and findings of the literature review.

Confidentiality

All surveys will be confidential to ensure privacy of the participant. Survey reports will be identified by a code only. Analysis of the data and reporting will be done at a national level to ensure that no grower or grower details can be identified.

Flow of Survey and Survey Structure Logic

Flow of the survey questions follow the seed use and seed supply function investigating key areas of grower management systems that directly influence and manage seed quality and physiological age in a logical order (refer Figure 25 and Figure 26).

Testing of Survey Functionality

Development of the draft survey to investigate key findings of the literature review was completed early October. The survey was then tested with two growers. These growers are industry leaders and provided valuable feedback on the functionality, practicality, suitability and relevance of questions. Changes were identified and actioned into the survey document. The final version of the survey was completed and reported to Horti Innovation as a Milestone.

Survey to Action

The grower survey was then actioned in October 2017 to target key growers of seed, commercial growers across the Australian Industry. The objective of the survey was to be scalable, relevant to the industry, practical and allow growers to respond with truth and candour.

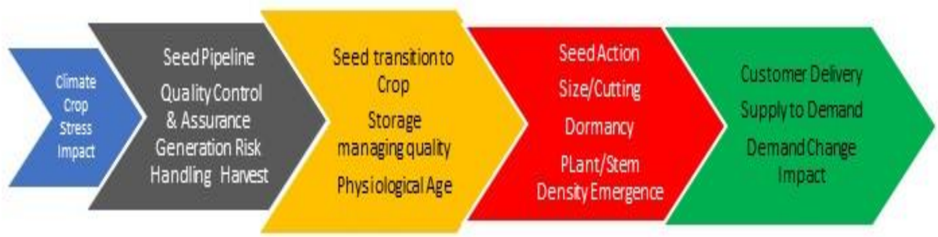


Figure 25. Potato Seed Flow Model from Seed Crop to Customer Supply

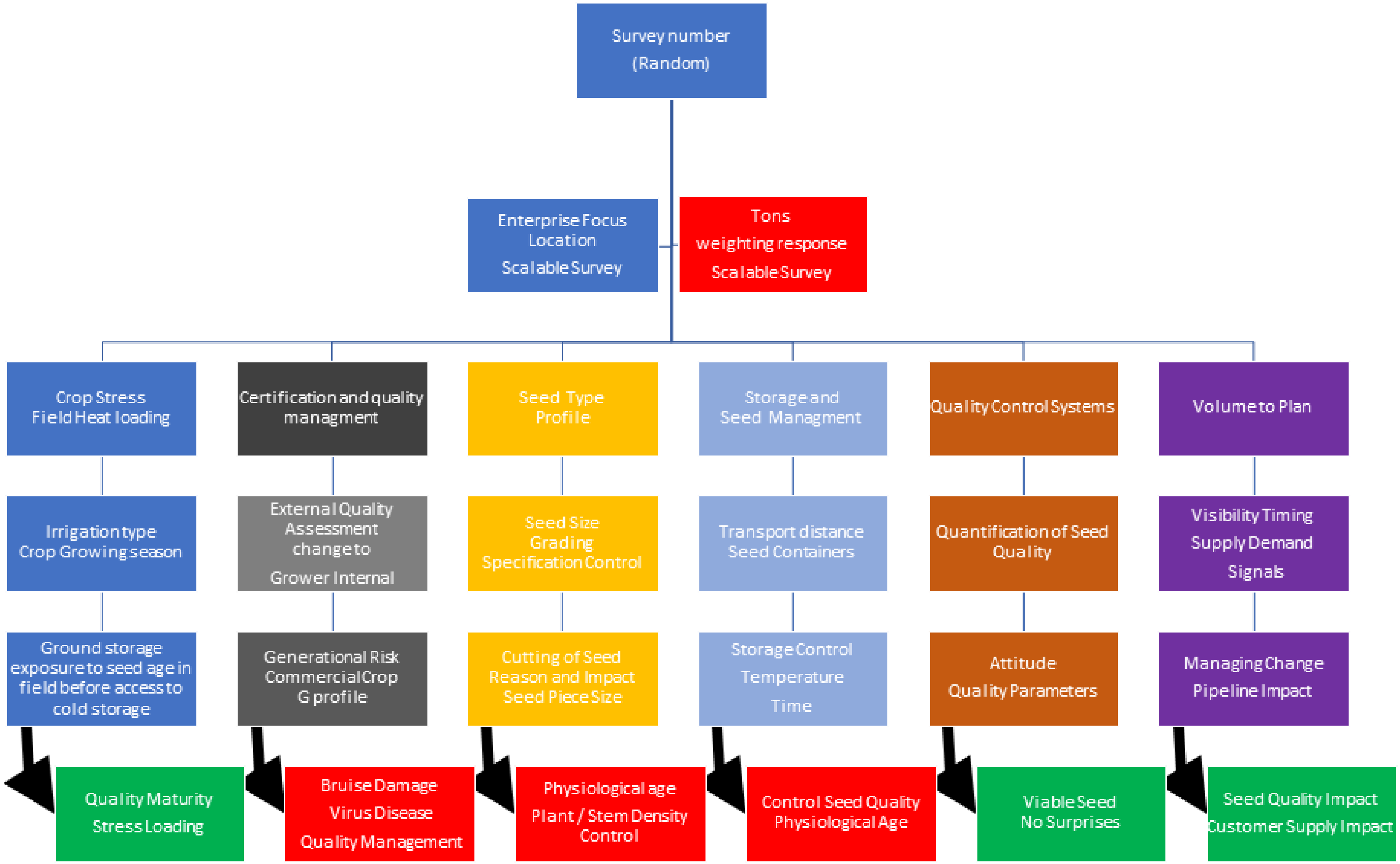


Figure 26. Grower Survey Questionnaire structure, design logic and flow

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HORT INNOVATION PROJECT PT16000

A REPORT ON THE 2018 SURVEY OF THE AUSTRALIAN POTATO INDUSTRY INVESTIGATING POTATO SEED QUALITY AND HANDLING AND ITS IMPACT ON THE AUSTRALIAN POTATO SUPPLY PIPELINE

Hort Innovation

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EXTENSION ACTIVITIES FOR THE AUSTRALIAN POTATO INDUSTRY – LITERATURE REVIEW AND SURVEY 2016/2017 PT16000

THE IMPACT OF POTATO SEED QUALITY AND HANDLING ON POTATO SEED PRODUCTION, PROCESSING AND FRESH MARKET PRODUCTION

Hort Innovation Strategic levy investment | POTATO – FRESH FUND | Hort Innovation Strategic levy investment | POTATO – PROCESSING FUND

The strategic levy investment project Extension Activities for the Australian Potato Industry – Literature Review and Survey 2016/2017 (PT16000) is part of the Hort Innovation Potato – Fresh Fund and Potato – Processing Fund.

Funding

This project has been funded by Hort Innovation, using the Potato - Fresh Fund and Potato -Processing Fund research and development levy and contributions from the Australian Government. Hort Innovation is the grower owned, not-for-profit research and development corporation for Australian horticulture.

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1. EXECUTIVE SUMMARY

Hort Innovation Project PT 16000 reviews the Australian Potato Industry Seed Handling and Seed Quality.

A literature review was completed looking at latest trends and research in Seed Quality. A survey was then completed across the Australian potato supply chain to investigate opportunities to drive sustainable, economic industry improvement.

The Australian Potato industry is geographically diverse, supplying fresh market and processing potatoes. Variety and climate impacts supply continuity and quality. Supply chain customers were surveyed to understand their key success elements that impact the supply chain. Relationships, grower economical sustainability and communication were pivotal to support consumer safety and deliver no surprise quality, with in full on time supply.

The Potato Industry Supply chain is long, 5 to 6 years. Seed quality and handling is business critical for the chain success. Certification, management of quality and physical seed management including cold storage were found to be well controlled compared to research data.

Key elements identified for driving a stronger, efficient and sustainable supply chain are:

Physiological Age Control

Improve understanding of physiological age, timely control of crop maturity, handling and storage. Adopt technology measuring, logging Physiological age (P Age) parameters, field climate, stress, storage temperature and storage environment (CO^2, O^2).

Communication

Increased cross chain communication, in season updates, long term vision to drive best estimate of demand, supply continuity, variety security. This will drive chain efficiency, reduce waste and achieve improved supply performance. Seed certification documentation to carry supplementary seed specification data on P Age factors.

Planting density, Seed Unit Density, Seed Planting Potential

Accurate seed piece size with stem potential to drive accurate stem density. Improve logistics and handling efficiencies by optimizing seed units per ton, industry sharing of a better chain profit. Optimize cut seed to reduce waste and cuts per ton. Use of Physiological age plus nutrition to drive seed tuber set.

Scalability, District Seed Brand Integrity

Identify strategies to build seed grower profitability though scalability initiatives, co-operation, contracted shared services and storage. Communication, extension, development of district grower groups seeking improvement through best practice to score card, quantifying sustainability and district performance.

The strategic levy investment project Extension Activities for the Australian Potato Industry – Literature Review and Survey 2016/2017 (PT16000) is part of the Hort Innovation Potato – Fresh Fund and Potato – Processing Fund.

2. INTRODUCTION

Project PT16000 was commissioned by Hort Innovation to complete a literature search and identify information and research on potato seed handling and quality. A report on the findings of the literature report was submitted to Hort Innovation. This report identified many key elements discussed in a wide range of papers, guidelines and research from researchers, industry leaders and particularly university research and extension groups across Europe, North America and South America.

A survey for Australian growers was developed to focus on the key elements identified in the literature review that addressed seed handling and quality. The topics that were investigated included:

- Irrigation method and time of production (Environment)
- Storage, storage infrastructure, transport and transport distance
- Management and quality control systems including generation
- Seed cutting and seed size
- Physiological Age and plant density

Face to face interviews were used applying a standard script which validated cohort comparison in the survey results. The survey method was effective with growers freely sharing their time and contributing in confidence. Surveys were also distributed personally to growers for them to complete and return in a postage paid envelope. Limited responses were achieved using this channel. Electronic grower surveying was also used to cover more fragmented industry sections.

The following paper summarizes the findings of the survey and identifies opportunities including areas of potential extension. The report is at the national level and maintains grower confidentiality.

Seed potato production is a critical link in the Potato Industry chain of supply. The Potato Industry delivers a perishable raw material to industry participants for conversion and value adding, eventually received by the consumer. The supply chain requires strong efficient linkage to enable sale and generation of value to return sustainable income and profit to the chain.

A focused survey was also completed with key potato grower's customers. This customer survey highlights core critical success platforms that will enhance the Potato supply chain (Seed to Crop) sustainability, efficiency and value to its customers.

Project PT16000 is an investment of industry research funds. This report summarizes conclusions and identifies extension opportunities. It works to establish a pathway forward to delivering improved seed quality and therefore productivity. To grow sustainable efficiency and deliver a positive return on investment for the grower investment.

Improving potato seed quality and handling is part of industry continuous improvement. Continuing investment into research and extension is essential to leverage the rapidly changing landscape of genetic development (variety), smart technology (data measuring and reporting) and satisfy the increasing complexity of consumer demand. The report must be translated into industry value through practical extension and communication.

3. METHODLOGY

Methodology used in Project PT16000 is set in the initial project brief and submission. This section of the survey report is included to frame up this scope, industry level and the project process. This qualifies the quantified conclusions and findings of the survey report and data included in the following report.

This report reflects the status of approximately 99% of the Australian potato industry by volume in regards to seed quality and handling and its impact on the potato industry supply chain.

3.1 LITERATURE REVEIW

Project PT16000 includes a literature review report into potato seed handling and quality which established a foundation for the subsequent analysis of the Australian potato industry seed handling and quality.

A report was completed as part of Project PT16000 and is included as an Appendix to the project report (Refer Appendix 1 (Philp & O'Brien, The Impact of Potato Seed Quality and Handling on Seed Potato, Processing and Fresh Market Production, A Literature Review, 2017).

A literature search was actioned on the subject of potato seed quality and handling looking at research and advisory reports, papers, lectures and extension notes. This search included all major world production areas of potatoes including North America/Canada, South America, Europe, Asia and Oceania (Australia). Research searched from 1940's to 2017.

This information summarized in the literature report framing up research and extension of key elements of potato seed handling and quality that influence yield, quality and crop performance. This includes seed handling, seed (physiological) age, storage and seed size, seed cutting.

A summary of the literature search report findings was reported to Hort Innovation SIAP at a meeting in January 2018. A copy of this power point presentation is included as an appendix in the PT16000 project report (refer Appendix 5 Project PT16000 Literature Review Summary a Power Point Presentation to SIAP January 2018) (Philp, 2018).

A survey script was developed to drill down on core elements identified in the literature review. The structure of the survey script aims to investigate the status of the Australian potato industry. This script design is included in Appendix 2 and also in this report (Refer Figure 4. Grower Survey Design Structure and Flow).

3.2 AUSTRALIAN POTATO SUPPLY CHAIN ANALYSIS KEY PERFORMANCE ELEMENTS

PT16000 is a project funded out of grower and industry funds. It is imperative that the project and reports focus on effective outcomes to drive industry success, sustainability and efficiency.

A supply chain model was developed from the survey work identifying general industry structure and linkage (refer Figure 1). This model helps us understand how potato seed handling and quality influences the stakeholders of the Australian potato supply pipeline.

This understanding is used to focus the project report and deliver survey results, conclusions and recommendations and therefore deliver value to the industry and subsequent return on investment.

A short electronic survey was actioned. This included seed, fresh and processing industry sectors and consisted of a sample of 15 cohorts. 6 responded in full.

This survey identified the ranking of the importance of some key supply chain elements. Results of this survey are discussed in Section 4 of the Survey Report (refer Figure 2). These survey results are not weighted by volume of the respondent.

The survey script is included in Project PT16000 report as Appendix 3 (Philp, Project PT16000 Horticulture Innovation Australia Potato Seed Handling and Quality, Understanding The Potato Growers Customers Key Success Factors, 2018).

3.3 AUSTRALIAN POTATO INDUSTRY SURVEY ON POTATO SEED HANDLING AND QUALITY

As per the Project PT16000 brief, a survey of the Australian potato industry was actioned to investigate the status of the Australian industry against the key research findings that affect potato seed quality and handling.

The survey consisted of 14 questions that quantified the industry performance by cohort in the area of seed quality and management. It also analyzed growers' attitude to key management strategy. The script structure and design is shown in Figure 4. Grower Survey Design Structure and Flow.

The survey design was proofed with 3 cohorts to review its functionality and effectiveness prior to rolling out. The script was adjusted to reflect feedback and include detail relating to potato cool storage atmosphere management. The final script version is included in the Project PT16000 final report as Appendix 2.

Survey was then rolled out as a face to face interview with potato industry businesses. Each interview took between 2 to 4 hours. The survey population included all states of Australia that grow significant volumes of potatoes.

Scalability of the survey is measured in tons. The objective was to survey at least 75% of the industry benchmark volume of 1.154 million ton as reported by the Australian Bureau of Statistics, Agricultural Commodities, Australia – 2014-2015 Ref 71210D004_201415.

The survey total volume as reported by cohorts is 1.143 million tons which achieved 99% of the benchmark volume. The survey exceeded its objective volume. This gives the survey a strong foundation for the analysis of trends and opportunities.

Analysis of survey responses is by weighted average of the survey respondents reported volume (Question 2) based on a benchmark volume of 1.154 million tons. This report reflects status of the majority of the Australian Potato Industry regards potato seed quality and handling and its impact across all major sectors of the industry (refer Figure 3).

It is important that volume is used in the results analysis, not grower number. The objective of this survey is to understand the Australian industry performance against the literature review findings. The practice of a seed grower is balanced against the impact of potato crop yielded. Each cohort responses are weighted by a factor calculated by dividing the cohort reported volume by benchmark of 1.154 million tons.

Other survey methods were also tested but are not included in the survey analysis. This data is less controlled and the total volume gathered in the survey method not significant compared to face to face sampling.

A sample of 10 growers were presented with survey documents and invited to complete the survey and mail back their responses. They were briefed on the project background. Only 1 response was received and this was not complete. Electronic survey was also tested using a simpler questionnaire format (refer Appendix 4) (Philp, 2018). A sample of 60 cohorts were sent the survey (including a follow up reminder) with a response of 7 cohorts completing the survey.

Data analysis was achieved through weighted average of the response using an excel spread sheet. All data reported in the survey report is summarized at the Australian industry level. At this level of summary, the method of weighting provides a robust analysis of survey response. Reporting at this level also protects the confidentiality of respondents.

3.4 SURVEY REPORT CONCLUSIONS AND RECOMMENDATIONS

This survey report draws analysis and conclusions from comparing project PT16000 survey responses compared to the literature review findings for the Australian potato industry. This includes using attitude rating and ranking of key management strategy to manage potato seed quality and handling.

From the data analysis and using respondent comments, conclusions and recommendations have been generated and summarized in section 7, Summary Conclusions and Suggested Recommendations of this survey report.

As part of the project reporting a Power Point Summary is also prepared for presentation to SIAP (refer Appendix 6).

This summary and project report use the data and findings from the survey report and should only be taken in the context of the project PT16000. The survey data should not be used for any other purpose.

An executive summary is included in this report as Section 1 Executive Summary.

