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

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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 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.

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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.

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[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.

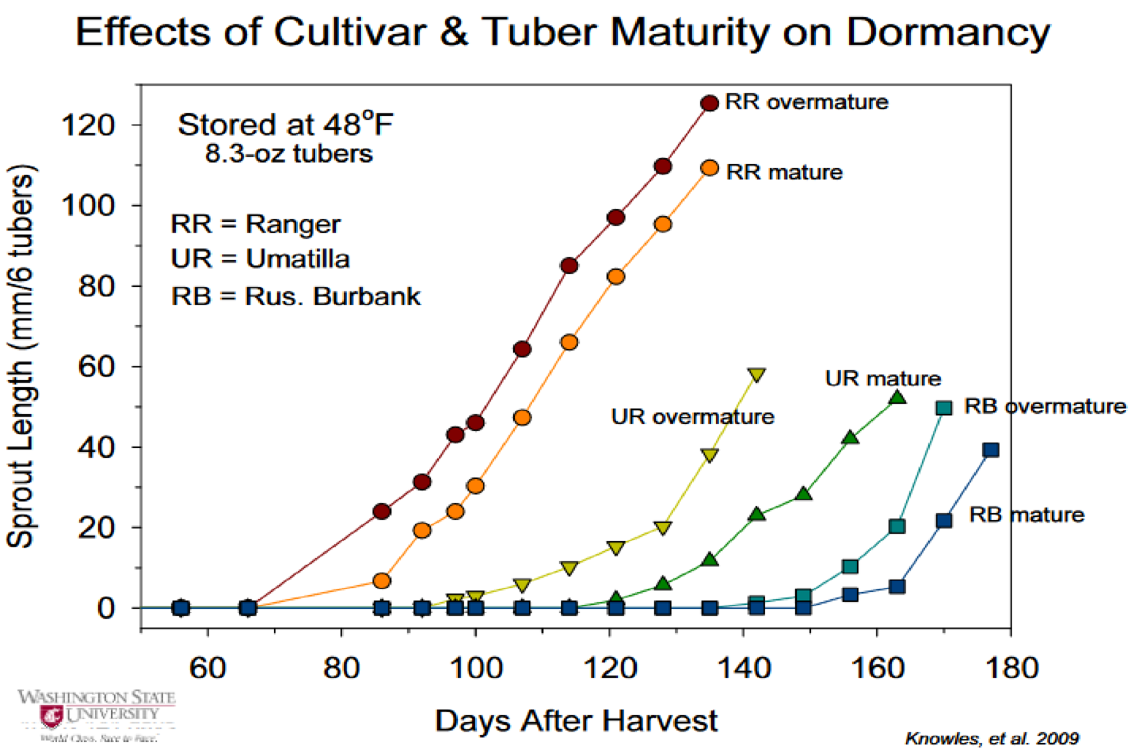


Figure 2. Effect of Cultivar and Tuber Maturity on Dormancy (Knowles, 2014)

[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.

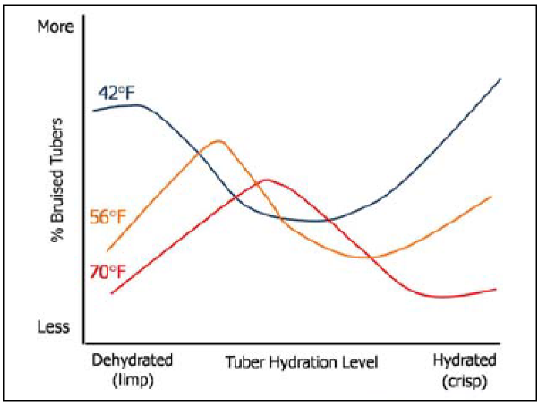


Figure 23. Tuber temperature and hydration levels have an impact on black spot and shatter bruise susceptibility. Dehydrated tubers are most susceptible to black spot while hydrated tubers are susceptible to shatter bruises. Generally, soil temperatures should be between 45 and 65°F at harvest time.

(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

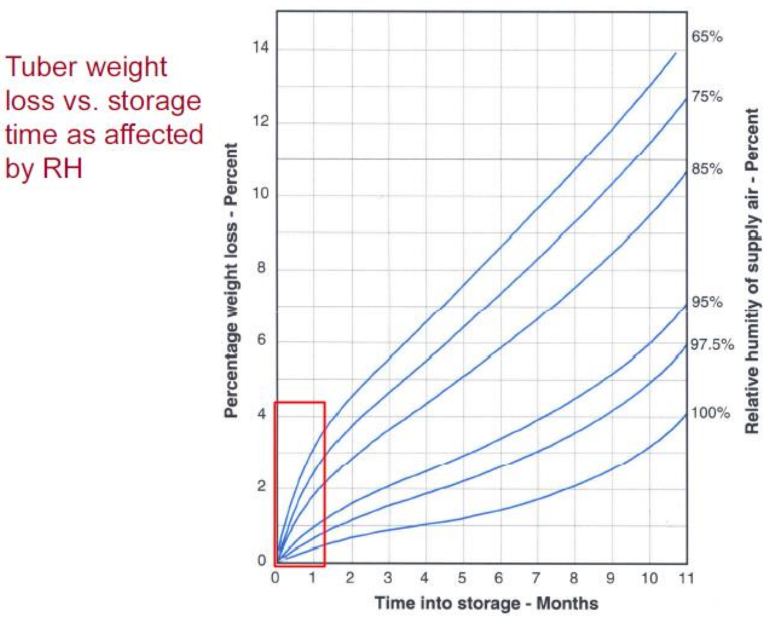
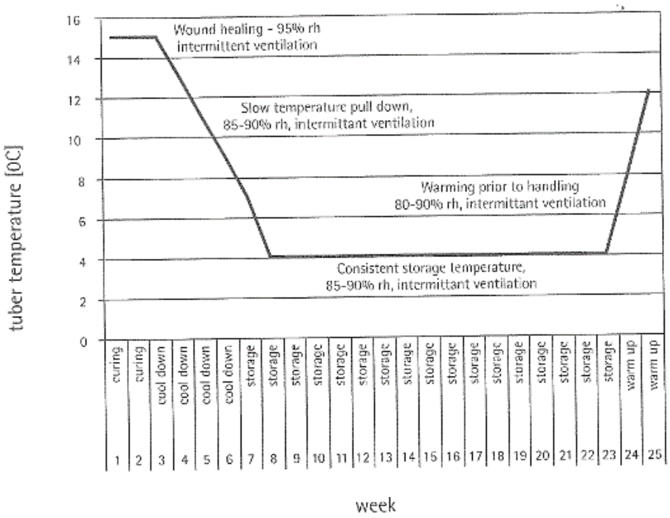


Figure 5. Impact of Relative humidity in storage on percentage weight loss over time **(Knowles, 2014)**

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).

