



Final Report

On farm evaluation of vegetable seed viability using non-destructive techniques

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Project Number: VG16028

VG16028

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Summary

Vegetable crops that are field established from seed require high seed quality, otherwise a substandard crop will result and essential farm inputs and investments are lost or wasted. The **project objective** of VG16028 is to provide the Australian vegetable industry with a range of options and recommendations to overcome poor seed quality and viability on farm. This program builds upon VG15021, which is developing transformational technologies for the vegetable industry to optimise seed quality, enhance healthy and uniform germination and improve seedling establishment. The **target audience** are Levy payers and commercial partners within the Australian vegetable industry, while supply chain participants and allied industries are the secondary audience. **Project activities** encompassed (1) Grower interviews to identify needs and opportunities. On farm visits and surveys of 10 leading growers and 2 industry affiliates within the Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW) vegetable growing areas have determined that seed viability, purity and/or quality issues are a major concern for industry; (2) A comprehensive literature review of: (2a) The range of available technologies to assist growers in maximising seed vitality on farm with a particular focus on new technologies for real time non destructive grading for seed viability, (2b) Information pertaining to the seed longevity of economically important vegetable crops and (2c) Conditions needed to maximize seed quality and storability on farm; (3) New relationships have been formed with researchers at The University of Sydney *Australian Centre for Field Robotics* with a view to a potential collaboration to progress technologies via future R&D Levy investment. **Outputs** are (a) a review of Industry needs and recommendations from the grower survey, highlighting areas that need improvement and providing recommendations for future R&D investment to improve on farm seed quality outcomes, (b) new knowledge to assist growers in maximizing seed vitality on-farm with a focus on emerging technologies that show potential to non destructively grade seed viability pre planting, (c) knowledge of research providers who can deliver the development of technologies via future R&D levy funding, (d) communication to Levy Payers via one field day and three industry bulletins detailing grower survey outcomes and recommendations for technology and future project development. **Outcomes** are recommendations for new R&D investment/s towards (a) development of novel technologies with the potential for real time grading to maximize vegetable seed quality and (b) a long-term program to optimise seed quality at the seed production and postharvest phase, to ensure seeds are of maximal quality before they reach the grower and then maintain quality on farm. A date is scheduled for autumn 2018 to discuss R&D strategies with key Levy payers towards future project development. Society benefits of new technologies and programs to optimize seed quality are reduced resource wastage - such as labour, fertilisers, irrigation, mechanisation and crop protection materials - and therefore a positive image of the industry as having sustainable produce.

Keywords

Up to 10

Vegetable industry; seed quality; seed viability; seed vigour; seed longevity; non destructive techniques;

Introduction

Historical Background

Vegetable crops that are field established from seed, such as corn, beans, carrots and spinach, require excellent seed quality as the primary and essential starting point of the production program. Poor quality seeds propagate a substandard crop, resulting in essential farm inputs and investments being lost or wasted, thus directly robbing the grower of profits. This is true for any scale of operation regardless of the size of the enterprise (George, 2009).

The vegetable industry Levy and HIA are funding a confidential program titled “*Sowing success through transformational technologies to boost productivity and commercial outcomes*” (VG15021) to develop technologies that optimise seed longevity and seedling establishment success for the Australian vegetable industry. Specifically, naturally occurring compounds and slow release technologies for improved vegetable crop performance are being developed with a view towards commercialization over a 4 year timeframe (2015-2020).

This current project, VG16028: “*On farm evaluation of vegetable seed viability using non destructive techniques*”, will complement and build upon the VG15021 program as there are clear opportunities to share and/or optimise technologies from one project to the other. Since VG15021 is already developing transformational on farm crop establishment technologies for the vegetable industry, the two projects combined will build a holistic approach to seed quality assurance for vegetable growers and future mechanisation, field robotics and/or precision agriculture will ideally be optimised simultaneously.

Project Rationale and Objectives

VG16028 is a multifaceted project. At project onset a review of Australian vegetable industry needs from face-to-face grower surveys identified pressing on farm seed quality issues that currently rob the grower of profits. A global review of new technologies, opportunities and/or future program activities to overcome the identified seed quality issues has since been completed using information from industry, literature and with input from new research allies who have the capacity to develop the most promising technologies. The key project focus has been a review of emerging non destructive and cost effective techniques to screen viable seed and maximise germination and vigour once planted. Information and recommendations from the VG16028 review will inform future R&D investment strategies. A meeting with key Levy payers is scheduled for autumn 2018 where future project investment will be determined, for example towards long term programs to optimise genetic and environmental influences pre- and post-harvest to maximise vegetable seed quality before seeds reach the grower and/or develop of robotics, intelligent systems and sensor technologies to maximise seed viability pre planting.

Significance for Industry

Program logic analysis (see Outcomes section below) identified that future R&D investment for VG16028 promises a significant **productivity boost** for industry, for example via (a) higher profits from enhanced crop establishment and uniformity resulting in improved crop growth and harvest outcomes, (b) reduced costs of production via enhanced resource efficiency, such as through less resource wastage if labour, fertilisers, irrigation, mechanisation and crop protection materials are not wasted, (c) reduced biosecurity risk, for example, if non destructive technologies are developed that can detect diseases that would otherwise be transmitted on farm from seeds and (d) enhanced breeding programs since successful germination and growth of difficult new lines will open currently unusable germplasm, providing a competitive advantage and reduced risk. Indeed new germplasm can be vital during disease outbreaks and if climatic extremes escalate. **New technologies and products** with new uses may arise from this project. For example, the Australian vegetable industry may invest in the development of technologies to non destructively grade seeds for high viability, which can then provide royalties to the vegetable Levy from IP and sale of technologies. **Spill-over benefits for society** may include improved resource use efficiency on-farm, reduced biosecurity risks and less resource wastage.