Recommendations:

1. **Extension and communication of findings to the Australian Potato Industry**
   Through media and a series of grower seminars the findings and conclusions are to be communicated to growers across key production areas. This includes Queensland, New South Wales, South Australia, Tasmania, Victoria and Western Australia. This extension is to include understanding of Physiological age, Lean Management and effective communication.
2. **Data communication through Certification Tags employing QR Codes**
   Research and communicate with leading seed certification organizations to investigate the use of QR codes and integrate electronic data transmission relating to key seed certification data.
3. **Investigate and Develop Industry adoption of Seed Count Standards Project**
   Research and quantify the advantages and disadvantaged of using seed count as a quality parameter in the Australian seed potato industry. Adoption of improved seed size uniformity and size specification can drive significant savings but may also influence remuneration for seed.
4. **Potato Seed Physiological management and control project**
   Investigate and research seed treatments that influence the growth regulator Luciferase. Luciferase influences change in Abscisic Acid and by influencing the balance of reducing sugars. This can initiate controlled potato seed dormancy break and reduction of apical dominance in potato seed.

4. POTATO SUPPLY CHAIN AND INDUSTRY CUSTOMER NEEDS AND VALUES

This project and its report is not about applied research, rather it presents the current state of practices related to seed quality and handling and points out where this differs from international Best practice.

Practical agricultural application ensures that findings can be translated into real, sustainable applied concepts and knowledge for the whole supply chain.

The report will be successful when it is used as a catalyst for sustainable development and continuous improvement by all stake holders across the potato industry.

The potato grower and potato seed grower can take the report as general information, consider it for their enterprise, and if it fits, test and develop the concepts in their situation.

A supply chain diagram (see Figure 1) frames potato seed fit in supply and demonstrates how the chain linkages can fit. As with any chain, it is the weakest link that drives risk of failure. The chain must connect with the customer's value equation. The ultimate consumer, by buying product from the supply chain, provides income inflow to the supply chain. Chain structure then feeds income and return on investment to the links (stake holders) in the supply chain.

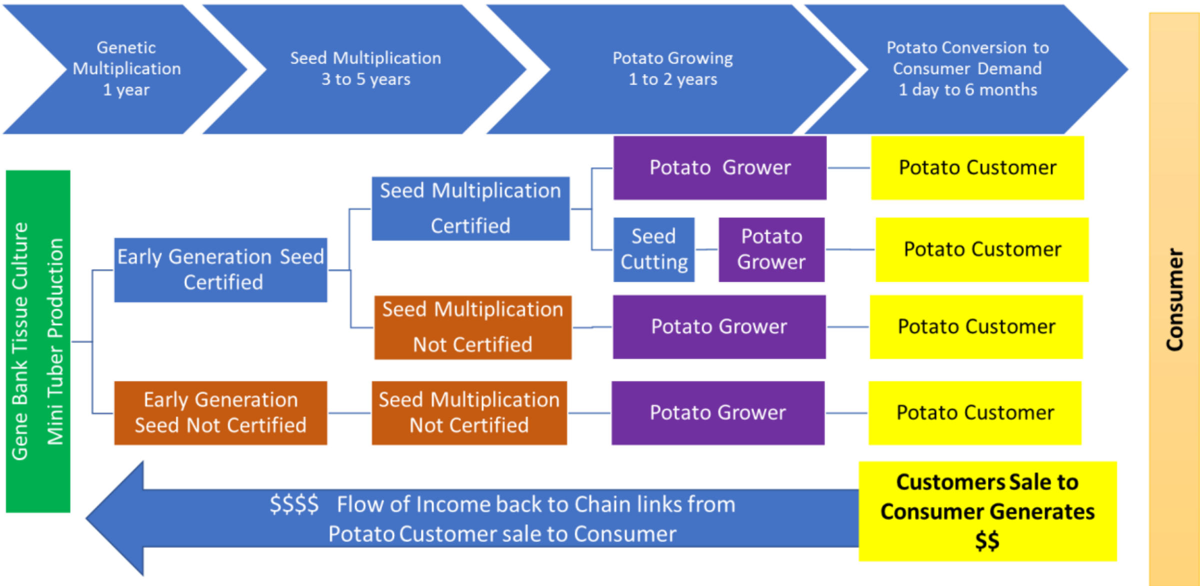

Figure 1. An example of a General Potato Supply Chain Model from Genetic Multiplication to Consumer

Seed quality and handling is a critical component that strengthens the chain.

A short survey (refer Appendix 3) with a group of leading potato growers' customers was designed to frame up some key elements that the supply chain considers important. The survey is general in nature and different sectors of the potato industry will have different needs. The potato grower should consider its customer's needs as part of their competitive advantage in delivering value to their customer.

The response below in Table 1, frames up themes and focus for the report relating to seed, seed handling and quality including:

- Trust
- Supplier / Customer alignment
- Reliability
- Economic quality and service (value)

Survey Participant Responses
Integration, Visibility, Trust
Linkage – Long lead time means should be connection from end user back to seed development
All involved in the Supply chain are aligned and are clear on their role to meet customers' requirements
Continued emphasis on quality and service from start to finish, economically
Reliability of supply

Table 1. Potato Grower Customer Survey Responses, Key Deliverables Needed from the Potato Supply Chain

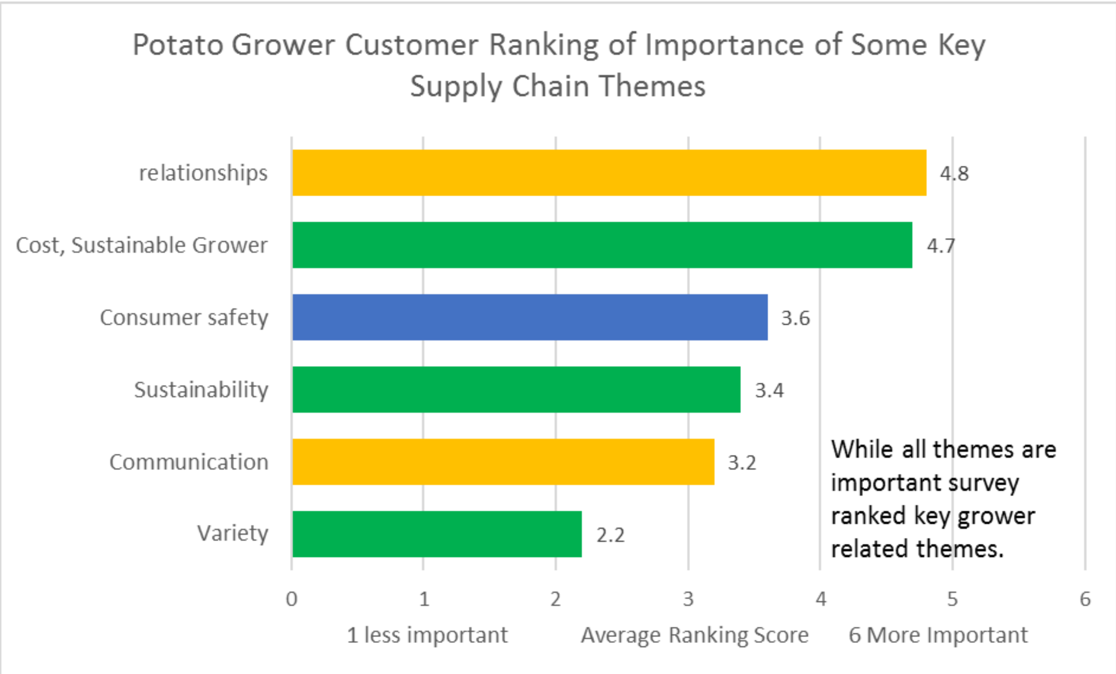

Figure 2. Potato Supply Chain Customers Ranking of Business Themes

5. VALIDATION SURVEY POTATO INDUSTRY COVERAGE AND ITS SCALABILITY

The survey was designed to investigate trends in potato seed and handling compared back to the findings of the literature survey. The project required that the survey be scalable to the industry and reflect the total industry.

Scalability and industry coverage of 99% was achieved against the survey benchmark#.

Respondents were asked to indicate an estimate of potato volume by crop use type in the survey. Total volume of 1.114 million tons was achieved (Figure 3). A benchmark of 1.155 million tons of potato production is used in the survey report (#Source Australian Bureau of Statistics, Agricultural Commodities, Australia – 2014-2015 Ref 71210D004_201415).

Crop use, processing or fresh, has variation in variety (genetics) and specifications of the product (size and solids). It was important that the survey covers this industry mix.

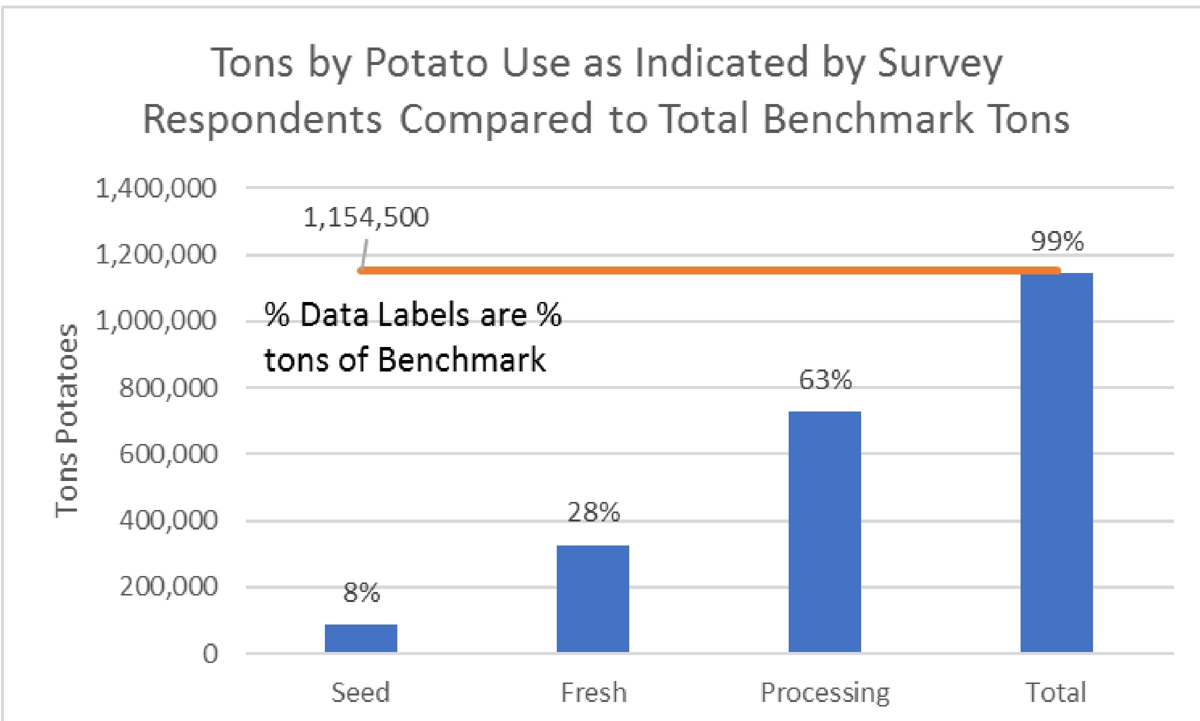

Figure 3. Tons by Potato Use as Indicated by Survey Respondents Compared to Total Benchmark Tons

This survey is not quantifying industry volume or volume of sectors. It is focused on trends in seed handling and quality. The volumes and sector splits are estimates only as indicated by survey respondents.

The survey covered New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia being states where significant potato production is carried out. Survey activity was weighted to sector volume and volume by state applying the Pareto Principle (80:20 Rule).

6. SURVEY FINDINGS FOCUSING ON CRITICAL SEED HANDLING AND QUALITY FACTORS

This report summarizes potato and seed potato growers' responses to the survey that was structured to investigate the findings of Project PT 16000 Literature Search. Survey design development is summarized in Figure 4 below.

This document's focus also considers the importance of elements reported by the supply chain customer survey.

This delivers the key learnings for the Potato Grower and Potato Seed Grower to understand and consider as general information. Taking the learnings, the grower needs to consider their management, farm structure, dimension, location and supply chain fit.

Extension of report findings and grower group discussions will enhance the value of this report as a catalyst for:

- industry continuous improvement
- sustainability and
- profitability

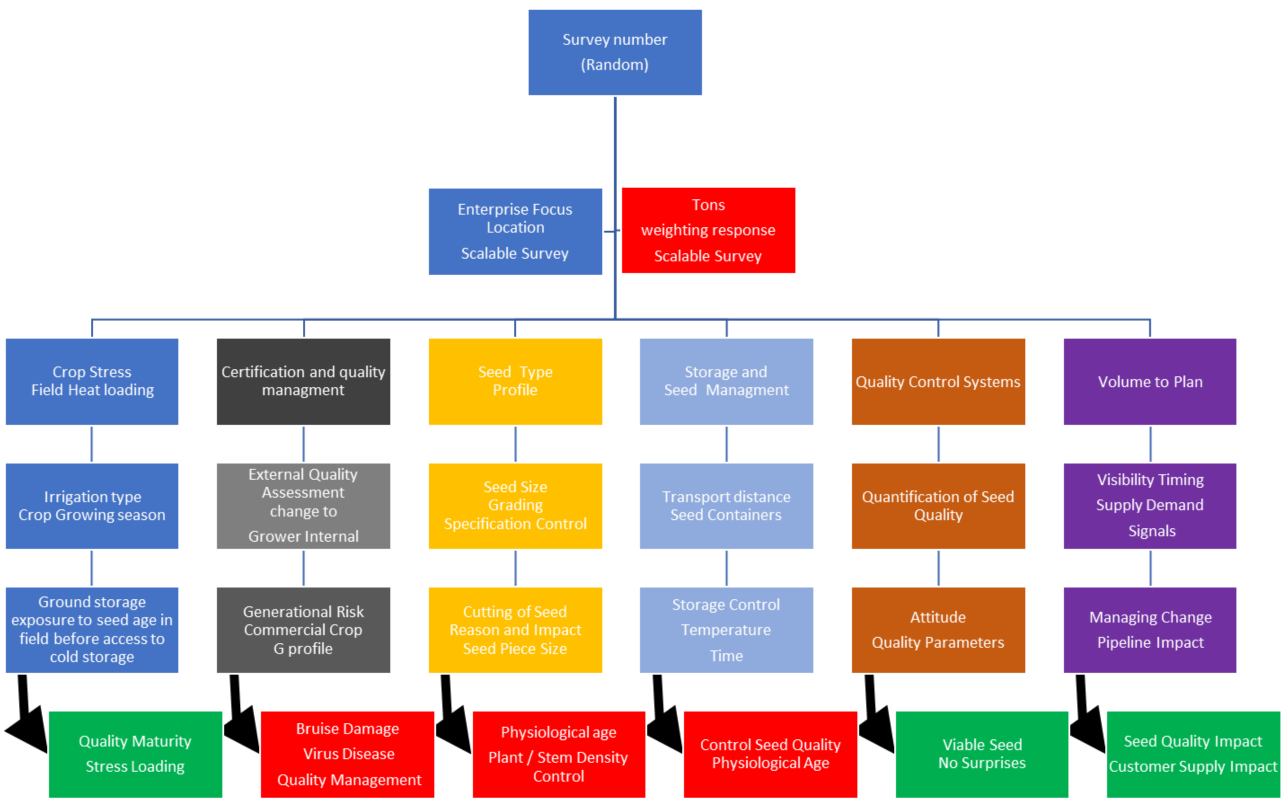

Figure 4. Grower Survey Design Structure and Flow

6.1 ENVIRONMENT AND ITS IMPACT ON SEED QUALITY

6.1.1 IRRIGATION TYPE, GROUND STORAGE AND CLIMATE

6.1.1.1 IRRIGATION

Irrigation type reflected the environment (geographic location) and precipitation pattern during the crop growing cycle. Centre Pivot was the most frequent type of irrigation (68%) with gun irrigation (20%) being the second most frequent method of irrigation. Lateral irrigation (4%) was considered less reliable than Centre Pivot and was adopted where paddock shape and land value made this type of irrigation more efficient.

Centre Pivots with variable application and paddock mapping (soil type and porosity) was best developed in Tasmania.

Semi-permanent 2% (movable irrigation pipes) and permanent irrigation (1%) was less important but more widely used in seed production.

6.1.1.2 GROUND STORAGE

Survey respondents indicated 18% of total survey population used ground storage. Ground storage varied depending on soil type, climate and time of production. Ground storage is defined in the survey as where crop harvest was deferred for more than 6 weeks post haulm destruction or crop senescence. Some seed growers used ground storage to reduce harvester capacity need, processing and grading capacity. Ground storage increases potential physiological age and can increase the risk of loss of seed quality.

6.1.2 GROWING WINDOW, SEED TRANSPORT AND CLIMATE

6.1.2.1 GROWING WINDOW AND CLIMATE

Most potato crops are grown to best fit climate and environment. There are production areas that extend growing of crop to fit customer demand and maintain continuity of supply. Cold storage is also used to extend the window of supply and hold quality of the potato supply.

Crop planting timing and co-ordination of quality seed with the correct Physiological Age is critical for controlled apical dominance, crop emergence and stem density. The alignment of seed supply with a geographic location that suits the planting window is further managed with cold storage.

Generally, crop production and seed supply for crops, where storage is used, have less time pressure (for example French Fry production in Southern Australia).

Crop production for fresh market or other processing uses (for example crisps) where finished product storage is less flexible for maintaining quality. They must have continuity of supply and control quality constraints for the end crop.