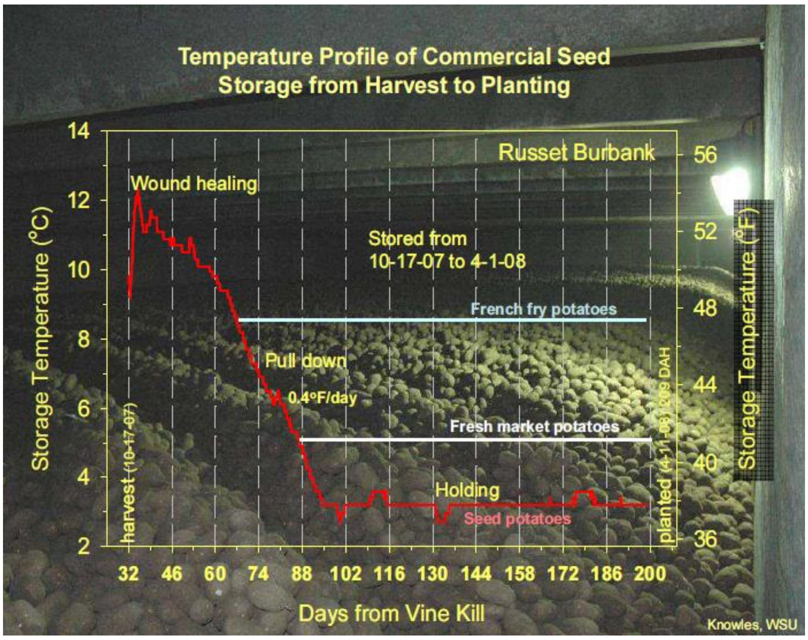


Figure 7. Temperature Profile of a Commercial Seed Storage comparing Seed Temperature to Limits of Processing and Fresh Market Storage **(Knowles, 2014)**

[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.

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

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.

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.

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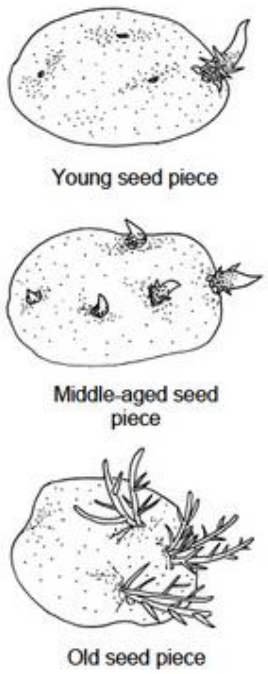
[5] **https://potatoes.ahdb.org.uk/sites/default/files/publication_upload/Store%20Managers%20Guide%20Updated%2011.05.12.pdf**

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)

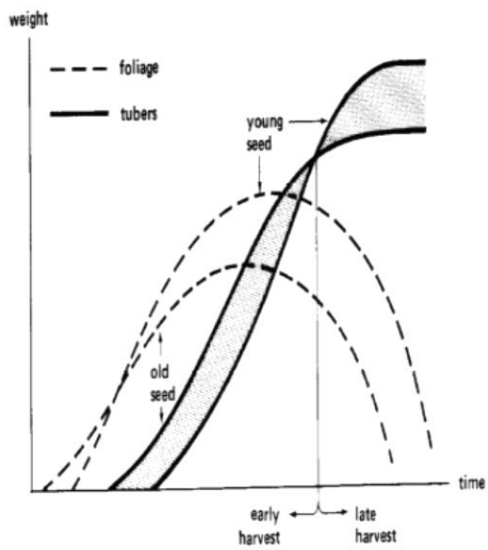


Figure 1 Growth of foliage and tubers from young and old seed; old seed has yields with early harvest v's young seed has yields with late harvest *(Wiersema 1985)*

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.