Table 2. Key Learnings Growing Window and Climate

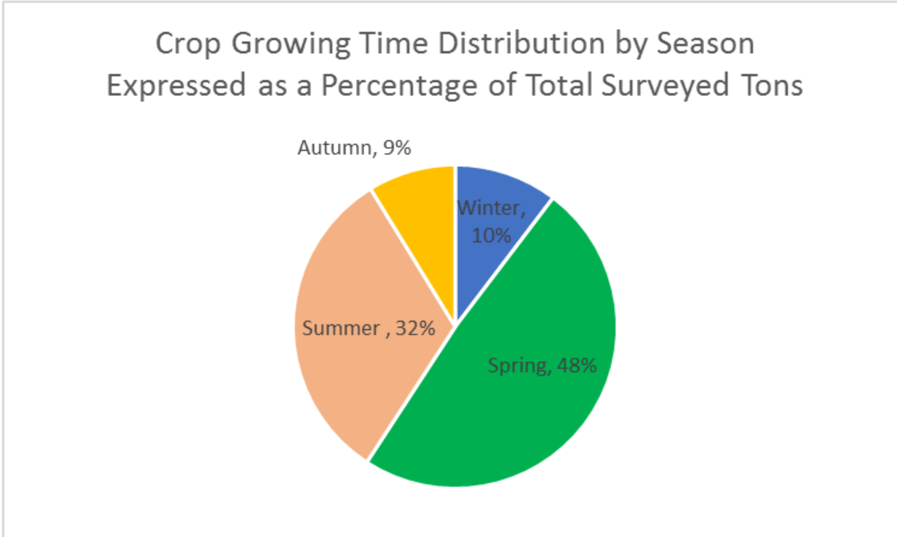

Figure 5. Survey Response Summarizing Crop Growing Season as a Percentage of Tons Harvested

6.1.2.2 SEED QUALITY, TRANSPORT DISTANCE FOR SEED, GROWING WINDOW AND CLIMATE

Transport distance and impact on seed quality is related to time of transport and ambient temperature. All seed is transported in non-refrigerated trucks either as bulk, 1 T wooden bins or 1.2 T Polypropylene Bulk Bags.

Bulk transport is used to improve efficiency of transport as 1 T bins presents a dead weight transport cost.

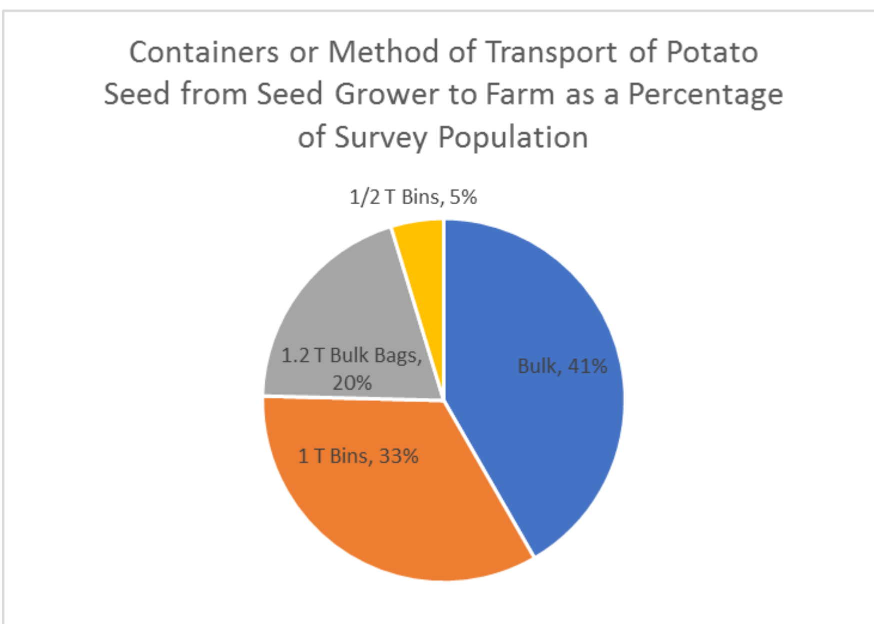

Figure 6. Seed Transport Containers used between Seed Grower and Farm

Surveyed growers preferred bulk or bins as it holds seed quality better than 1.2 T Bags. Bulk bags can cause skin abrasion (scuffing) which can drive physiological aging. Scuffing and sweating of the seed can also lead to seed break down.

Geographic location, distance from seed production to farm drives the use of 1.2 T Bulk Bags, optimizing freight cost and avoiding back loading of bins. Conversely the greater travel distance increases risk of seed breakdown and loss of quality in transit.

71%	of seed is grown off farm and requires transport
58%	of seed is transported by soft-sided tautliners or flat top trucks
41%	of seed is transported as bulk either tippers or moving floor bulk trailers
89%	of seed is transported less than 500 Kilometers
No refrigeration is used in seed transport	

Table 3. Key Learnings Seed Transport

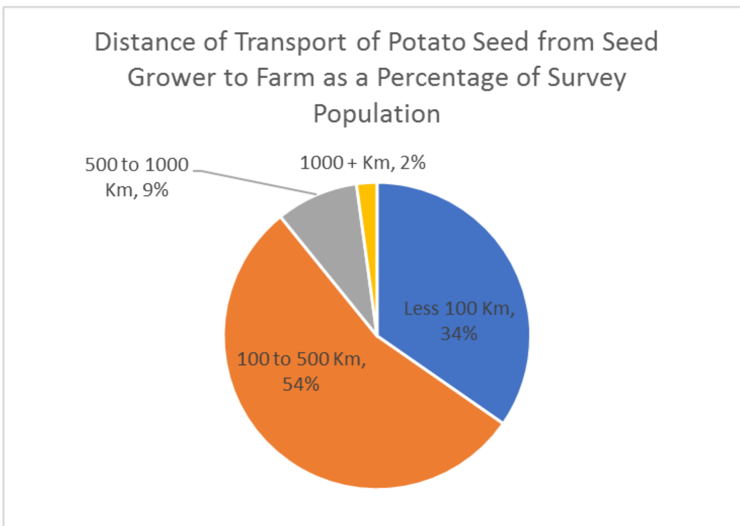

Figure 7. Distance of Transport of Potato Seed as a Percentage of Survey Population

One grower surveyed said that the transport (500 km) in a secure un-tarped truck was an advantage in helping age spring grown seed and accelerate dormancy break for autumn plant.

Risk mitigation is used to justify long haul for a percentage of seed. Geographic diversity spreads the risk but at an additional freight cost. The efficiency of the seed production location and mini tuber multiplication helps support the use of more remote seed production locations such as Kangaroo Island and southern Western Australia.

Freight cost and seed handling costs are a key consideration in seed production. Tasmania has geographic diversity in a small area through topographical structure. This allows efficient seed production while ensuring adequate segregation of production zones.

6.2 CERTIFICATION, PHYSICAL SEED QUALITY, VIRUS AND DISEASE PROFILE

Potato seed quality is a critical success factor for a strong supply chain, efficient sustainable potato production, reliable timely supply and profitability for stakeholders in the supply chain. The survey investigated how the potato industry saw quality, management of quality and the generation status of the crop.

Seed quality is measured in the certification process and is part of the condition of sale (contract) and directly influences price and demand. The certification or quality assessment can either be managed by an independent trained and accredited auditor or own management. Own management is often used to internalize seed production and reduce seed cost.

The following quality parameters form part of the quality matrix, fecundity and performance of seed:

- Seed size (measured in millimeters through a square ring)
- Physical quality and damage (a visual measurement expressed as percent defect)
- Disease or rots that are visual
- Viruses and Diseases not visual
- Physiological age allowing stable storage, timely breaking of dormancy to fit production plan
- Genetic purity, single variety, no contamination
- Generation status, Physical seed quality, virus and disease is currently managed through independent certification or grower own management

6.2.1 CERTIFICATION AND SELF MANAGEMENT OF POTATO SEED QUALITY

Seed pipeline management balances production cost, disease and virus levels to deliver quality assured seed fit for purpose. Certification involves the application of quality standards and compliance to production protocol that is enforced through crop inspections, sampling and assessment at grading by trained and qualified inspectors.

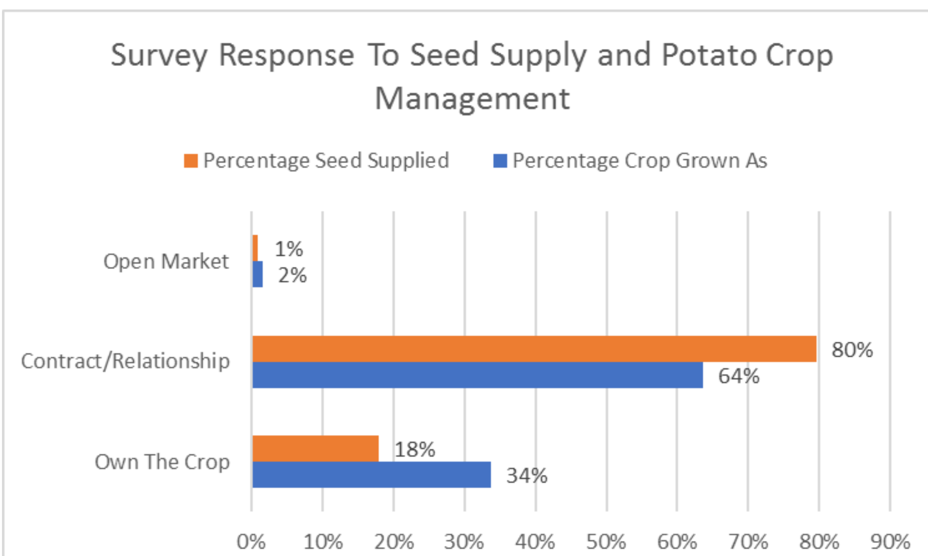

Figure 8. Survey Response Showing Relationship of Own Crop, Contract or Open Market

Overall potato seed and potato production is either directly controlled by the grower or is managed by contract or long-term relationship (verbal contract). Very little open market activity was reported.

Potato production has a significant lead time as shown in the potato supply chain diagram (refer Figure 1). Owning the pipeline, having a strong relationship through formal contract or long-term relationships (informal contract) was regarded as very important (refer Figure 8).

6.2.1.1 POTATO INDUSTRY CERTIFICATION AND INDUSTRY GENERATION PROFILE

Where potato seed passes certification, the parcel of seed receives a controlled certificate stating compliance, date of burn down, variety and generation. The certification cost is approximately $25/T (Source VicSpa Feb 2018). Certification is often a requirement of seed sale and compliance to biosecurity regulations for transport of potatoes between States.

Some growers choose to internalize the quality assurance of potato seed and not certify seed. This is aimed to reduce cost of production. These grower's need to have sound internal quality protocols and controls to consistently deliver the quality of seed.

72%	of Potato Seed planted is Certified
45%	of Potato Seed planted is planted as G3 or less

Table 4. Key Learnings Australian Potato Seed Certification, Planting Generation Profile

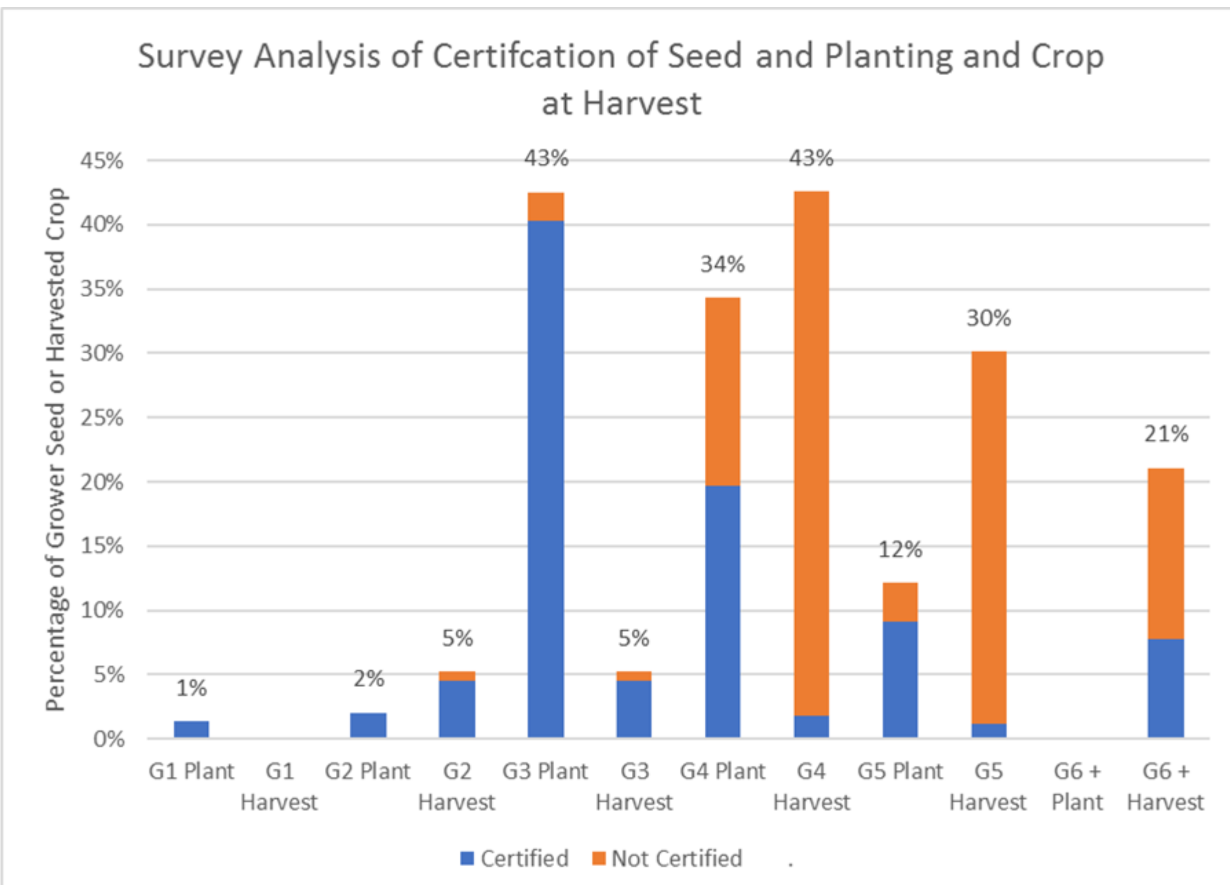

Figure 9. Graph Showing Certification Profile by Generation of Seed at Planting, Generation at Harvest

Some potato growers "bulk up seed". Early generation seed with an elite quality standard (Black label 0.2% Virus level) is purchased. This seed is then multiplied (grown and harvested as seed) for one (1) generation, before being planted for a commercial crop. While lower generation potato seed may have a higher cost, the grower internalizes some of the cost of production and reduces of freight costs.

The survey showed that over 70% of potato seed planted is certified while 20% of seed is managed internally.

6.2.1.2 POTATO SEED CROP INSPECTION AND COMMUNICATION WITH THE SEED GROWER

Seed quality and crop establishment performance was identified as a key success factor in the literature review. While still using independent certification to quantify quality, many potato growers visually inspect the seed crops during the seed crop's growing phase or while the harvested seed is being graded to better understand seed quality.

Many potato growers have formal contracts with the seed suppliers (grower). This frames up quality, price and delivery timing. Timely delivery is important to achieve management of physiological age.

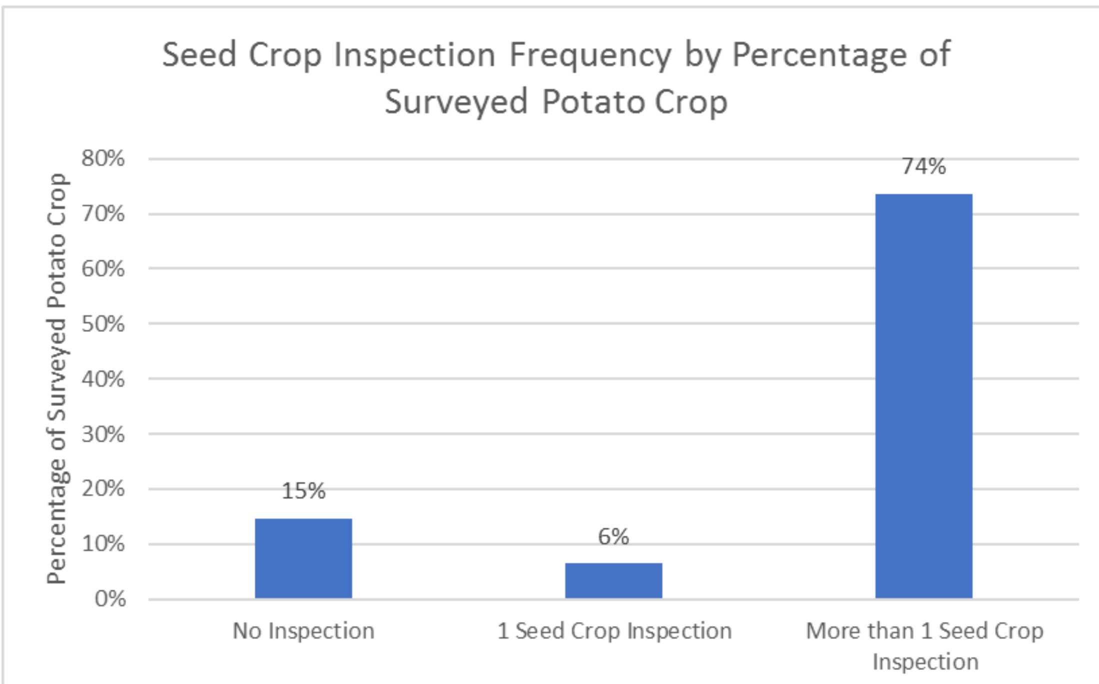

Figure 10. Frequency of Seed Crop Inspection during the Growing of the Seed Crop

Communication between the seed grower and the potato grower helps improve the understanding between the businesses in:

- production plans
- long term direction of variety demand
- feedback on quality

This allows the seed grower to better manage their enterprise to deliver their customers' expectations and strengthen the supply chain.

80% of potato grower's (by volume) visit their Seed grower and inspect the growing seed crops for that year at least one time Grower's commented that inspection of the seed crop (that generates seed for the next commercial crop) at least once during its growing is a **Critical Management task**

Table 5. Key Learnings Frequency of Seed Crop Inspection

6.2.2 SURVEY OF PHYSICAL SEED QUALITY, DISEASE AND VIRUS MANAGEMENT

Potato physical seed quality and freedom from virus and disease is critical for efficient sustainable potato production.

Certification of seed helps the delivery of quality seed to meet potato grower requirements. In section 6.2.1.1, it was identified that over 70% of crops planted use certified seed.

Generation is the quantification of the number of times a crop is planted and then harvested for seed. The Australian industry refers to this as Generation or G "x". The lower the generation the fewer times the crop is grown from its primary multiplication as meristem reproduction in agar. This is the "tissue culture" in a controlled environment. Controls and quality assurance in the tissue culture procedure ensures clean, disease and virus free plantlets are generated for seed production.

The fewer reproduction cycles (lower generation) or multiplications means lower generation seed has a higher cost. The improved crop performance from lower generation seed may offset seed cost. This is being assessed by potato growers with some sections of the industry using G3 planting material to drive crop efficiency and sustainability.

The generation profile, identified in the survey, is discussed in section 6.2.1.1 (refer Figure 9).

6.2.3 PROFILE OF PHYSICAL POTATO SEED CROP QUALITY AND VIRUS – ITS MANAGEMENT

Physical quality including bruise, break down and cracking impacts seed performance and risk of break down. The industry uses seed certification as a method to quantify seed quality. Using certified seed standards, the industry was surveyed to understand how the industry saw seed quality.

Red label certified seed has less than 5% physical defect and less than 2% virus. The following analysis uses this standard as a benchmark for all seed, both certified and grower managed as shown in Figure 12. Virus is often does not show a visual symptom in the seed potato. Virus can significantly affect potato crop yield and quality that can ultimately impact the supply chain customer. Virus is managed by production of seed in areas with low virus vector populations and geographic separation from main crops.

Virus loading in the crop is also managed through shortening the number of generations between meristem culture and crop harvest. In section 6.2.1.1, the weighted average of the Australian Potato industry generation profile is discussed. Survey results show crop age by generation as a percentage of certified crop by planted generation and harvested generation in Figure 9.

97% of surveyed volume report virus levels at less than 2% … Well Controlled 72% of surveyed volume report physical damage as less than 5%

Table 6. Key Learnings Physical Quality and Virus

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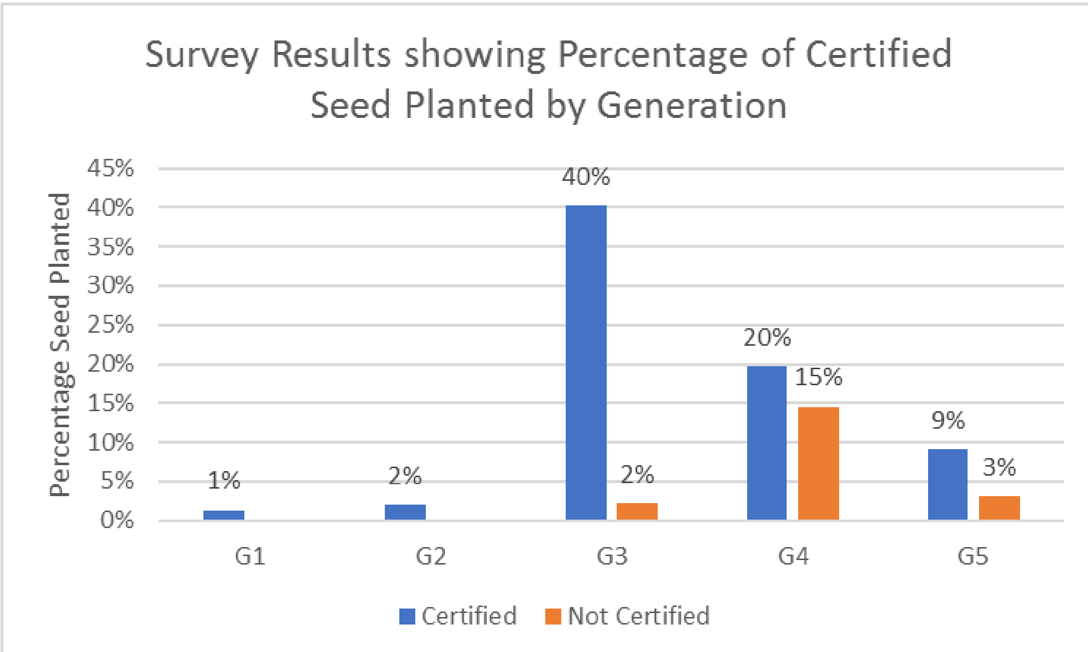


Figure 11. Survey Results showing Percentage Planted Seed by Generation Compared to Not Certified

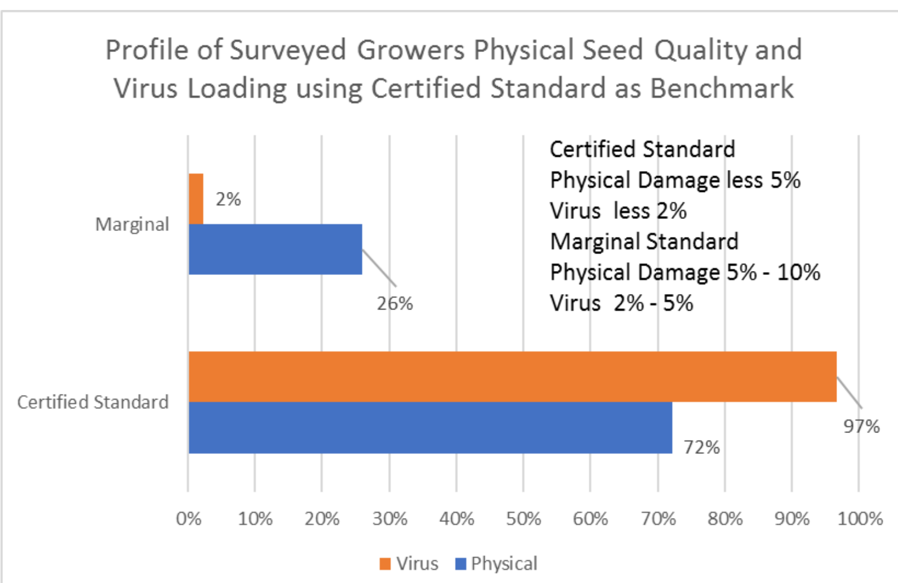


Figure 11 shows the trend of certification of early planted generations reflecting grower management of virus risk.

The survey also asked growers to estimate the percentages of seed that meet certified standard. For simplifying discussion, the data was grouped to reflect certified quality and marginal quality (see Figure 12). Marginal quality reflected a higher acceptance of physical defect compared to virus.

Figure 12. Surveyed Seed Quality Profile of Physical Damage and Virus

6.3 POTATO SEED SIZE AND GRADING STRATEGY, CUT SEED OR WHOLE ROUND

The literature survey identified that seed size was important in driving crop performance and yield. Seed size or seed piece size demonstrated a direct relationship to yield. Variety also influenced the optimum size range as well.

The survey probed Australian grower practice regarding seed size and seed cutting strategy.

Seed cutting strategy decisions are complex and includes consideration of the following factors:

- Seed shape and size and suitability for planting
- Seed cost
- Seed physiological age
- Weather conditions and risk of seed break down

Use of whole round seed is widely used where planting conditions may present risk of seed piece break down and where varieties tend to be round or oblong round.

Seed purchase and payment is driven by weight (price is $ per Ton). Seed size and ultimately the planting area potential of the seed parcel is a critical value driver of seed. Grading of seed allows the seed grower to add value. This ensures product delivered meets the buyer's expectation and contract conditions.

6.3.1 WHOLE ROUND SEED VERSUS CUT SEED

Cutting seed does not increase seed growing points (eyes) per ton or planting potential based on eye number.

Cutting seed does allow piece size and shape management. This can influence apical dominance or physiological age of the seed planting potential.

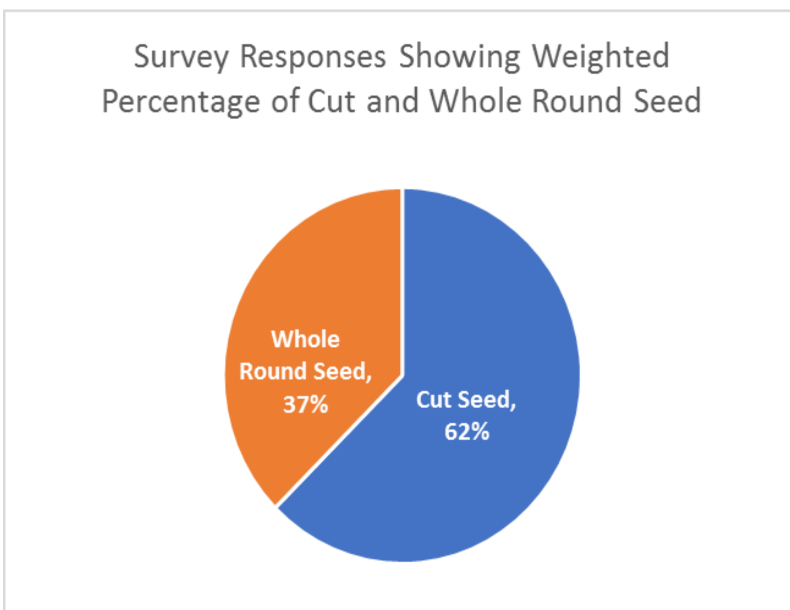


Figure 13. Survey Response Showing Percentage Whole Seed Versus Cut Seed

Cutting of seed breaks the periderm (skin) and increases risk of diseases or virus transmission. This can significantly increase infection rates in the planted crop. Adequate suberization of cut surfaces is required to reduce risk of seed piece break down. The suberization process elevates the tuber metabolic rate, temperature, oxygen demand and can impact Physiological age.

Cutting of seed is an added cost and labour sink and results in wastage. Rate of wastage is impacted by seed size, grading accuracy and cutting machine technology.

The survey indicated that average waste of cut seed was 6.4%.

Using a nominal value of $750/T cut seed therefore costs $48/T in waste. The seed planting units after waste therefore have a real cost of $798/T ($750+$48) before labour or other cutting costs.

Variety selection and tuber shape reflects use of the potato. French fry prefers long cylindrical tubers compared to crisps using a round tuber. Seed shape reflects this genetic trait. Seed grading and cutting is used to generate seed piece shape and size to enable efficient planting.

Plant density and planter performance are considered critical elements in achieving yield and tubers that meet preferred size and weight. The Tasmanian potato industry has developed a specialized step in the supply chain to grade, cut and condition seed to meet optimum variety, crop and location needs.

Variety trait impacts the number of eyes per seed tuber and eye location. Cutting of seed and seed piece size needs to address this trait by using seed tuber size, number of cuts and the arrangement of cuts. Each cut seed piece must have an eye. Tasmania uses quality control to measure and deliver seed piece to specification to control seed piece potential. Each batch of seed's quality and size profile is documented. This enables very accurate seed placement and improved control of plant density.

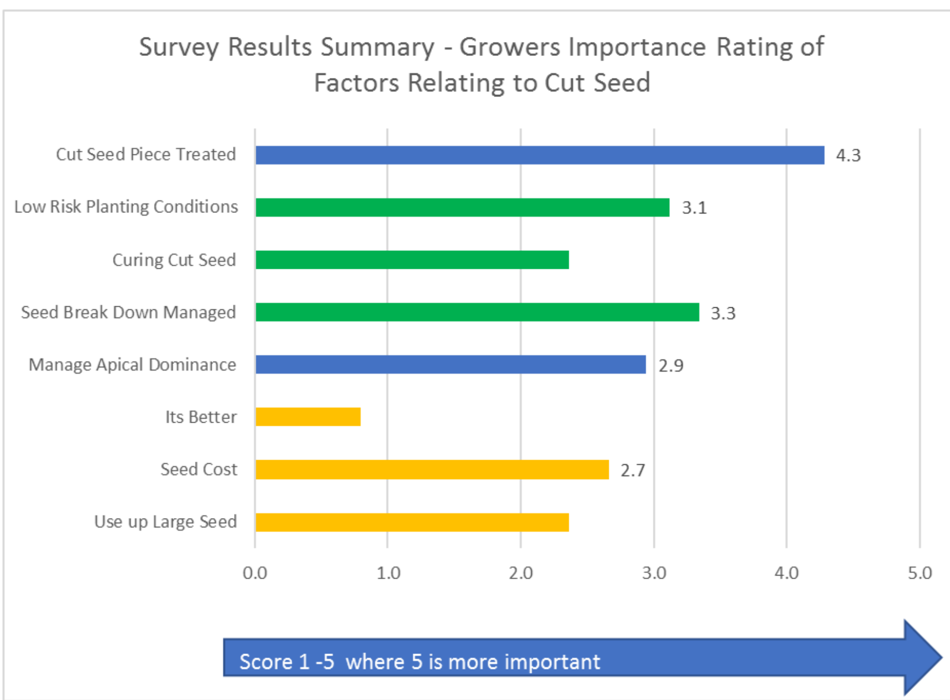
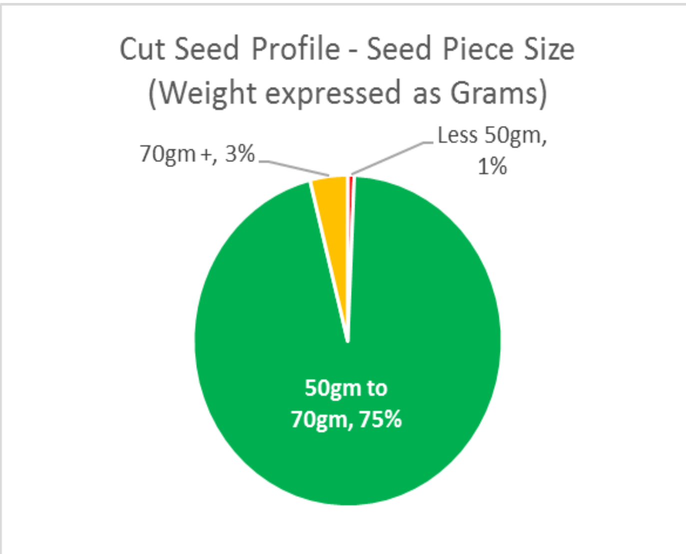


Figure 14. Grower Rating of the Importance of Factors Relating to Cut Seed

Grower use of seed treatments to aid suberization and reduce seed piece rejoining was considered important. Cut seed gives less flexibility and requires more attention to detail at planting. Management of apical dominance rated more important than seed cost reduction.

Some seed growers also commented that they cut large, unsaleable seed and planted it for their own use. This salvaged resources and reduced cost.



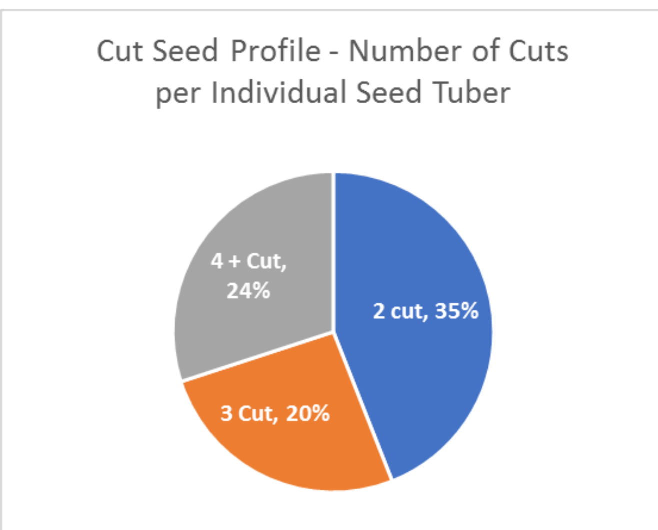
The seed cutting process management is more controlled in segments of the processing potato industry. This control reflects the tuber shape of varities used and the need to generate a seed piece size profile that improves planter performance.

Crisping and fresh market industry segments reported less cuts per seed with less quality control on the cut piece size. They often used visual assessment going for a "blocky" shaped seed piece.

Tasmanian seed production was clearly the best practice in managing seed cutting quality and delivering graded, consistent seed piece size profile and removal of blind seed pieces.

Figure 15. Cut Seed Profile – Number of Cuts per Seed Tuber

Cut seed piece weight was identified in the literature review as critical. It impacts yield and plant performance. Optimum seed piece weight varied with variety but the suggested range was 50gm to 70gm. The majority of respondents (75% by weighted Average) identified 50gm to 70gm was the seed unit size range targeted.



Growers using mainly whole round seed have less management focus on cut seed size due to variety shape requiring less cutting.

Growers using whole round seed often only cut seed greater than 65mm. This uses the seed and reduces planter issues. Cut seed is used during the season when weather and soil conditions presented lower risk for seed piece break down. Some growers mix cut seed and whole round seed to mitigate a planting failure due to cut seed break down.

Figure 16. Cut Seed Profile - Seed Piece Weight

Growers seldom cut seed to influence physiological age. However, some processing varieties tend to be apical dominant so cutting did provide improved seed performance on early planted seed.