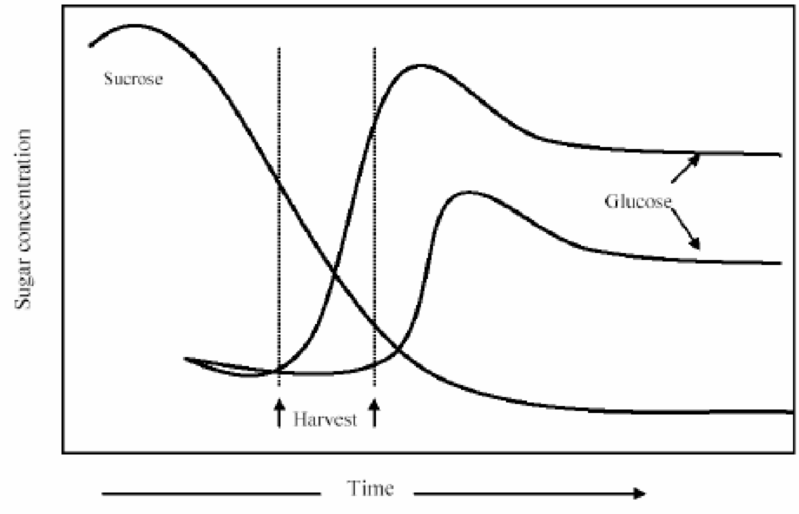


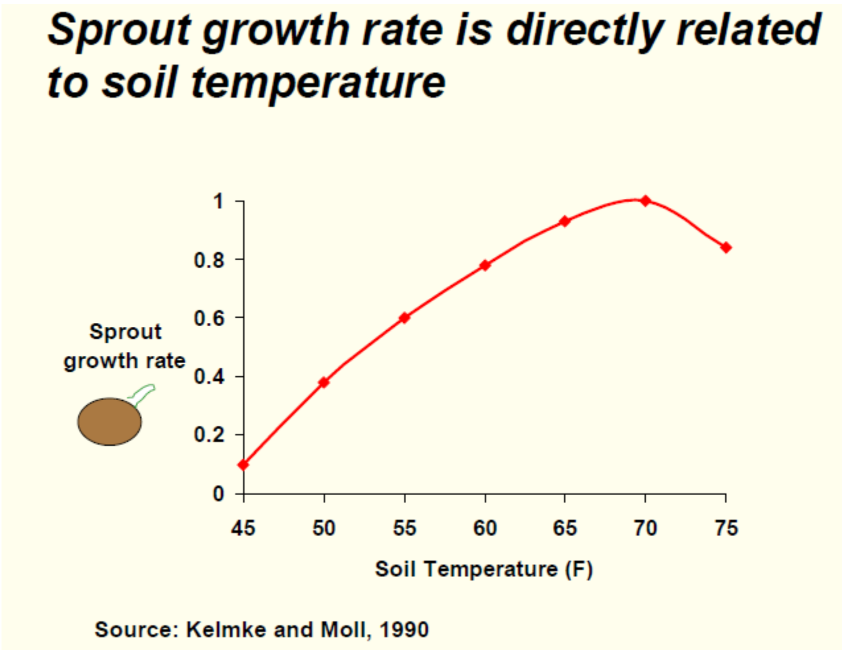
Figure 1. Changes in sugar concentrations in tubers during tuber growth and after harvest. Tubers at the first harvest point are immature (high sucrose levels) and will accumulate higher glucose levels during storage than tubers harvested at the later date when chemically mature. (Source: Pritchard,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

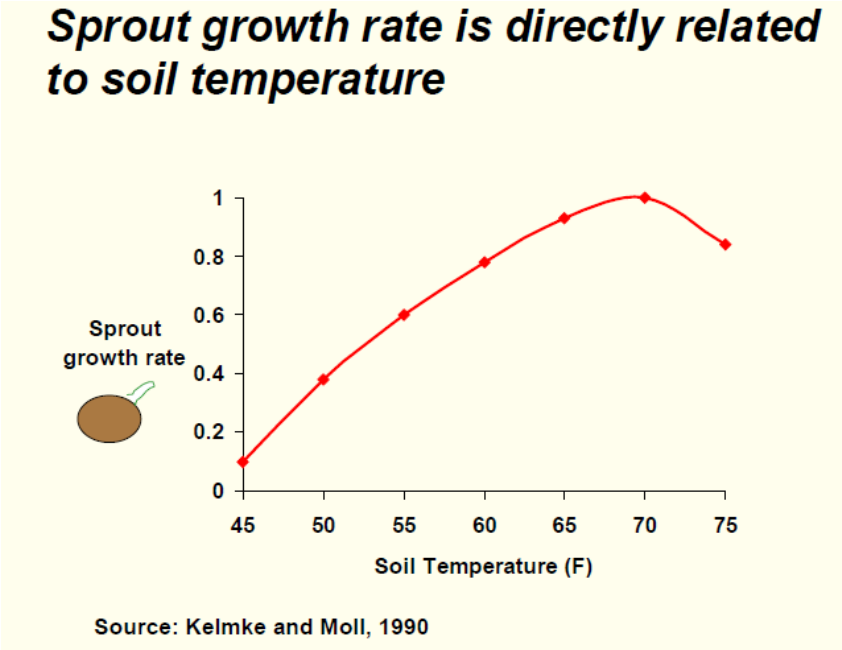


Figure 13. Soil temperature impact on sprout growth (Thornton, 2014)

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.

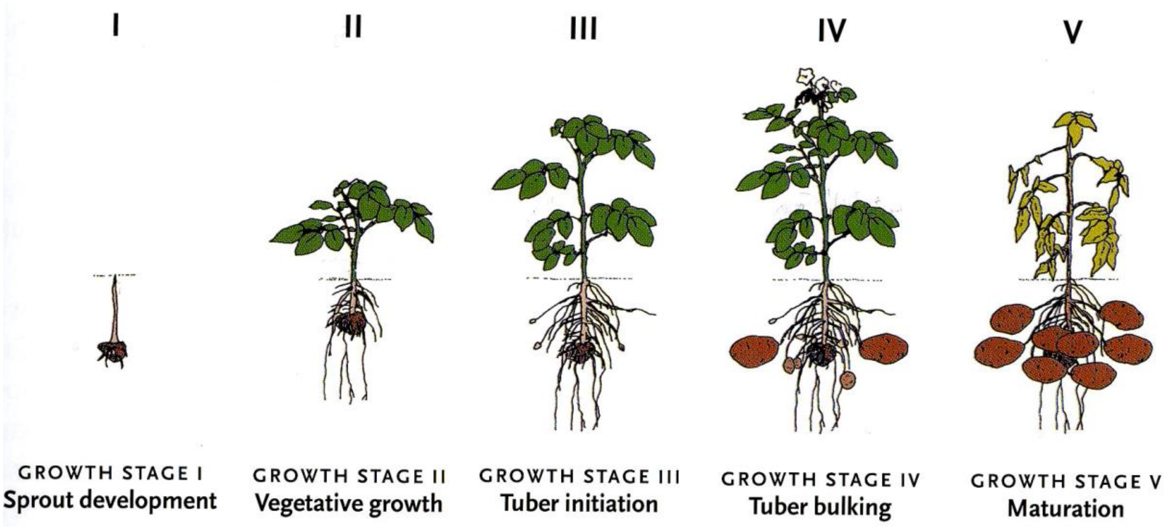
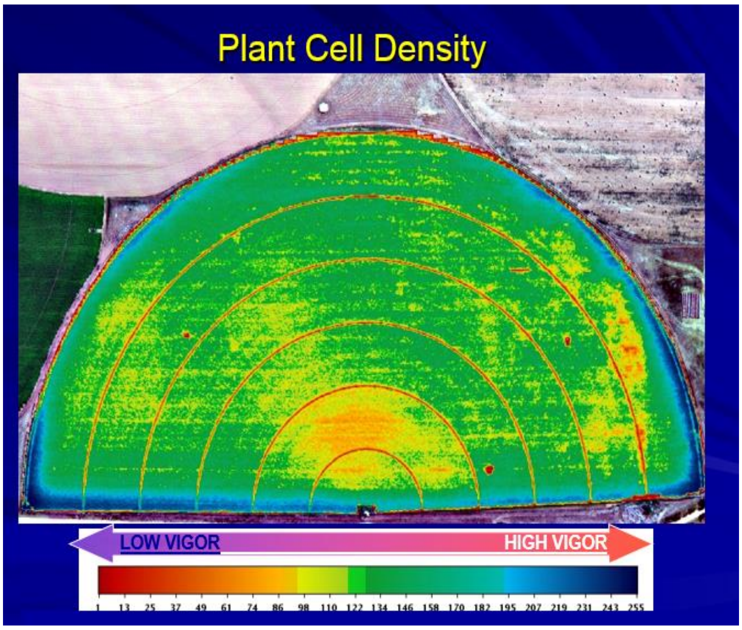