Scalability of cutting operations clearly gave benefits in:

- Cost (cutting rates tons per hour)
- Accuracy of cutting with pre-grading and batching
- Evenness of seed lots and segregation of seed lots
- Hygiene and sanitation as standard operating procedure
- Blade maintenance (sharpness)
- Visual inspection post cutting (volume cut per hour allows cost defrayed across seed)
- Curing and cold storage facilities
- Quantified batch reports with **seed piece counts**
- Management control of quality and volume (ensuring right seed, right paddock, right volume to cover planting area)

Seed piece control through average counts per weight drives accurate planting, reducing waste. **Seed piece treatment and weather condition risk are critical good planting management.** **Aged seed should never be cut.** **Seed wastage, labour is offset by improved planter efficiency, planter accuracy = plant density management.** **Variety is main driver for using cut seed.**

Table 7. Key Learnings Cut Seed V's Round Seed

6.3.2 POTATO SEED GRADING AND SEED SIZING

Fundamental agronomic rules of potato production do not meet current potato seed sales practice.

1. Potato seed is transacted and priced as $ per ton
2. Potato seed units are planted by count per square metre
3. Potato seed set per square metre tends to be a constant, driven by variety and stem count
4. Yield is driven by average tuber weight
5. Return on investment is driven by price, by yield

(A) Seed Growers Return $/Ha ≠ (B) Seed Customers Value $/Planted Ha

(A) Seed growers return $/Ha = Seed Marketable Yield T/Hectare × Price $/Ton
(B) Seed customers Value $/Ha = Cost per Seed Unit (Seed Price $/T ÷ Seed Count/T) × Seed units/Ha

Equation 1. Traditional Seed Grower's Supply Chain Value Equation

The literature review identified that optimum seed size varied with variety. Seed size was critical for yield and the first 40 days of crop performance.

Planter accuracy improved where seed is graded into similar sizes. Seed shape increases the importance of seed grading. Oblong round seed does not “flow” as well as round seed and is more size sensitive.

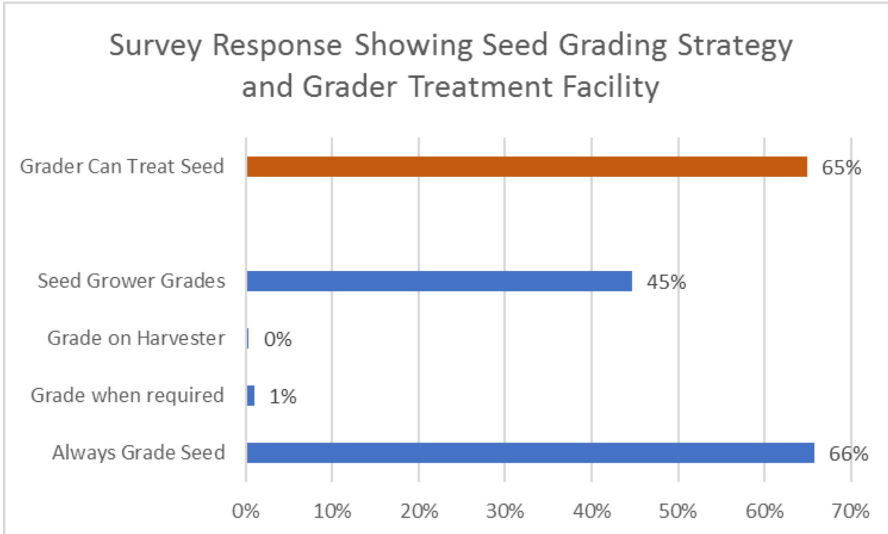


Figure 17. Survey Response Showing Percentage of Seed Graded, Seed Treatment Capability

The survey shows that most seed is graded (66%), with 45% graded by the Seed Grower. Some potato grower's grade on receival prior to cold storage as the seed is handled at this point to decant from bulk or 1.2T bulk bags.

The application of seed treatments is only possible for 65% of seed graded.

Most seed is sold (64%) graded from 35mm to 70mm size range, while some seed is split graded, 35mm to 50mm or 50mm to 70mm. Planting equipment accuracy is often challenged by seed greater than 70mm. Seed greater than 70mm has a low sales value. While it can be cut, it often becomes waste at the seed growers cost.

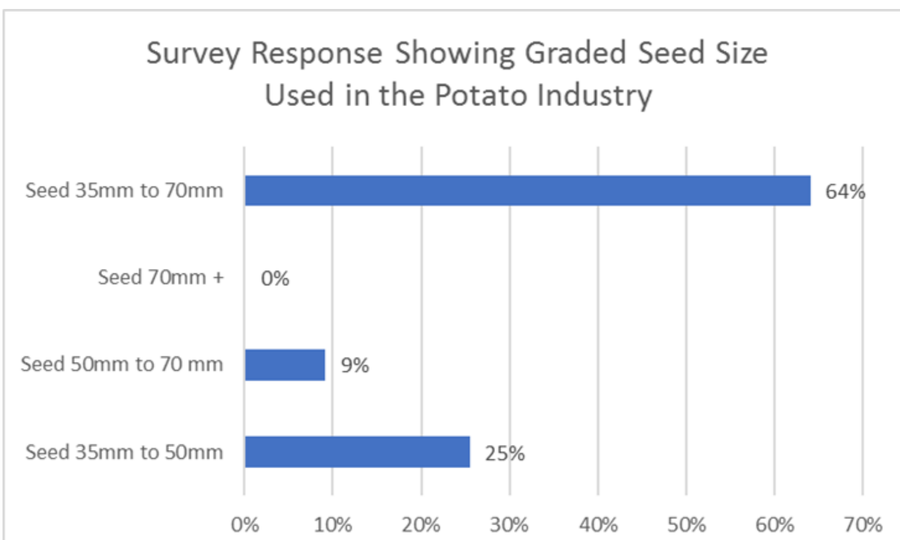


Figure 18. Survey Response showing Graded Seed Sizing by Percentage

Grower feedback highlighted variability of the planting potential of graded seed. Seed may comply to contract standard and certified standard but the seed count per 10kg can vary significantly. Seed count is the key driver to the planted area per ton of seed (refer section 6.3.3).

(D) Seed Coverage T/Ha = (E) Seed Unit Count /Ha ÷ (F) Seed Unit Count/Ton

(D)	Seed Coverage T of Seed/Ha	= Tons of seed units required per Ha at given planting density
(E)	Seed Unit Count/Ha	= Number of seed units per linear row M ÷ row spacing M x 10,000
(F)	Seed Unit Count/T	= Average number seed units per 10 kg × 100

Equation 2. Calculating Tons of Seed Required Per Hectare for Planned Plant Density

(G) Planted Seed Cost $/Ha = (H) Seed Coverage T /Ha × (I) Graded Seed Cost $/Ton

(G)	Planted Seed Cost $/Ha	= Average Seed Cost (after grading) per Ha at planned plant density
(H)	Seed Coverage T of Seed/Ha	= Tons of seed units required per Ha at given planting density
(I)	Graded Seed Cost $/T	= Average Seed Cost $/T x (1+% Waste)

Equation 3. Cost of Planted Seed per Hectare Using Seed Coverage to Planned Density

Planted Seed cost per Hectare is driven by seed unit cost per ton.
Seed buyers report varying “boldness” of graded seed and this can create surprises at planting.
Planting hectare coverage directly related to Seed unit count per Ton (also expressed as Count per 10kg).
Seed Grower Return is driven by seed yield per Ha not the customer planted area and seed value per Ha.

Table 8. Key Learnings Seed Value v's Seed Price

Note:
Seed planting potential is also directly influenced by seed fecundity and its physiological age (refer Section 6.5).

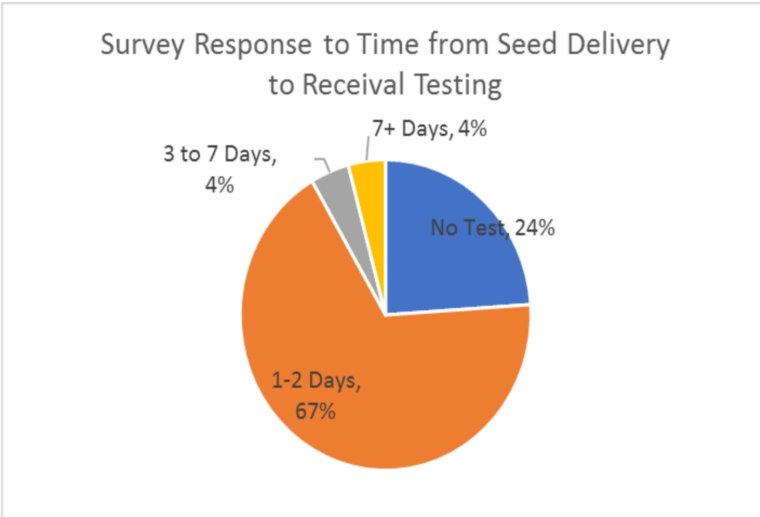
A quote from a leading Seed purchaser….”at the end of the day I buy viable eyes per Ton”

6.3.3 POTATO SEED RECEIVAL AND QUALITY ASSESSMENT CONFIRMATION

Quality assurance of seed lots meeting standards and compliance to contract terms and conditions (formal or informal), is a fundamental management tool that builds sustainable crops. This delivers customer expectations.

At transfer of ownership or management responsibility (internal transfer from seed production to commercial production) seed needs to meet the agreed quality parameters. The sooner seed quality or volume variance is identified in the chain of supply and communicated the better. Impact can be better managed……No Surprises.

The survey probed the quality assurance process to understand the industry position when reporting variance on seed quality and volume. In section 6.2.1.2, communication and grower site visits were reported. 74% of seed buyers inspected seed more than once (refer Figure 10). Seed is a critical building block for continuity of customer supply. Attention to detail is considered important and justifies investment in frequency of inspection.



The survey reports that 24% of industry seed volume is not tested on receival and relies on the seed grower delivering seed to specification and the certification process. Inspection was completed on 67% of industry seed volume.

Some larger growers with scalability have resources allocated to inspect and test seed on delivery. Should seed not comply to specification when tested the seed load is rejected and returned to the seed grower without unloading. Figure 19 shows time between delivery and seed inspection or testing.

Figure 19. Survey Response Looking at Incoming Seed Quality Testing

In section 6.3.3.1, the importance of seed unit count per ton is discussed. The survey also investigated tuber temperature assessment discussed in section 6.3.3.2 . Tuber temperature can influence physiological age and risk of tuber damage during handling.

6.3.3.1 POTATO SEED QUANTIFICATION OF SEED UNIT COUNT (TUBER COUNT)

Delivery of seed can be up to 6 months before planting. Identifying seed unit volume (T) and quality at receival and before cool storage is critical to ensure the planned planting area can be achieved at planting. In the past, potato growers would run with a surplus seed volume to cover planned plantings. However, increasing production cost, seed cost and PBR/Variety management are placing pressure on growers to manage cash flow and margin. This results in less buffer. Growers only plant crops with a firm contract or a firm market.

Seed in grade specification may be “bold” in size profile. That is, seed in the size range of 40mm to 70mm has a greater percentage of seed between 50mm to 60mm. This type of size variance can impact planted area covered per ton by 5% to 10%. A grower offered a practical example where normal planting rate moved from 3.0T/Ha to 3.7T/Ha resulting in an additional 7.0T of seed to plant a 10Ha parcel.

16% of the Survey volume did not complete any tuber count assessment or relied on graded seed sizing (refer Figure 20). 83% of volume indicates a formal quality assessment, however, some of these respondents only completed a visual inspection. This was a quick check that seed visually met the certified label conditions, size range complying to the seed specification ordered. Where the seed lot was visually ‘bold”, they would complete a quantified test.

Best Practice on Seed Receival and Assessment
A. Agreed quality specifications, variety, volume
B. Prompt assessment of delivery to confirm meets A above
C. Immediately communicate with supplier if it does not meet A above – Quantify miss

Table 9. Key Learnings Seed Quality Assessment and Communication

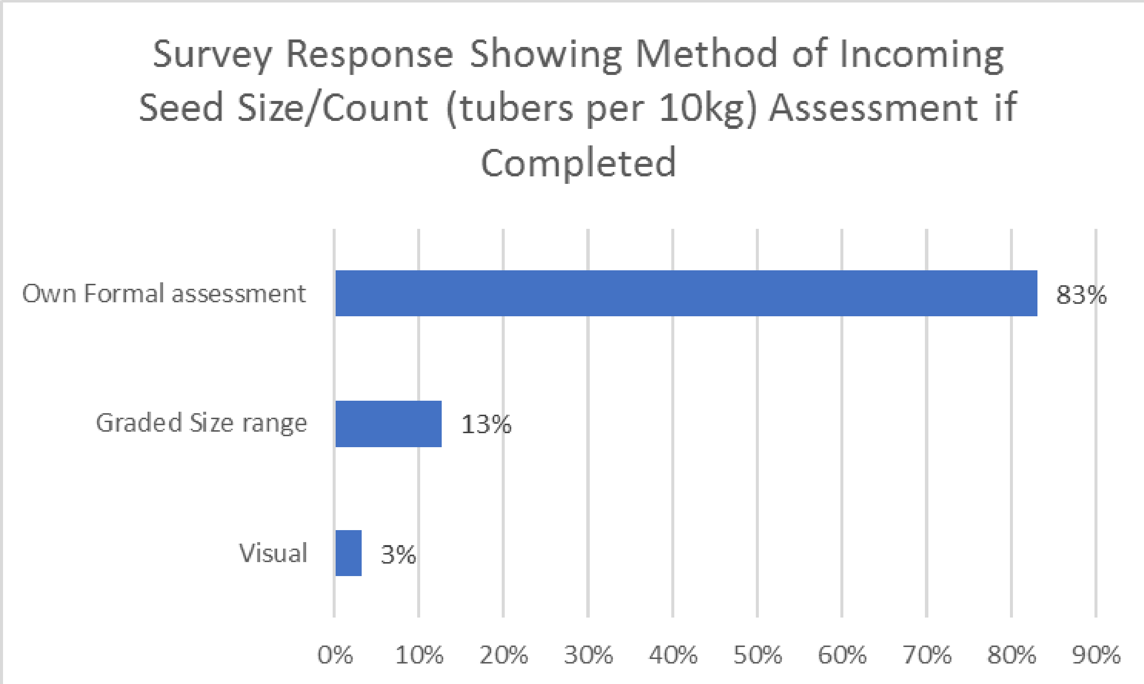
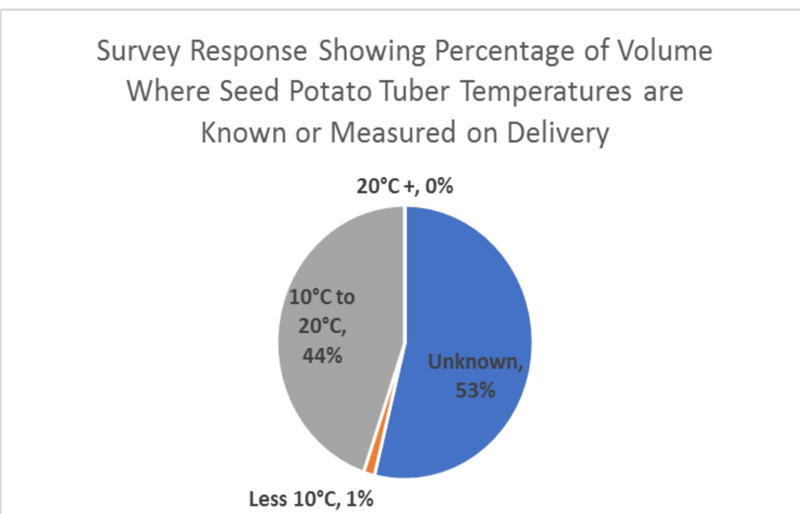


Figure 20. Survey Responses Showing Percentage of Seed with Tuber Counts per 10Kg Completed

6.3.3.2 POTATO SEED TUBER TEMPERATURE AT RECEIVAL

In Figure 21, Seed temperature at delivery is investigated. Tuber temperature can significantly impact physiological age and stable storage shelf life (refer section 6.4).

53% of growers by volume did not test tuber temperature. 44% knew tuber temperature was between 10°C to 20°C. Some of this cohort assumed temperature because seed was most likely to be at ambient temperature.



Seed is likely to be at ambient temperature because it was recently harvested, graded, or transported. It has not been placed in cool storage. Grower's commented that seed held in cool storage and graded immediately prior to transport and delivery is warmed to greater than 12°C. This is to minimize risk of potential seed physical damage and development of condensation on the seed surface. Uncontrolled condensation can promote seed rot and breakdown.