Figure 14. Growth Stages of the Potato showing tuber development timing and position **(Thornton, 2014)**

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.

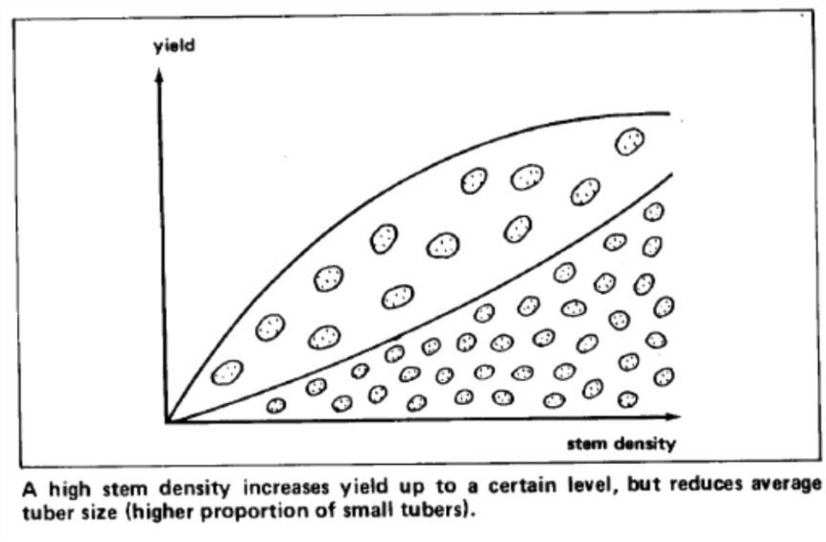
Suttle (Suttle J. , 2012) completed work looking at the effect of azole type P450 inhibitors including diniconazole and paclobutrazol on ABA. Paclobutrazol (Cultar) is registered for reducing internodal shoot length by inhibiting biosynthesis of gibberellins in plants. The work showed although ABA content 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.

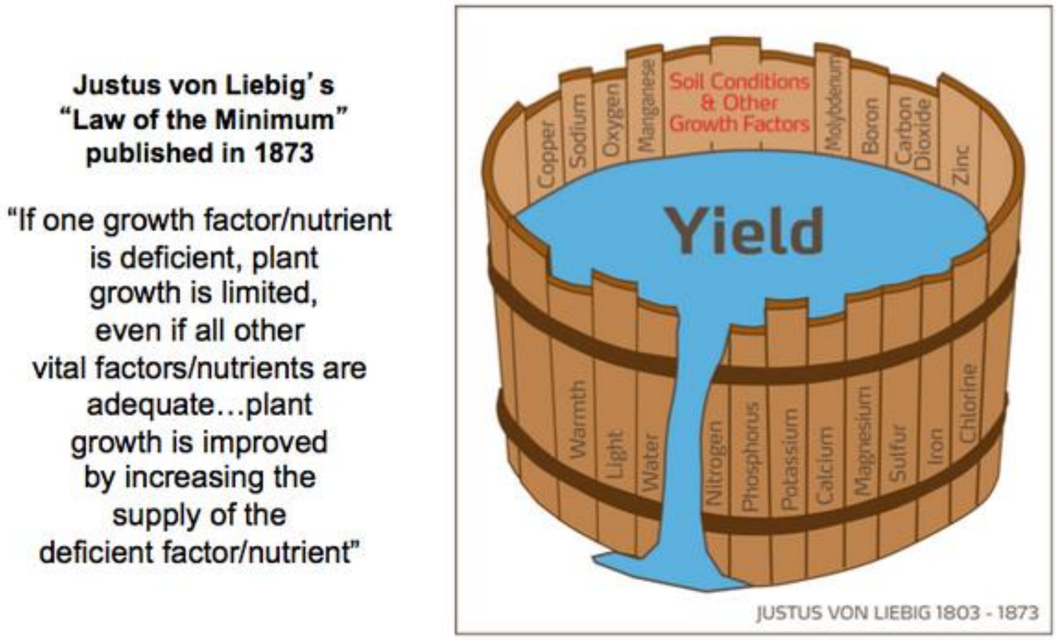


Figure 17. Liebig's law of the minimum is often shown as Liebig's Barrel with the shortest stave limiting the barrels capacity (Kemnovation, 2017)

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.

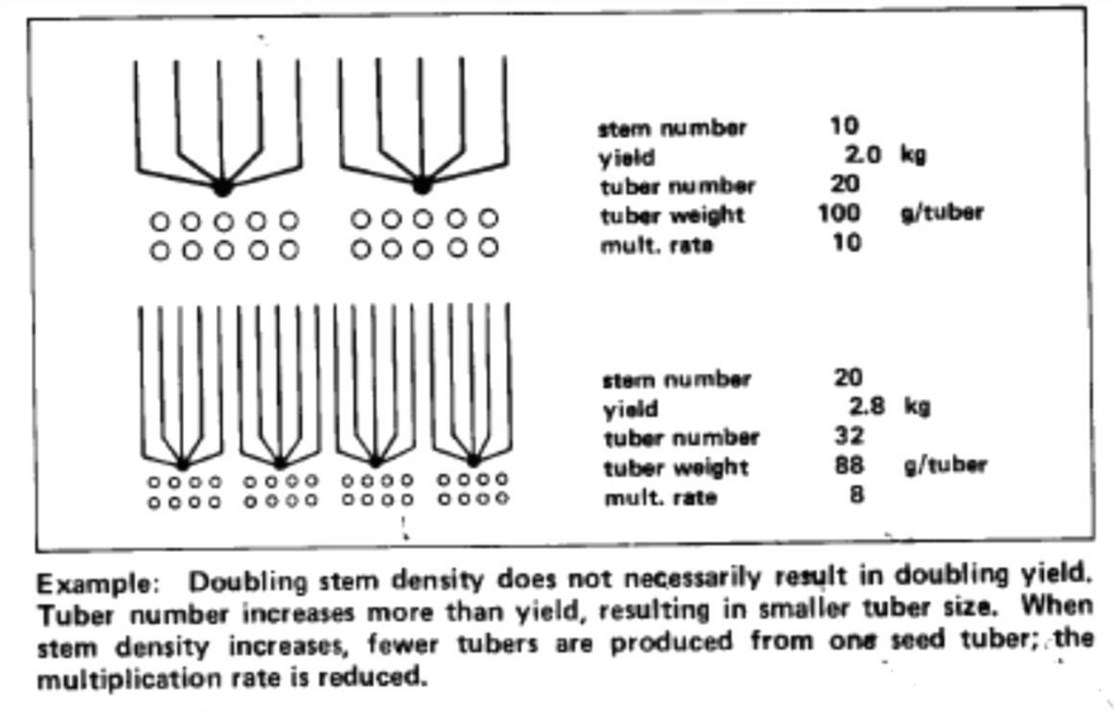


Figure 18. Wiersma showing an example of the impact of Stem Count and its relationship on Tuber Number and size (Wiersema, 1987)

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.