Figure 21. Percentage of Seed Volume with a known Potato Tuber Pulp Temperature on Receival

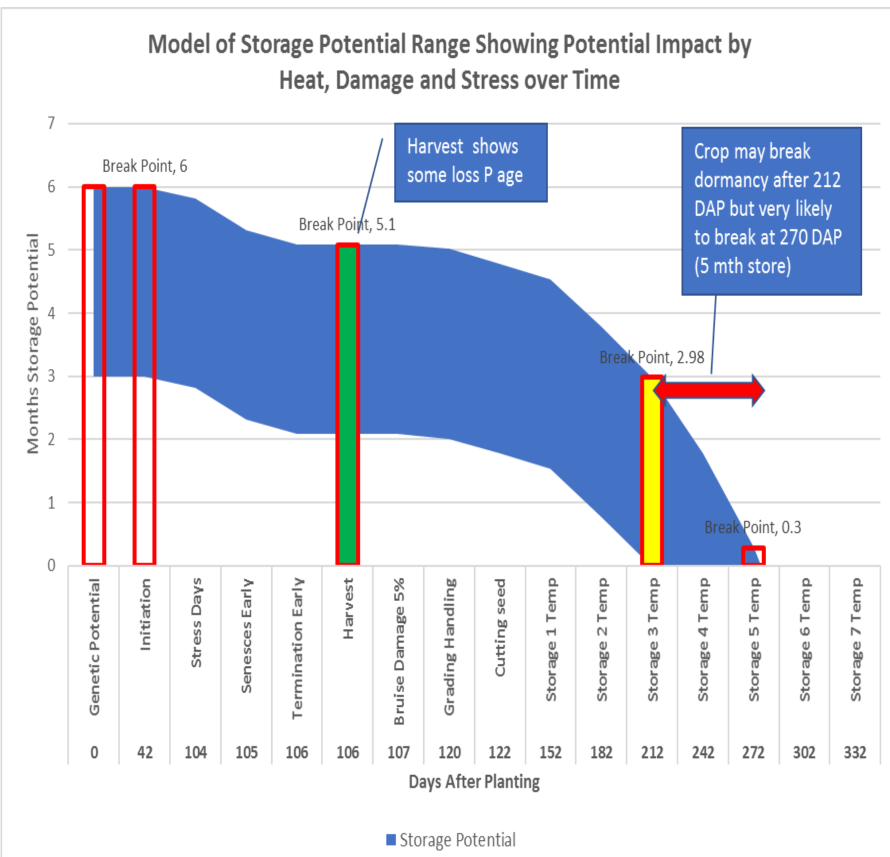
6.4 POTATO SEED PHYSIOLOGICAL AGE AND STORAGE

In the literature review, **Physiological Age (P Age)** or **Apical Dominance** was seen as the most critical element in managing crop planting density and in generating stem count and yield. Poor management of P Age will risk the grower failing to deliver their supply chain customer's expected volume. The survey prioritized focus into factors that influence P Age and respondent's attitude on P Age.

In the literature review report, Philp illustrated P Age accumulation. This reflects the cumulative influence of environment, growing management, handling, temperature and storage. P Age is a biochemical controlled trait. The rate of metabolism in the tuber can accelerate change. Predicting dormancy break is important for ensuring seed is active and not apical dominant and will emerge evenly after planting.

A model of P Age concept in Figure 22 shows the growing cycle, harvest, handling and storage. Cool storage is used to slow the biochemical process. Degree days are sometimes used to predict P Age potential. In the literature review Abscisic Acid (ABA) was reported as the main growth regulator that influenced storage and status of P Age. Below in Figure 23, a model of growth regulator change during the crop life cycle, helps to explain the biochemical process.

Tuber temperature and time from senescence (crop termination or burn down) are critical in managing P Age and stable seed storage. Seed production timing and crop planting must be synchronized to ensure seed breaks dormancy at the desired date to ensure crop maturity fits the grower's supply plan.



Main stream crop production for French Fry production fits into the optimum efficient growing window as this manufacturing process can use cold storage to extend supply. Crisp and fresh market have less opportunity to use storage and must grow crops across a geographic matrix with varying growing seasons.

Growing potatoes on the Atherton Tablelands to supply demand from October to November requires seed to be grown on the edge of seed production windows.

In the literature review variability of P Age was discussed, including across cool rooms, both laterally and vertically.

Figure 22. Modelling Concept Demonstrating Storage Stability and Physiological Age Change

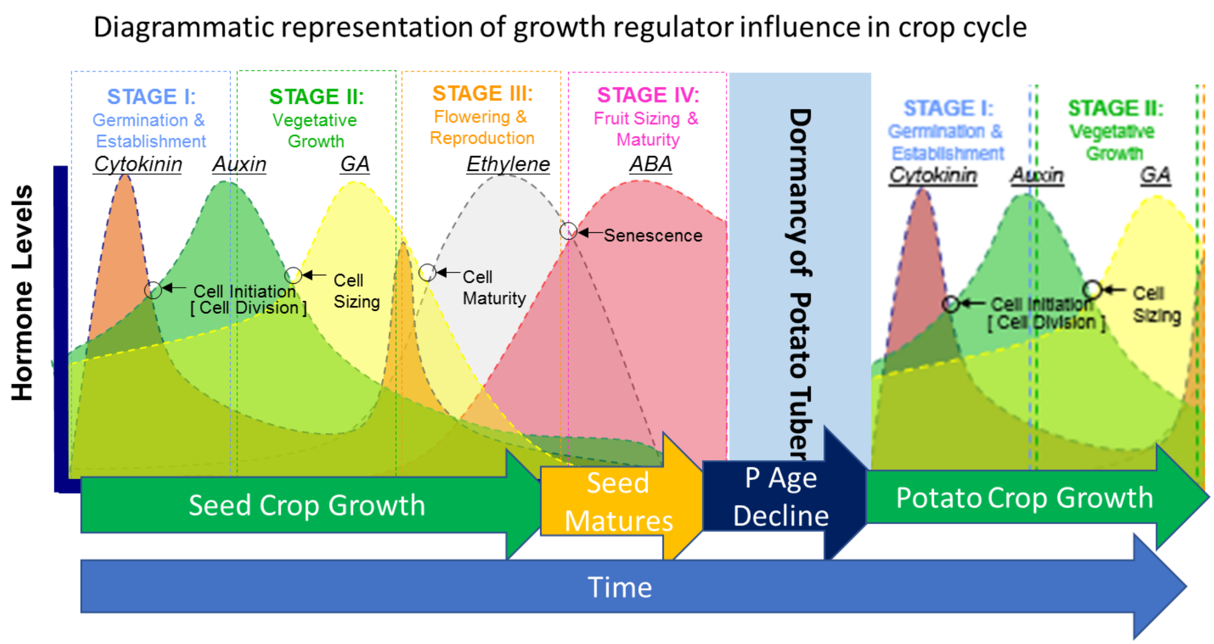
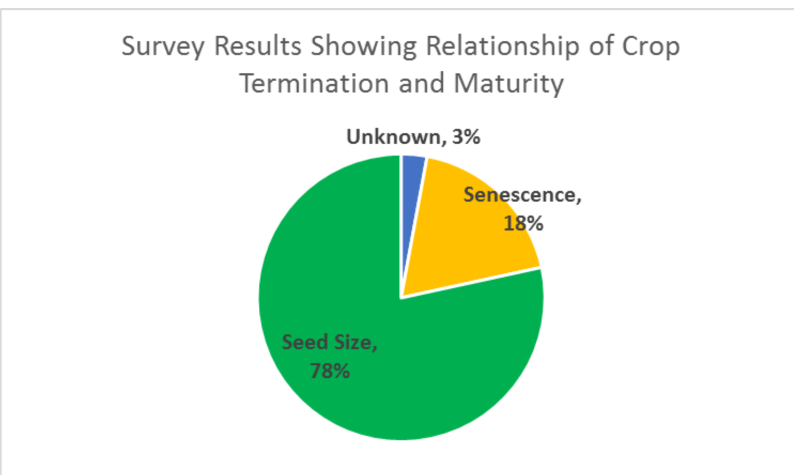


Figure 23. An Example of Growth Regulator Change Over a Crops Life Cycle (Cavallaro, 2010)

6.4.1 POTATO CROP MATURITY, DESSICATIONS AND SEED QUALITY CONTROL

Seed crop production requires seed tubers to be in a specific size range (refer Figure 18) for marketable yield. Crop spacing is the initial control for seed sizing.

Crop termination using either mechanical or desiccants is the major tool seed growers use to control crop size. Virus control and the certification process also requires crops to be desiccated immediately after certification inspection.



In the survey, crop desiccation was looked at to understand the management strategy. Respondents reported that 78% applied desiccants to control seed size while 18% allowed the crop to reach golden or naturally senesce. Of this, 80% used split application and 14% used a single application.

Split application can reduce risk of stem end browning and tuber damage.

Figure 24. Survey Response showing Crop Termination for Seed Sizing V's Senescence

This data raises the question on yield potential by tuber number versus early termination of the seed potato plant to control tuber size. For long cylindrical tuber shape size management may deliver fewer cuts, less waste and reduce risk of seed unit break down.

6.4.2 POTATO SEED STORAGE, SEED QUALITY CONTROL AND PHYSIOLOGICAL AGE

Cold storage of potato seed is widely used to manage seed physiological age and synchronize seed dormancy break to planting window. Seed storage has a significant cost in energy and capital cost. Scalability of operation drove cold storage sophistication and automation. A cold storage facility is a longer-term investment. Technology tended to be set at the time of construction.

The Tasmanian industry has an extra level in the supply chain where specialist operators prepare seed for their customers. Their size allows them to have higher capacity graders, cutting equipment and specialized conditioning rooms. Energy cost is offset by using heat exchange systems between seed cooling and seed conditioning. The result was the customer getting very accurate and consistent quality seed that is ready to plant.

Growers were surveyed on their consideration of P Age at seed receival before storage of seed.

While there is no quantified seed dormancy test, question response showed a level of awareness to P age. Transition from dormant to seed breaking dormancy is often the focus of visual assessment by the grower.

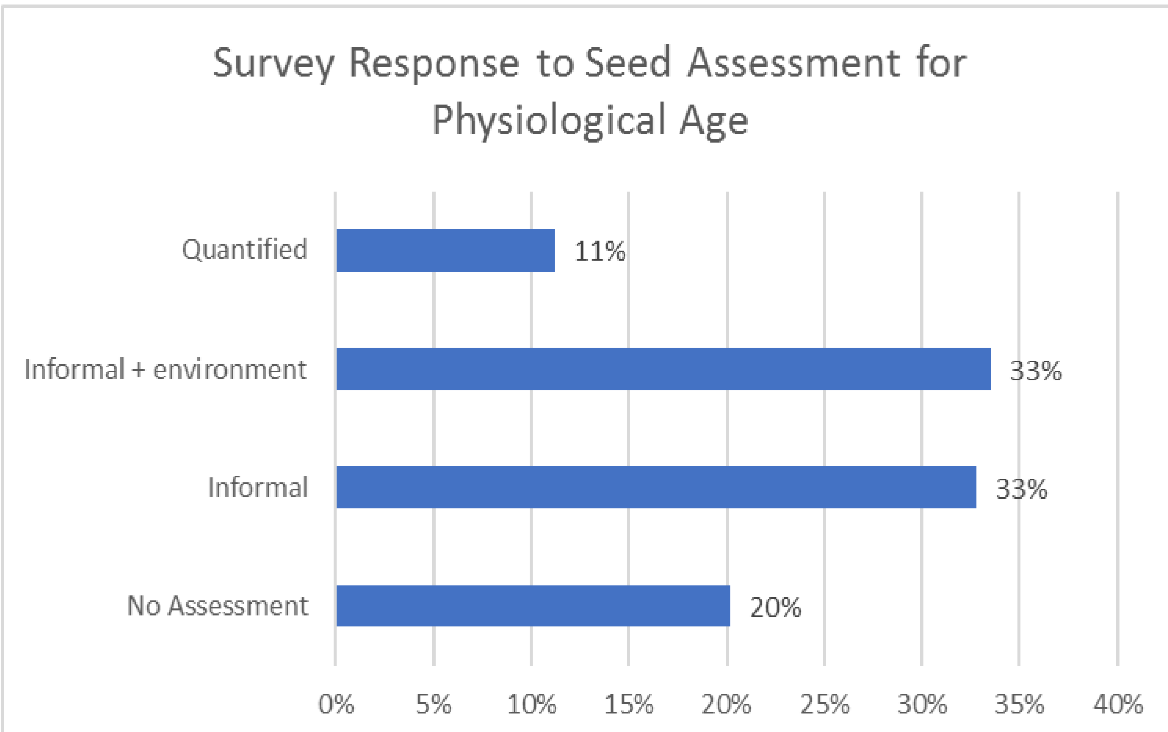


Figure 25. Survey Response to Volume of Crop Assessed for Physiological Age

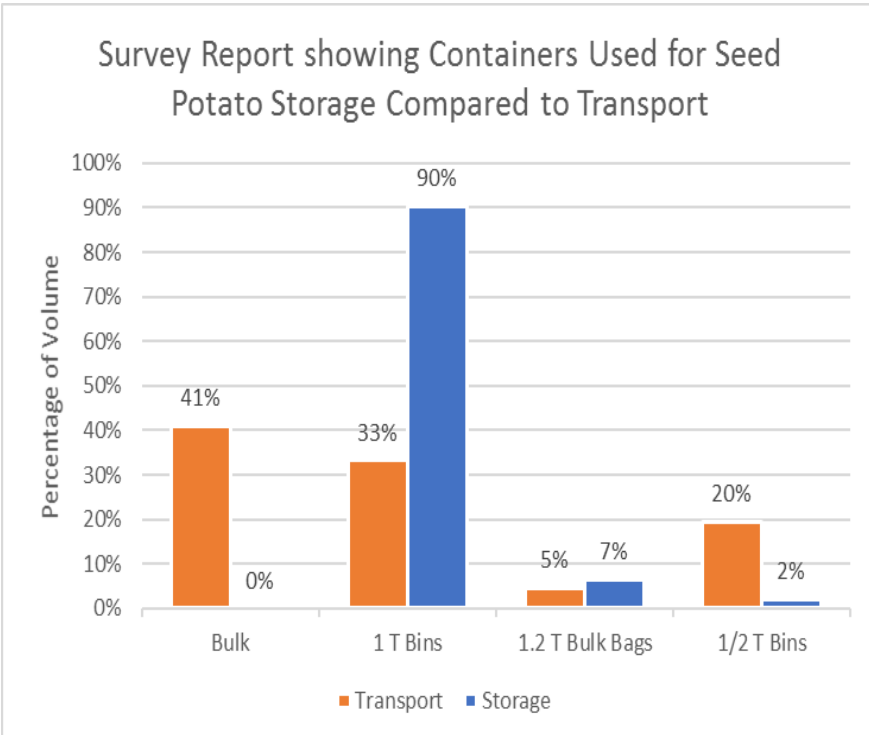
Crop termination ("Burn Down Date") and harvest date were considered essential information in assessing P Age status.

The literature review showed optimum cold storage temperature was 2°C to 5°C. 93% of volume reported that seed is to be stored in this optimum temperature range for cold storage. Some growers responded that they (6 % of volume) stored seed at ambient temperature to manage dormancy. This fitted with the seed harvest timing and fast turn around for planting.

90% of seed volume is stored in 1T wooden bins with 7% in Bulk Bags. 33% of seed volume is transported in 1T bins.

Seed is decanted into 1 ton bins from other transport containers including bulk. Bins represent a significant investment for growers and transition to alternate containers would require time.

Handling can impact seed age and the literature survey identified the importance of tuber temperature during handling to reduce damage.

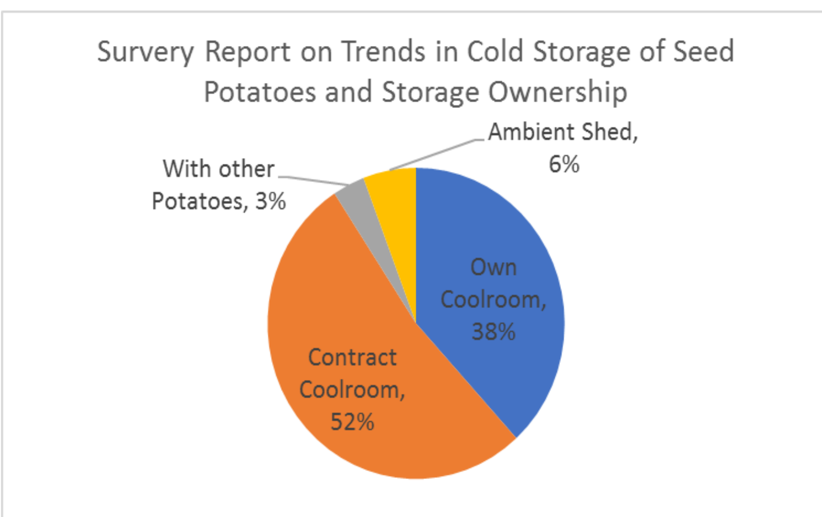


Scalability of enterprise size and its margin impacts the potential to invest in working capital items such as cool rooms. Use of contracted cool rooms reduces working capital required for seed growing enterprise.

Supply chain structure also includes specialist suppliers who provide services in storage of seed, seed grading and seed cutting.

This contracted capacity is spread across multiple seed growers and delivers scalability to the chain. In this supply chain model, the seed grower or seed customer delegates control of the seed quality to the chain resource.

Figure 26. Survey Results Showing Containers Used in Seed Storage and Transport



The efficiency, quality control and communication depend on the service provider. Commercial reality drives the efficiency balancing cost against service and value provided. Scalability enables investment in capacity and technology as the cost is spread over a greater volume of potato seed.

Communication and long-term commitment is essential to enable the storage service provider to deliver quality volume to plan. It is essential for quality seed to be placed in the store to expect quality out.

Figure 27. Cold Storage Ownership Trends

The length of storage indicates storage cost. External storage often has a higher cost than own storage. This may be offset by savings on opportunity costs or by additional services such as cutting and supply management that add value for the grower. The length of storage of seed relates to seed production and harvest to crop planting. Crop planting depends on supply timing.

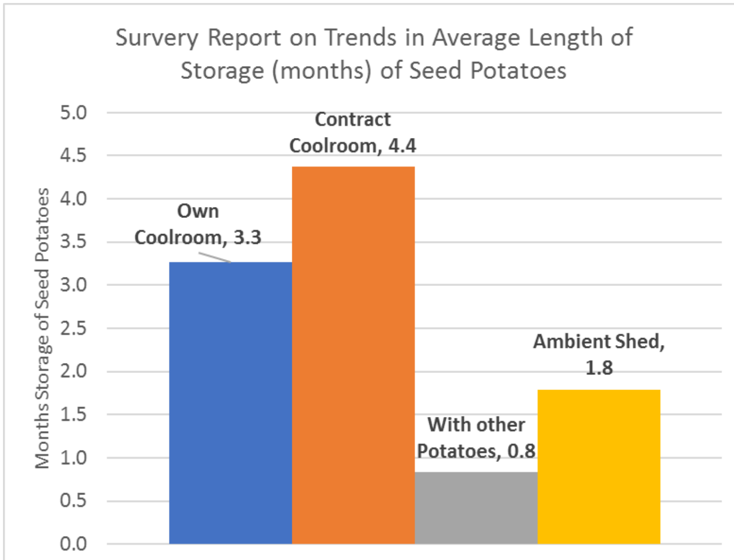


Figure 28. Average length of Potato Seed Storage

The literature review identified that cool storage performance was advantaged with the following:

- Variable Speed fans, lower running cost (power saving), better temperature control, less weight loss
- Computerized, better temperature control and air exchange management, less labour
- Humidification less weight loss, better retention of quality

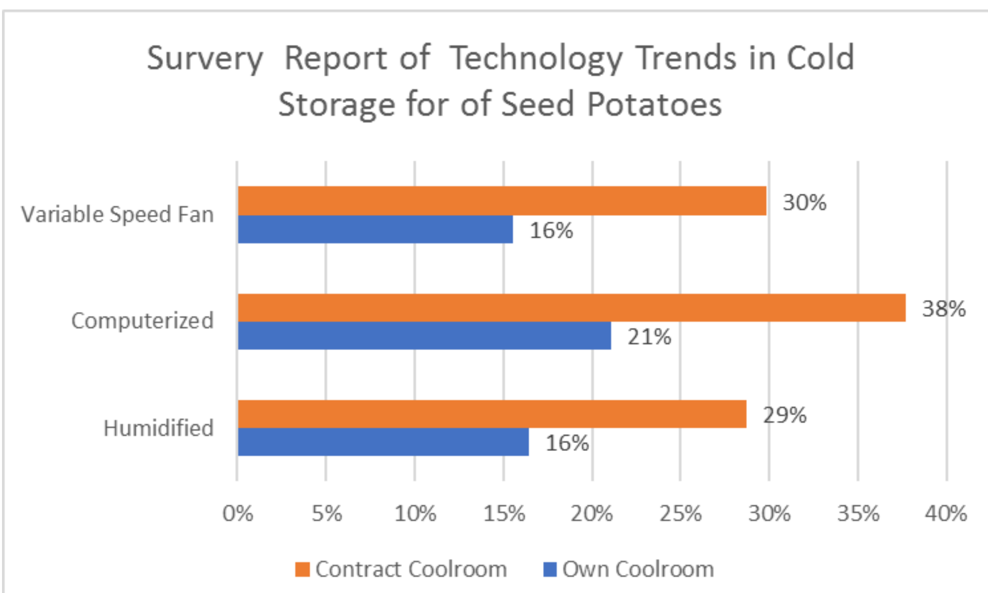


Figure 29. Contract or Owned Cool Rooms Using Variable Speed Fans, Computers, Humidification

Contract storage may have greater capital investment in stores and store systems but by storing greater volumes off set this cost over multiple growers. Owned storage has a 10 to 20 year life cycle so often technology of the store was fixed at the build date. Overall, contracted storage had better storage infrastructure including variable speed fans (power saving, better quality), computerized temperature control and humidification.

Oxygen and Carbon dioxide is measured in 27% of the total volume of stored potatoes. This also reflects the use of contract storage.

Fan speed and air change capacity was unknown by most respondents. In discussion with respondents on this question, they commented that it was an important specification for cool rooms, they would have it in their cool room specs but they did not know it off hand. Older cool rooms relied on regular opening of the door to manage air change.

Use of data loggers is well practiced in the export of potatoes. Growers responded well to the idea of using data loggers in their operation.

Growers drawing seed from the same seed production district expressed varying views on quality delivered by that district, delivery performance and reliability. One grower experienced bulk delivery on time with great service, another grower considered the district as being in a time warp of the 1960's.

6.5 MANAGING PLANT DENSITY, STEM DENSITY AND ACCURATE PLANTING

The literature search showed stem density was one of the keys to sustainable yield from crops and getting consistent size and quality. Stem density is driven by even **Physiological Age**, consistent bud activity across seed units and accurate planting. Sustainable and profitable potato production comes from optimum plant spacing to the crop environment, variety generating marketable yield to input cost per hectare.

Growers identified that planter accuracy and operator attention to detail was important in accurate planting. Seed cutting is used to deliver seed unit planting ability, the "blocky" seed piece. Seed unit flow and compatibility to planter metering systems is fundamental to achieving the planned stem density.

Use of GPS guidance in planting operations reduces operator work load and enables more focus on the planter. Cameras or mirrors are used to improve vision for the operator.

Calibration of planters to place seed at the desired spacing is well practiced in the industry. Often the simple tools ensure operators can check spacing during planting. Standard operating procedure needs operators to continually check spacing accuracy during planting.

Grower comment regards managing spacing accuracy

"I went down to the local hardware shop and purchased tape measures. I gave one to every manager and put one in the cab of every planting tractor. I told them to use them"

Low cost investment for accurate management of a critical crop performance factor.

Table 10. Key Learnings Simple Management Tools Help Deliver Accurate Planting Performance

90% of the surveyed volume reported that they calibrate planting equipment each spacing change in a paddock and when they changed paddocks. One grower shared the "tape measure" initiative used to focus accuracy on seed unit spacing in the field. This reflects the importance of plant density in production (refer Table 10).

Growers of 21% of the potato volume surveyed considered P Age and 17% considered stem density management at planting.

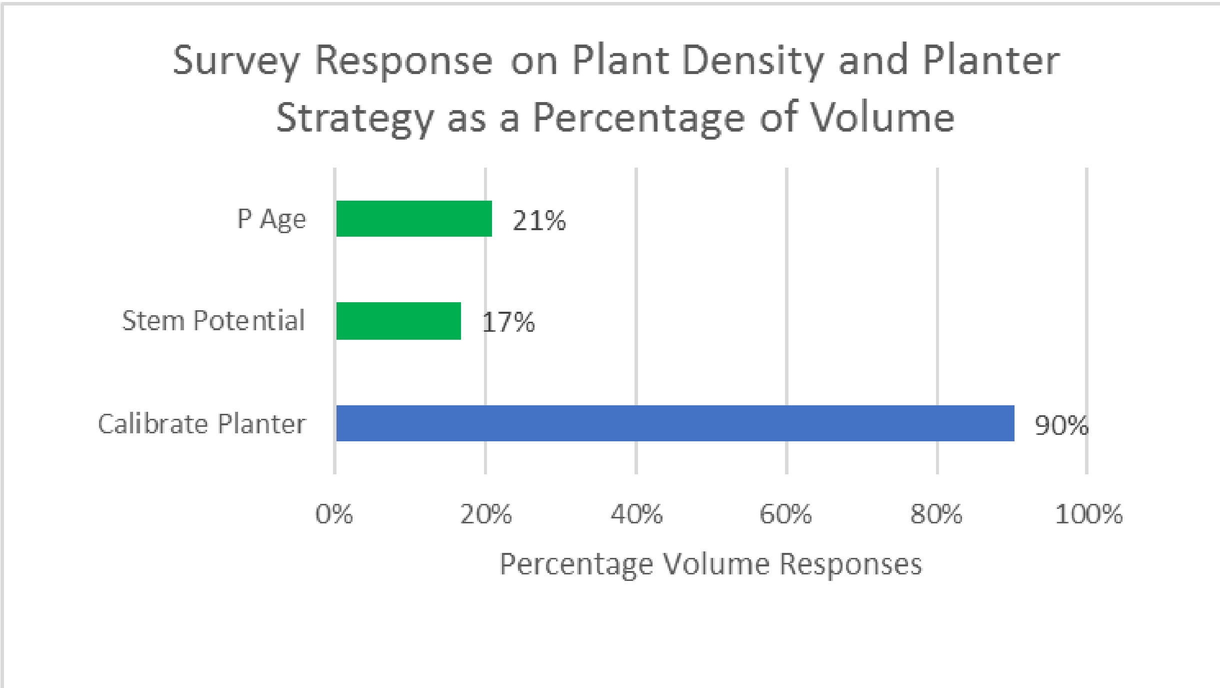


Figure 30. Survey Response on Planting Density and Calibration of Planters

Working from the literature report, clusters of seed quality and seed management elements were identified (refer Figure 4). As part of the survey process cohorts were asked to rate the importance of cluster elements from 1 (less important) to 5 (more important).

Rating identified how important growers considered or rated a seed management element and their awareness of the element. For example, research identified that the seed element, crop performance in the first 40 days, was highly correlated to yield. Cohorts rated this important, a 5, the highest rating score. The industry is aware of the seed quality element of performance in the first 40 days and its importance to the potato crop success.

Cohorts were then asked to rank the top 5 most important elements. This ranking was in order of importance, 1 being most important, 5 being less important. This shows the management thought process across the cluster of elements and the hierarchy of managing seed quality elements in the cluster.

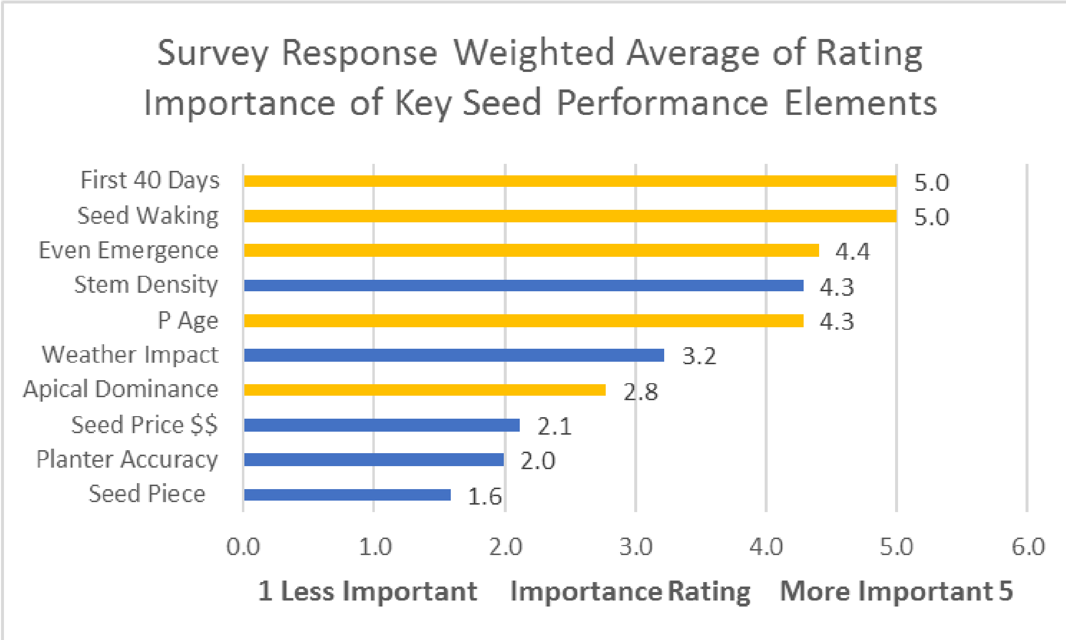


Figure 31. Weighted Average by Volume of the Rating of Importance of Seed Managment Elements

Cohort's saw stem density as the most critical element, ranking it 1. Seed Price was ranked 8th. Seed Piece break down and planter accuracy was ranked less important as they could be controlled through management.

There is a gap between P Age and Apical Dominance. Some cohorts commented on Apical Dominance management using plant density and seed management.

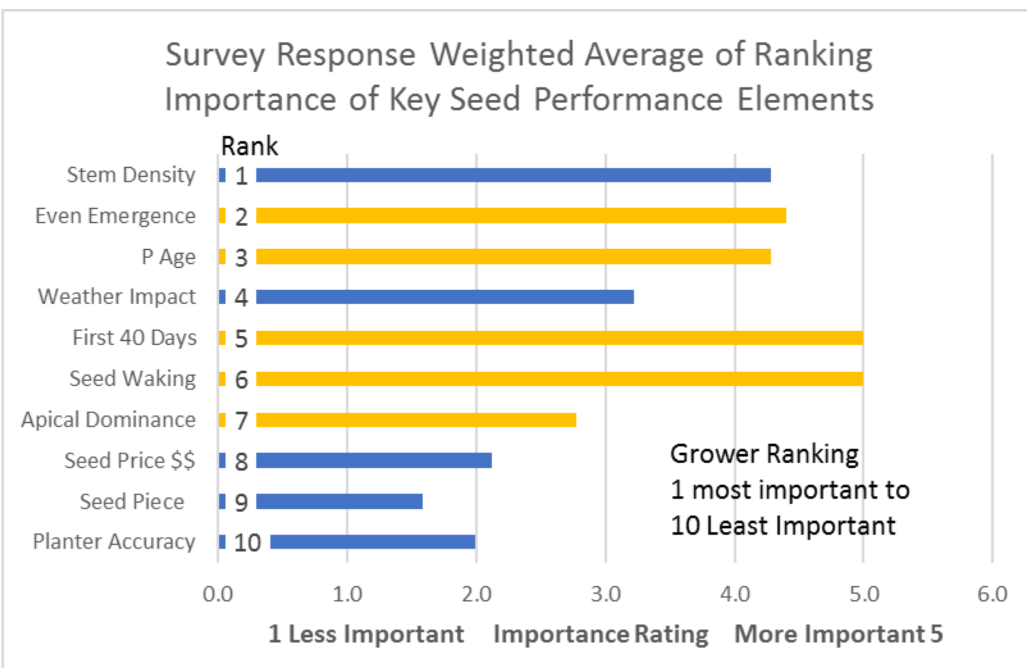


Figure 32. Survey Response showing Weighted Average Ranking of Key Seed Performance Elements

6.6 SCALABILITY, EFFICIENCY AND TIMELY PERFORMANCE

The potato industry supply chain needs are discussed in section 4. Using an electronic survey (see Appendix 3) critical seed management elements and the relationship between supply chain links were investigated. This focused on how seed handling and seed quality impacted the supply chain.

This project's output aims to lead supply chain participants to better understand opportunities for continuous improvement and sustainable cost-effective growth.

Several themes that influence seed quality and seed handling were identified during the survey work. However, they fall outside the scope of this project.

These themes relate to the financial health of businesses, scale and efficiency, investment in the business, replacement of assets and farm succession (age demographics of supply chain participants).

The researchers thank the participants for their transparency and for sharing their concerns and successes relating to the Potato Supply Chain.

1. Investment in equipment and adoption of technology.
   The issue of capital investment and return is limiting the replacement of assets. Cost of specialized potato production equipment such as harvesters, grading equipment means that some regions and areas of the industry has ageing equipment. This may impact seed handling and seed quality.
   Farm management economics and the balancing of capital investment, depreciation versus repairs and maintenance and unplanned down time.

2. Plant capacity to meet changing customer time lines, customer demands.
   Some seed contracts require grading and delivery of seed within a specific time frame. Changing contract conditions that affect supply timing may not fit a growers processing and grading capacity. This can also affect grower's ability to manage the impact of weather on the harvesting grading process.

3. Family farm models and whole farm return, the next generation.
   Family farm models rely on whole farm performance to generate income to support the business. Changes in profitability of rotational enterprises can drive exit or downsizing. Sudden change due to acquisition, for example Almonds, Avocadoes can be driven by macro agribusiness economics. The next generation of growers expectations are changing with some wanting a different lifestyle to farming and see farming as not being "attractive".

The potato supply chain financial fitness is driven by yield, marketable quality and efficiency.

Seed quality and handling has identified themes that will improve chain fitness and robustness while making better use of resources. Processors and Australian industry are driving their internal efficiency through adoption of "Lean Management". An example of Lean Management is the improved accuracy of seed size to meet the seed customer's needs. Increase tuber count per Ton in graded size range delivers suitable sized seed units but drives the supply pipeline value equation for the supply and potential seed grower return.

Seed count drives planting area per ton. Optimized planting area per ton potential reduces transport cost, more hectares per square metre of cool room and lower power costs per hectare.

6.7 DELIVERING QUALITY AND VALUE TO MEET CUSTOMER EXPECTATIONS

Relationship and communication are core platforms for a mutually successful business. Sometimes an “extra” small step actioned by the supplier can deliver big savings for the customer, for example, digging that extra load at short notice and keeping the factory running, retail store supplied.

Attitude and relationship on supply quality performance can be different from the same district for different businesses. One grower purchasing seed out of seed growing district reflected on it delivering real value. This was quality, timely supply making the grower’s business successful. This grower is acknowledged for quality and delivery performance by his customer (a processor). Another grower commented that the same seed district did not “perform” well for the business, issues with supply timing and quality, “reminds me of UK seed supply industry back in the 1960’s”.

Focus on seed quality, volume and timely supply requires a foundation of ongoing two-way communication. This communication needs formal (email) and informal (phone) with both parties listening.

The survey works to identify what is important to the supply chain customer and what drives the value equation.

As part of the survey, cohorts were asked to rate key elements impacting supply. Rating was from 1, least important, to 5, most important. The survey identified that seed grower shortfall was rated the most important seed supply element (refer Figure 33).