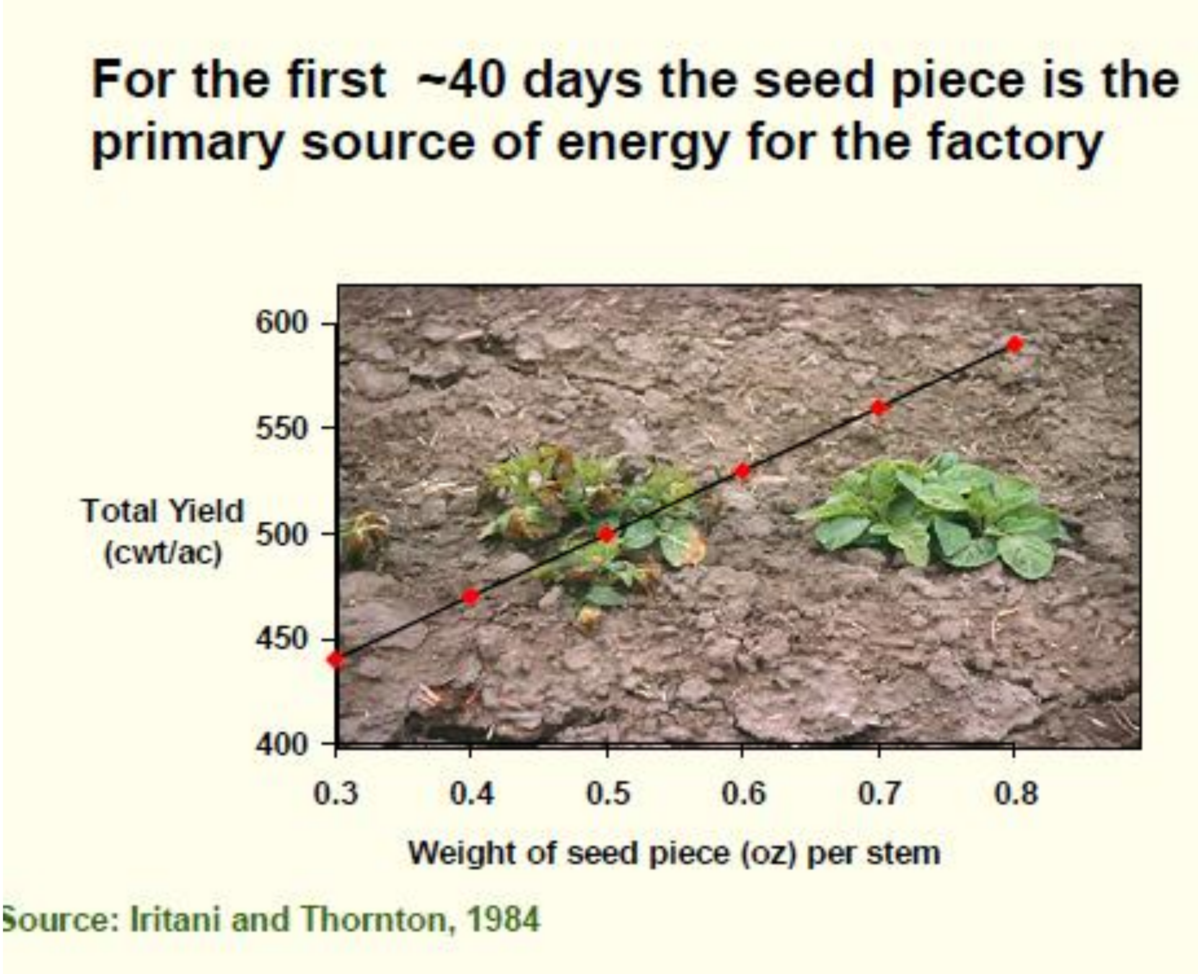


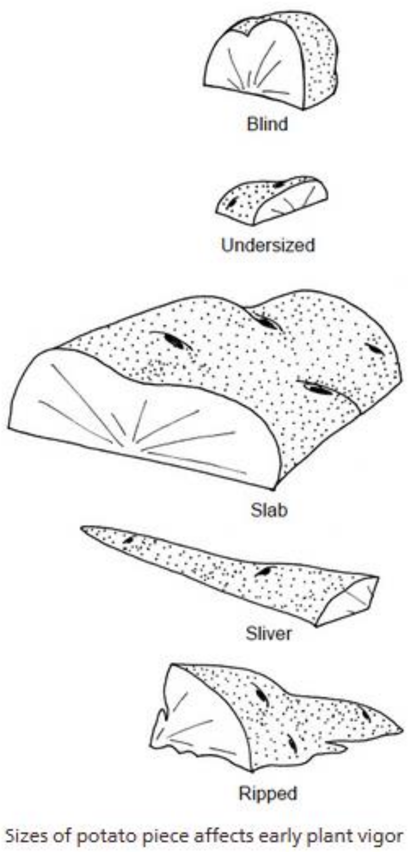
Figure 19. Thornton illustration of relationship of seed piece weight per stem on yield (Thornton, 2014)

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).



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.

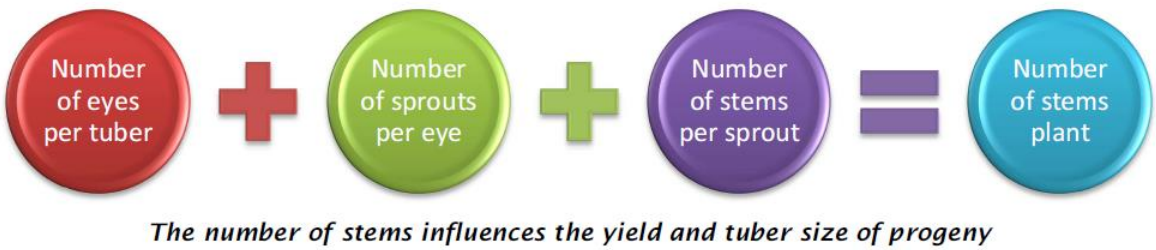


Figure 22. Stem Count per plant as a product of Variety (eyes per tuber), sprouts and stems **(Crump, 2009)**

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.**

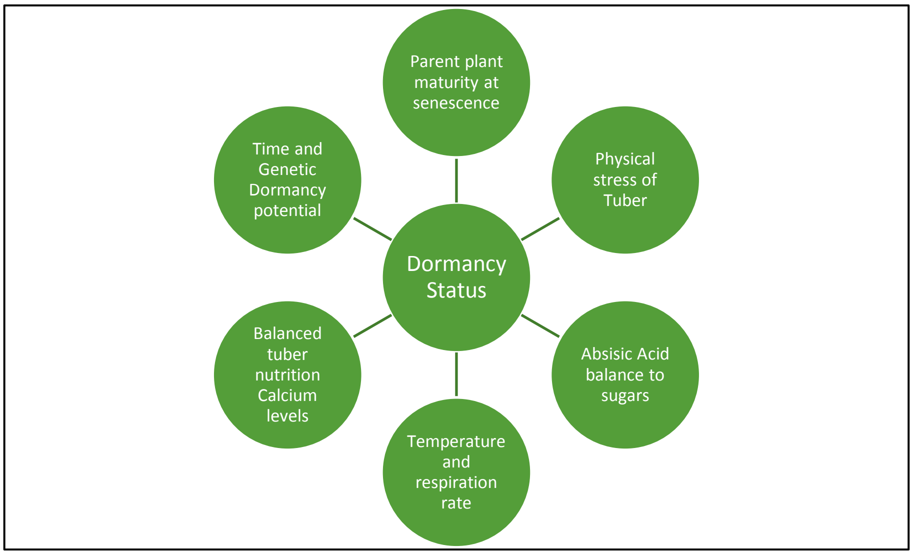


Figure 23. Some key elements affecting Physiological Age and Dormancy Status of the Potato (Philp, 2017)

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.

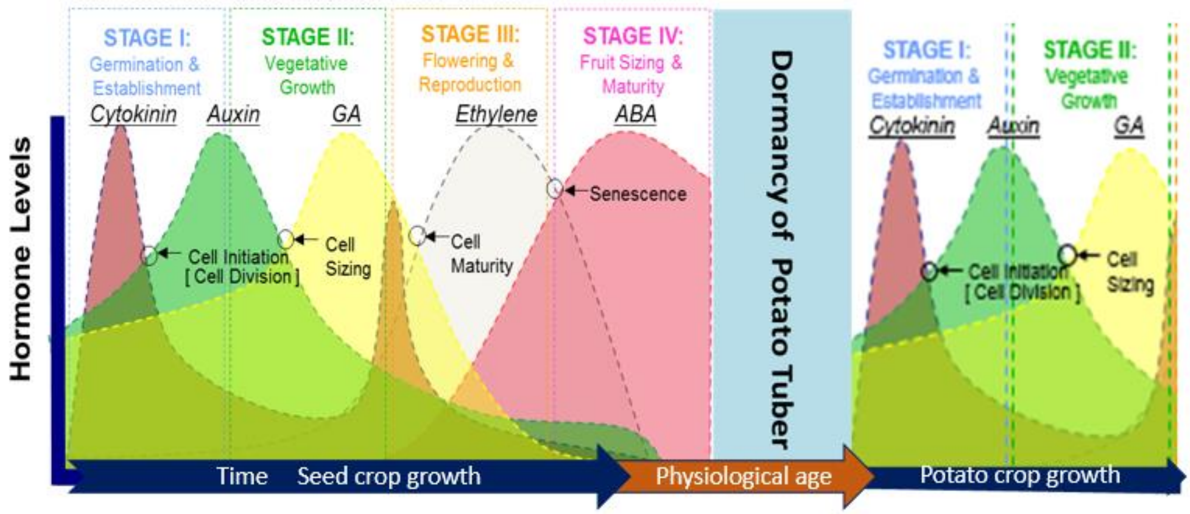


Figure 24. Diagrammatic model of the function and relationship of growth regulators in plants over the plant life cycle (Cavallaro, 2010)

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.

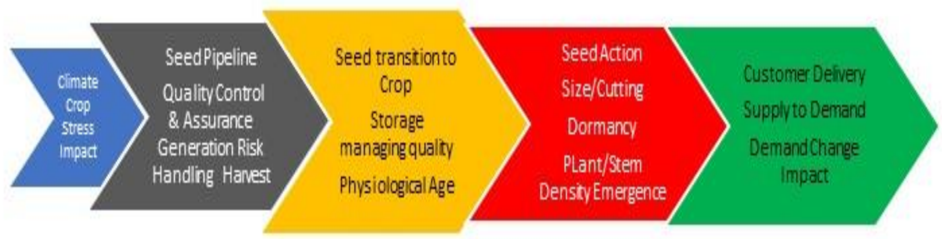


Figure 25. Potato Seed Flow Model from Seed Crop to Customer Supply

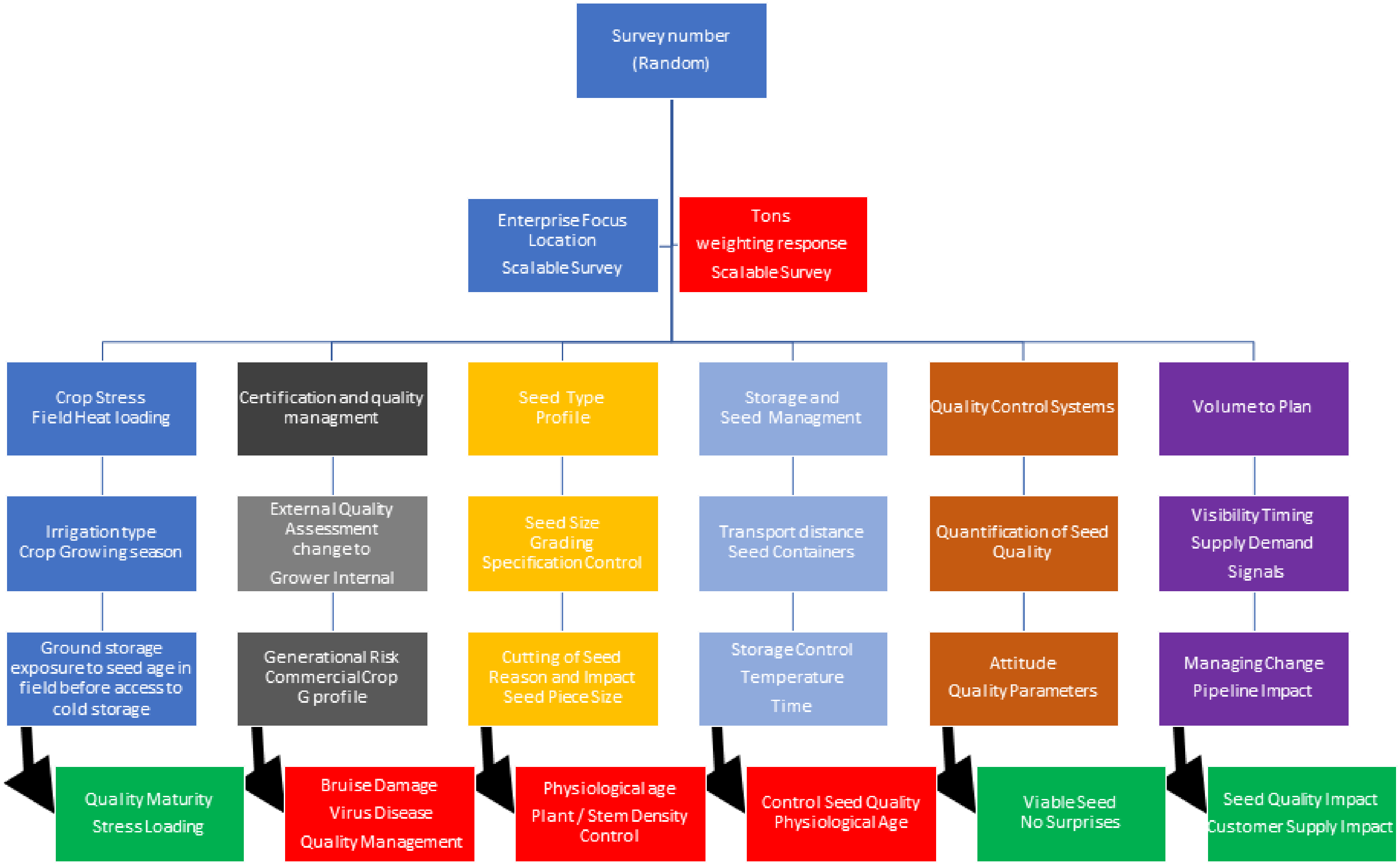


Figure 26. Grower Survey Questionnaire structure, design logic and flow

6.0 WORKS CITED

Al-Mughrabi, K. (2016). Control of Potato Storage Conditions for the Managment of Post-harvest Losses due to Diseases. *Canadian Horticultural Council http://www.hortcounica/wp-content/uploads/2016/02/Potato_Storage_Management_Fact_Sheet_English_Final.pdf*, pp 9.

Blauer, J. (2013). Manipulating Stem Number, Tuber Set and Size Distribution in Specialty Potato Cultivars. *American Journal of Potato Research*, Vol 90, Issue 5 pp 470-496.

Bleasing, D. (2004). *Seed Potatoes A Best Practice Handling and Storage Guide for Growers and Store Operators.* Australia: Horticulture Australia Limited.

Bohl, W. (1995). Potato Seed Management: Seed Size and Age. *University of Idaho CIS 1031*, pp4.

Bohl, W. (2010). Commercial Potato Production in North America. *American Potato Journal, Second Revision Supplement Volume 57 and USDA Handbook 267*, pp 85.

Bohl, W. H. (2011). Potato Seed Piece Size, Spacing and Seeding Rate Effects on Yield, Quality and Economic Return. *American Journal of Potato Research*, Vol 88 Issue 6 pp 470-468.

Brown, P. (2005). *OPtimising production and storage conditions for seed potato physiologcal quality (HAL Project PT02012).* Sydney Australia: Horticultural Australia Ltd.

Buss, P. (2017). Plant Density . *Personal Correspondance P Buss Sentek Australia*, 2.