Survey cohorts commented that, communication was a critical element to allow management and reaction to the variance to plan.

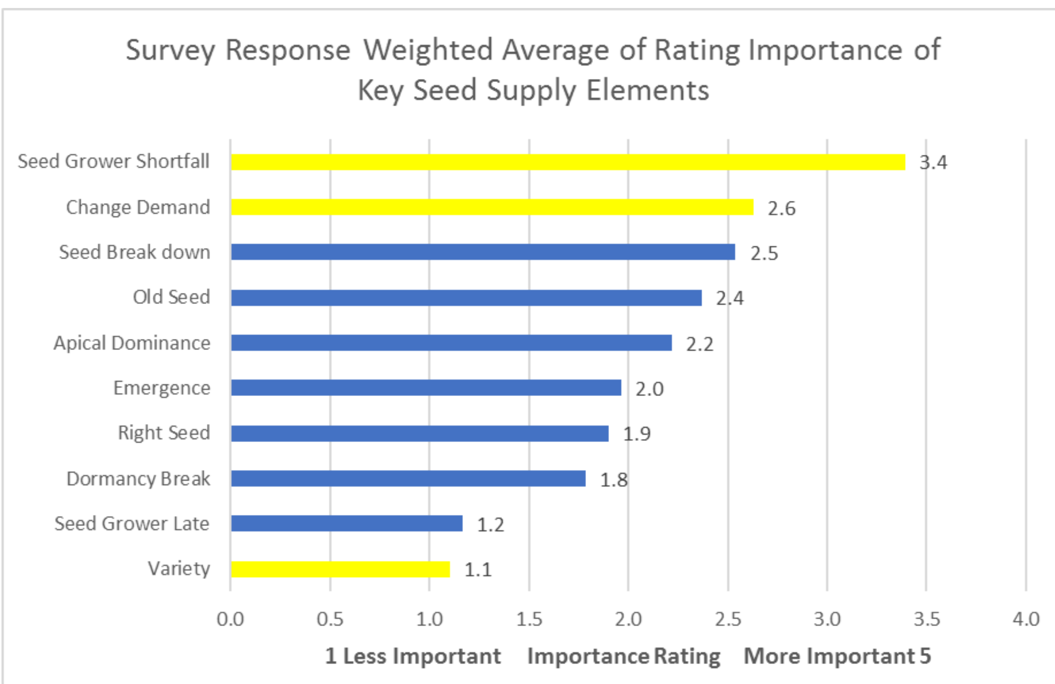


Figure 33. Rating the Importance of Seed Supply Elements that Impact the Supply Chain

The survey also asked cohorts to rank the 5 most important supply elements from 1, most important to 5, less important. Cohorts identified change of demand, to be the most important seed supply element. The earlier communication of change was shared, the better. This is critical for the seed link of the supply chain and the seed link's length.

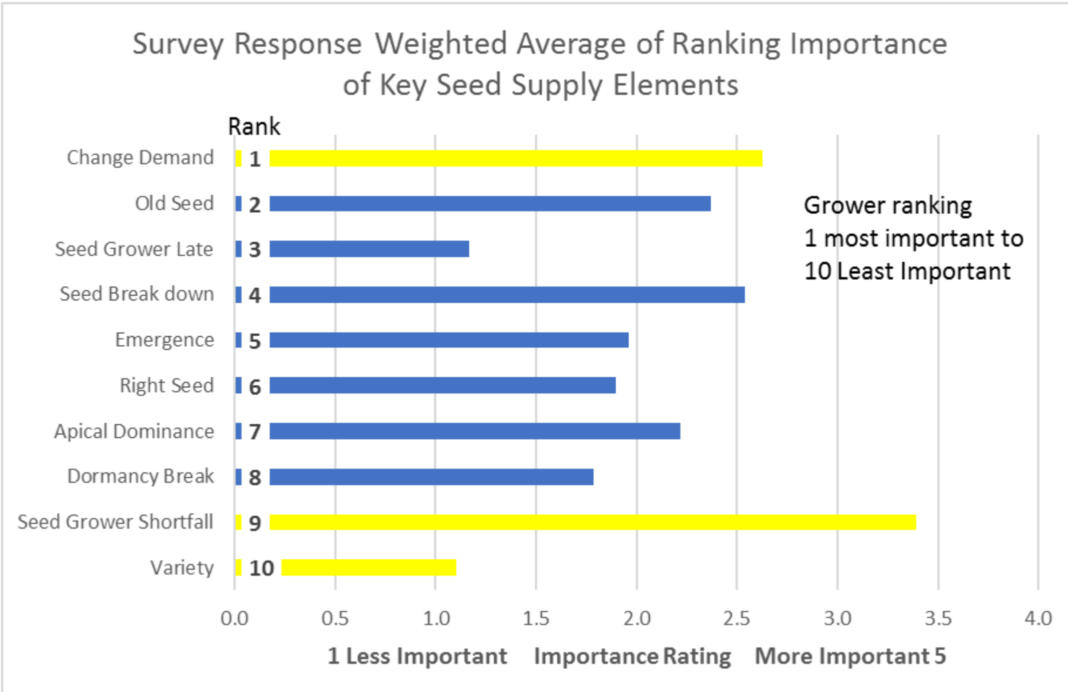


Figure 34. Survey Response showing Ranking of Importance of Key Seed Supply Elements

Lean management philosophy emphasizes the importance of early communication and communication of the exception. An example of the exception in the potato supply chain is the "short supply of seed to plan" generated by poor recovery during grading of the required seed size. Yield and size variation may be due to weather events. If the seed grower communicates exception to plan at harvest to the customer, the customer then has opportunity to solve the variance.

7. SUMMARY CONCLUSIONS AND SUGGESTED RECOMMENDATIONS

Project PT16000 identifies developments in research, best practice in potato seed quality and handling using a literature search. The findings from this search then drive a focused survey of the Australian potato industry. This explores the status of the Australian potato industry compared to the literature review findings.

This report maps the findings of the survey. It is focused on how seed quality and supply can impact the Australian potato supply chain. The report frames up a path forward to achieve improvements across the potato supply chain.

This grower survey is reported at the Australian industry level.

Communication and sharing of the finding of this report through extension to supply chain stakeholders is critical to deliver value from the investment of industry funds. The supply chain members will differ in where and how these elements of that impact their business and supply chain contribution.

To build the stronger supply chain, work must focus on strengthening the weaker links. The stronger links need to support the change process through leadership and motivation in adoption of best practice.

7.1 INDUSTRY QUALITY STANDARD, DISEASE AND VIRUS MANAGEMENT, INNOVATION

Overall, the survey shows that physical quality, disease and virus is considered reasonably well controlled by the industry. The use of certification and quantification of quality in the industry is in a strong place.

Use of seed Generation and shortening the supply chain is an opportunity. Survey shows lower generation volume is significant. Success of best practice seed models needs to be understood including the cost implications and trade off advantaged crop performance of the lower generation strategy.

A shorter supply chain will need stronger communication to manage deviation from plan due to supply demand, weather events, climate and biosecurity risk. The shorter the chain the less opportunity for management of change (to multiply tons) for planting. However, the shorter the chain the more responsive the chain can be to deliver change in plan for variety, volume and seed of the best age.

Technology is becoming available to accelerate the use of breeding (genetics) and variety traits to improve industry efficiency and performance. This allows shortening of the variety development pipeline, reducing cost and accessing advantaged traits.

Remote sensing will allow better vision of crop variance.

Tissue testing will allow quantification of virus and disease loadings in seed at a lower cost. This will enable earlier quality management of seed. The seed pipeline avoids the cost and impact of carrying poor quality seed.

7.2 COMMUNICATION AND DELIVERY TO THE CUSTOMER QUALITY EXPECTATIONS

Relationships and communication are shown to be the critical glue strengthening the links of the potato supply chain. Cohorts with better vision of plans reported better control of the seed quality. This empowered them to deliver more efficient, sustainable economic supply.

Supply plans change and climate can impact crops. Communication empowers the management and delivery of the customer’s quality expectations.

The industry trend shows that by volume, most seed suppliers are visited more than 2 times by their customer. This reflects communication best practice. Grower’s value this investment of time and managing the future input to their potato enterprise. It directly impacts the seed quality and volume control.

7.3 MANAGING PLANT DENSITY AND SEED PHYSIOLOGICAL AGE

Plant density and more importantly stem density is the primary element in achieving best genetic potential of crop yield, tuber size and crop timing. Physiological age is a biochemical pathway that is consistent and predictable. Understanding the levers that drive the pathway, such as stress and temperature over time will allow seed growers to deliver more P Age predictability.

Communication of P Age science and drivers will empower the seed grower's customer to better use P Age to their advantage.

Use of infield data loggers, in store data loggers and accurate records will help the seed grower's customer better manage their supply chain. Controlling P Age predictability in the supply chain will give seed growers more time to manage the seed quality and grading. This improves the economics of the supply pipeline. Less waste, sustainable management.

Predictable P Age will enable growers to improve accuracy of stem potential from seed including seed and crop early performance (first 40 days). Stem density is the single greatest driver of economic yield.

7.4 SEED UNIT SIZE CONSISTENCY AND DRIVING DOWN COST USING LEAN MANAGEMENT

The global research shows that seed unit size is a critical measurement that drives crop yield and crop performance in the first 40 days. This is reported in the literature review.

While seed is supplied per ton, graded to customers specifications (size range), the clear message from the survey is, the purchaser is buying the planted area. Physiological Age and stems per tuber is part of the multiplication potential of seed units reducing seed cost per planted area.

Tuber count per 10kg or tuber count per ton is a measure that industry needs in specifications to drive seed value. Reflecting the value of planting potential in the seed price, in specification seed count per ton, will financially reward seed growers to deliver seed unit numbers not tons. Seed value per seed unit, not tons, drives the return per area for seed growers. Using these metrics, the value equation reflects the supply chain and drives quality and sustainable efficiencies (refer Equation 3).

Optimizing productivity for the seed grower with delivery of seed units has significant potential cost efficiencies for the supply chain. More income can be generated for a similar cost per hectare input cost. Potential cost savings that flow through the chain include:

- Seed grower — less lifts, storage capacity, more sales $/Hour over grading equipment
- Logistics — more planted hectares per truck unit, bulk bag, bin
- Grower — less shifts, increased hectares every planter fill, better logistics less storage
- Storage — more hectares per storage ton, lower storage cost per hectare (energy savings)
- Certification — more hectares of future crop managed per inspector

Tuber shape and eye fecundity drives cut seed. Cut seed is aimed at presenting a "blocky" seed unit to fit planter technology. Control of seed unit size can mean less cuts per ton. Less cuts per ton will reduce waste and reduce risk of break down through a reduction of cut surface area.

Change to include seed unit number per 10kg, requires little equipment change and already is widely used in the processing industry. Change to include quantification of seed unit density per ton will require understanding of value savings, and a tradeoff analysis on change. Change in contract terms and conditions for some of the supply chain may take time. Adoption will be driven by the value of managed seed unit size.

7.5 RELATIONSHIP TIME FRAMES AND SUPPLY CHAIN LENGTH

Alignment of business cycles within the supply chain is important. Shortening the supply chain can strengthen it and build a more responsive supply chain matrix. Variety change takes time. It requires assessment for due diligence, risk assessment and qualification (fit for purpose). Fresh market also balances the competitive advantage of variety in the variety selection.

Relationships between the potato supply chain members must be timely to deliver early visibility of change. Communication must reflect positive intent and generation of value (reward) balanced against cost of production.

In section 7.1, the reduction of generation age in potato production was discussed looking at a disease and virus perspective.

Technology and change in understanding genetic mapping will accelerate variety development. This will help the understanding of the variety performance in different environments (growing locations). In short, the opportunity to drive improvement and cost effective sustainable industry change will accelerate with understanding genetic trait mapping.

7.6 SCALABILITY AND COST EFFECTIVE LEAN MANAGEMENT

Potato production in Australia often features the family farm unit. Investment in resources including land, capital assets and long-term variable assets (equipment) must consider the performance of the whole farm. Whole of farm income includes rotational crops that need to generate income but also build productivity for the potato crop.

In broad acre agriculture, various models of co-operation are available that show sharing resources, for example equipment, and working together can drive justification of investment advantaged technology or capacity. For example, investment in a high-performance boom sprayer allows more area per hour per person, use of latest controlled application technology releasing of other farm resources. By simply increasing effective boom width in potatoes reduces number of spray tracks across the crop. Spray rows generate bruising damage and loss of yield potential. Increasing yield and quality directly impacts the delivery quality to the supply chain and potential return.

Understanding proven structures, the agreements, timing and effective coverage is essential for co-operating groups to look at the potential. This can drive productivity and financial return in traditional proven potato production areas of high land value.

7.7 TOOLS QUANTIFIYING QUALITY DATA AND SEED STRESS

Technology and communication is driving a revolution in remote sensing, data recording and data analysis. This makes data usable, leading to more informed decisions. Irrigation water is a limited resource, its availability and cost driven by climate and politics. Potato seed quality, performance and P Age is impacted by stress.

Technology is now available to measure and record soil moisture, total dissolved solids (salinity) and soil temperature. This data also shows growth decline and senescence of potato crops to be better predicted.

Cool room temperature, CO^2 and O^2 levels can be measured and recorded using data loggers. Non-computerized cool rooms use manual air exchange control. Data loggers will improve understanding of seed stress in storage and manage potential deviation in expected P Age and dormancy breaks. This would cover interruption of power supply or early removal from cool rooms to save power. Using technology like this helps accurate communication of critical information.

7.8 PHSYIOLOGICAL AGE MANIPULATION AND CONTROL

Research work in Australia indicates that P Age can be manipulated through various storage and handling strategies. P Age and dormancy management are a critical platform for plant and stem density performance. Currently the potato industry relies on burn down date and period of cool room storage. Growers continue to get surprises from the cool room and variation in parcels of seed dormancy.

Mapping of cool room temperature and air movement is important and will also allow for more energy efficient management of seed stock quality.

Australian research work indicates that Abscisic Acid (ABA) and dormancy break can be manipulated with seed treatments to achieve time-controlled dormancy break, reduction of apical dominance across tubers. Natural biochemical pathways show various regulators can be turned off to accelerate ABA decline. ABA influence on the degree of tuber dormancy is a complex matrix. On manipulating ABA, other growth regulators in the tuber bud zone can be influenced, resulting in 100% bud activity.

7.9 NEXT STEPS

The findings of this project need to be communicated to the industry stake holders and development of an extension program initiated. The project has identified the importance of seed and seed quality in the potato supply chain. It has identified opportunities to improve the chain, its profitability, sustainability and input cost reduction.

Extension of the learnings of this project should be actioned through a series of workshops on a grower district level communicating the following:

- Communication and quantification of seed quality and physiological age
- Understanding of longer term planning and waste reduction
- Understanding future trends in genetics and learnings in agronomic management of the supply chain
- Seed tuber size measurement and value development
- Quantification of data using data loggers, remote sensing, both in field and in cool rooms
- Principles of lean management

Further research in the development of P Age management through ABA management should also be developed.

8. THANKS AND ACKNOWLEDGEMENT

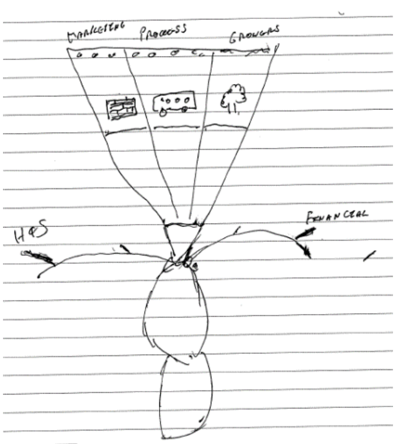
Thanks for the support from the SIAP and its team for the encouragement and input on this project. Thanks also to Anthony Kachenko and Bianca Cairns of Hort Innovation for their guidance in delivering this project and report.

Peter Philp and Peter O'Brien also wish to thank the peer group reviewers who generously gave their time, input and direction that helped ensure this project delivers value to the industry. In particular we mention Ken Morley, Ben Dowling and Terry Buckley for those late night discussions.

Thanks goes to the industry survey respondents who helped identify the important elements of supply chain performance that were used to keep this report on point.

To all the participants who freely gave their time to complete the survey, who spoke openly with truth and candor, thanks for your efforts and input.

The report talks about a Pathway into the future of the potato industry. Using a grower's analogy, that was shared during the survey work;



"It's like riding a motor bike. We can use the controls and the handle bars to manage progress and direction."

This includes vision with the head light focused on the business's Marketing, Processes and Growing.

Progress is managed using the accelerator and the brake balancing Health and Safety and Financial.

Sustainability. Efficiency, social responsibility or financial performance are critical platforms. As custodians of the land we farm, we must plan and keep moving forward through sustainable continuous improvement building for our future generations.

Figure 35. Grower Illustration showing a Concept of Grower Business Management (T Buckley 2017)

This report and research gives us some clear road signs that appear in the head light of the motor bike.

The next steps are:

- communicate change (extension),
- identify and prioritize delivering value (adoption process),
- setting direction then accelerate forward (adoption).

This project has been funded by Hort Innovation, using the Potato - Fresh Fund and Potato -Processing Fund research and development levy and contributions from the Australian Government. Hort Innovation is the grower owned, not-for-profit research and development corporation for Australian horticulture.

Hort Innovation Strategic levy investment | POTATO – FRESH FUND | Hort Innovation Strategic levy investment | POTATO – PROCESSING FUND

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