Cavallaro, D. (2010). A digramatic model of interelationship of growth regulators in plants and the morphological development of the plant. *after Stoller Australia's presentation "Hormone Regulation in Plants"*.

Crump, N. (2009). Physiological Age of Seed Potatoes " The young the old and the sproutless". *Vic Spa Technical Paper*, pp 5.

Cunnington, A. (2008). *Store Manager's Guide.* Kenilworth Warwickshire UK: Agriculture and Horticulture Development Board.

De Stefano-Beltran, L. (2006). Chemically forced dormancy termination mimics natural dormancy progression in potato tuber meristeems by reducing ABA contenet and modifying expression of genes involved in regulating ABA synthesis and metabolism. *Journal of Experimenal Biology*, Vol. 57, No. 11, pp. 2879-2886.

Delaplace, P. (2009). Potato (Solanum tuberosum L.) tuber ageing induces changes in the proteome and antioxidants associated with the sprouting pattern. *Journal of experimental Botany*, Vol 60, No. 4 pp 1273-1288.

Hemberg, T. (1949). Siginifcance of Growth-Inhibiting Substances and Auxins for the Rest Period of the POtato Tuber. *Physiologia Plantarum*, pp 24-36 Volume 2 Issue 1 .

Iritani, W. (1984). Potatoes Influencing Seed Tuber Behaviour. *PNW 248*, 15 pp.

Jackson, K. (1997 (2)). Seed Age A major Factor determining Spacing of Round Seed to Maximize No. 1 Grade Yield. *HAL Conference Presented by John Kerr*, pp2.

Jackson, K. (1997). PT 314 Evaluation of round potato seed in Queensland. *HAL Report (Horticulture Research and Development Corportaion)*, pp43.

Johnson, S. (1997, 2015). *Bulletin #2412 Selecting, Cutting and Handling Potato Seed.* Maine USA: The University of Maine.

Kemnovation. (2017). Justus von Liebig's Law of the Minimum published in 1873. *Kemnovation web site* , http://kemnovation.com/crop-nutrition/.

Knowles, N. (2014). Potato Storage Management, Postharvest Physiological and Quality Maintenance Potato Science Lecture 23 Washinton State University. *http://web.cals.uidaho.edu/potatoscience/files/2014/04/Potato-Science-Lecture-23-4-17-14.pdf*, PP 66.

Lulai, E. (2016). Wounding induces changes in cytokinin and auxin content in potato tubers, but does not induce formation of gibberellins. *Journal of Plant Physiology*, 191:22-28.

Meyhuay, M. (2001). Potato Post Harvest Production. *Food and Agricultural Organiziation of the United Nations http://www.fao.org/3/a-ax440e.pdf*, pp 56.

Neilsen, M. (1989). Potato seed productivity: Factors influencing eye number per seed piece and subsequent performance. *American Potato Journal*, Volume 66, Issue 3, pp 151–160.

Oliveira, J. (2014). Seed potato physiological age and crop establishment. *Agronomy New Zealand*, Vol 44 pp 85-93.

Philp, P. K. (2018). *Electronic Survey Scripts Project PT16000 Horticulture Innovation Australia Potato Seed Handling and Quality Survey.* Adelaide: Philp Horticultural Services.

Philp, P. K. (2018). *Presentation Summary of Literature Review Project PT1600 A Review of Seed Quality and Handling Impact on Potato Production in Australia.* Sydney: Horticulture Innovation Australia.

Philp, P. K. (2018). *Project PT16000 Horticulture Innovation Australia Potato Seed Handling and Quality Understanding The Potato Growers Customers Key Success Factors.* Sydney: Horticulture Innovation Australia.

Philp, P. K., & O'Brien, P. J. (2017). *The Impact of Potato Seed Quality and Handling on Seed Potato, Processing and Fresh Market Production A Literature Reveiw.* Sydney: Horticulture Innovation Australia.

Rhoades, R. e. (1988). *Traditional Potato Storage in Peru: Farmers' Knowledge and Practice.* Lima, Peru: International Potato Centre (CIP).

Rodríguez, L. E. (2010). Factors and mechanisms related to dormancy in potato tubers. A review. *Agron. colomb. vol.28 no.2 Bogotá May / Aug. 2010* .

Sanford, S. (2006). Benefits of Adjustable Speed Fans for Bulk Potato Storage Ventilation Systems. *Wisconsin's Annual Potato Meeting, Stevens Point, WI - February 14-16, 2006*, (p. 10). Steven Point.

Sterret, S. (2015). *Potato Seed Selection and Manaegment.* Virginia : Virginia State University.

Struik, P. (1990). Manipulation of tuber size distribution or a potato crop. *Potato Research*, Vol 33 417-432.

Suttle, J. (2004). Physiological regulation of potato tuber dormancy. *American Journal of Potato Research*, 81:253.

Suttle, J. (2008). Effects of Synthetic Phenylurea and Nitroguanidine Cytokinins on Dormancy Break and Sprout Growth in Russet Burbank Minitubers. *American Journal of Potato Research Suttle, J.C. 2008. Effects of Synthetic Phenylurea and Nitroguanidine Cytokinins on Dormancy Break and Sprout Growth in Russet Burbank Minitubers. American Journal of Potato Research. 85:121-128.*, 85:121-128.

Suttle, J. (2009). Ethylene Is Not Involved in Hormone- and Bromoethane-Induced Dormancy Break in Russet Burbank Minitubers. *American Journal of Potato Research. 86:278-285. doi:10.1007/s12230-009-9081-3*, 278-285.

Suttle, J. (2012). Chemical Inhibitionof potato ABA-8'-hydroxylase activity alters in vitro and in vivo ABA metabolism and endogenous ABA levels but does not affect potato microtuber dormancy duration. *Journal of Experimental Botany*, Vol. 63, No. 15, pp. 5717-5725.

Thornton, M. (2014). Potato Growth and Development. *UNiveristy of Idaho Expo Feb 20*, pp 39.

Wiersema, S. (1987). Effect of Stem Density on Potato Production. *International Potato Centre (CIP) Technical Bulletin 1 C8 W5*, pp18.