Thus key linkages to the Australian vegetable industry **Strategic Plan** are through Pillar 2: Market and Value Chain Development, by developing promising novel technologies (SIP strategy 2.4.2) and giving Australian products a

competitive advantage over imports (2.3.4); Pillar 3: Improved Farm Productivity, Resource Use & Management by developing transformational R&D to enhance the productivity of the Australian Vegetable industry (3.1), reducing the costs of inputs such as labour, fuel, energy, fertiliser and other costs (3.5) and improving biosecurity by proactively managing biosecurity risks to industry productivity (3.6) and Pillar 1: Meeting consumer needs both domestically and internationally by maintaining a positive image of the industry through society benefits (1.4). Further, knowledge and recommendations have been communicated to Industry through multiple networks for increased industry engagement (SIP strategy 4.2) such as an industry field day in the Sydney Basin, two industry bulletins and a strategic R&D planning day scheduled for 2018.

Methodology

The vegetable industry Levy and HIA are funding a confidential program titled “*Sowing success through transformational technologies to boost productivity and commercial outcomes*” (VG15021) to develop technologies that optimise seed longevity and seedling establishment success for the Australian vegetable industry. This current project - VG16028: *On farm evaluation of vegetable seed viability using non destructive techniques* - complements and builds upon the VG15021 program as there are clear opportunities to share and/or optimise technologies from one project to the other. A Monitoring and Evaluation Plan was completed for VG16028 at project onset, as shown in Table 1. An updated M&E plan, with progress against each activity, is provided in the Outcomes section below.

This project (VG16028) has a multifaceted approach for maximum industry impact, including:

(1) An industry review component that identified grower needs and opportunities: At project onset a review of Australian vegetable industry needs from face-to-face grower surveys identified pressing on farm seed quality issues that currently rob the grower of profits. Responses have been collated and will be reported to industry via a bulletin and/or magazine article.

Specifically, on-farm visits and surveys of 10 leading growers and 2 industry affiliates within the Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW) vegetable growing areas have determined that seed viability, purity and/or quality issues are a major concern for industry. Many growers described quality seeds at their most important farm input and detailed grower responses are collated and attached as ‘Output 1’.

(2) A global review of new technologies, opportunities and/or future program activities to overcome the identified seed quality issues was then completed using information from industry, literature and with input from new research allies who have the capacity to develop the most promising technologies. Grower recommendations to overcome issues are collated and attached as ‘Output 1’ and summarised in the Evaluation and Discussion Section below.

Literature review

The Australian vegetable industry needs high quality seeds to ensure high seedling emergence rates and a uniform crop for a successful harvest. Levy payers across industry identified that seed viability, purity and/or quality issues are a major concern for industry, hence a comprehensive literature review, attached as ‘Output 2’, has been completed to provide R&D solutions from literature or provide recommendations towards the development of such solutions.

(2a) Emerging non destructive and cost effective techniques to screen viable seed and maximise germination and vigour once planted were the main literature review focus and were compared without bias to one another. The tests and technologies to grade seed quality that were reviewed included: destructive tests that are used in accredited laboratories around the world and new tests that are emerging from research facilities (Section 3 in the literature review), currently available machinery to process seeds for improved quality (Section 4) and new non destructive technologies that use innovative computer-assisted analysis systems for real time automation of seed quality grading (Section 5). Industry recommendations were provided and are summarised in the Evaluation and Discussion Section below.

(2b) A vegetable seed longevity review component was completed since VG15021 identified a lack of seed longevity knowledge about Australian vegetable crops. Taxonomic trends for seed longevity exist; for example, the seeds of many crops (as well as wild and weedy plants) can be characterized as short- to long-lived according to their order, family (Probert *et al.*, 2009), genus (Hay *et al.*, 2006; Kochanek *et al.*, 2008, 2009) and species (Schoeman *et al.*, 2010; Kochanek *et al.*, 2011). Thus Section 6 reviewed factors that determine the germination and vigour peak that can be attained by a seed lot at physiological maturity and factors that determine the rate of subsequent seed deterioration including: genetic effects, pre-harvest parental effects, seed maturity at harvest and postharvest conditions.

Additional industry reviews

(2c) An on-farm seed storage review explored whether poor seed storage options may contribute to poor seed quality

on farm. Poor seed storage conditions, including high relative humidity and high temperatures, result in rapid seed quality decline (Kochanek *et al.* 2010, 2011). For example, seed storage in a hot shed can kill short lived crop seeds within one month. This review occurred during on-farm grower interviews, and recommendations are summarized in the Evaluation and Discussion Section.

(3) Input from new research allies who have the capacity to develop the most promising technologies has been sought. Specifically, a relationship has been formed with researchers at The Australian Centre for Field Robotics (ACFR) at the University of Sydney and their input sought with a view to a potential collaboration to progress non destructive and cost effective techniques to screen viable seed via future R&D Levy investment.

(4) Technology transfer activities to ensure widespread communication of project findings to vegetable Levy Payers included one field day in the Sydney Basis, completed during March 2017, and two industry bulletins that detail (1) grower survey outcomes and (2) recommendations for technology and future project development. Furthermore, a date is scheduled for autumn 2018 to discuss R&D strategies with key Levy payers towards future project development.

Table 1. The monitoring and evaluation (M&E) plan for project VG16028 documenting a schedule for activities and outputs and short-term to intermediate outcomes.

Project Activities and Outputs	Achievement timeline		
	3 months	6 months	*Discussion upon project completion
Grower needs & future technology development			
i. Do growers confirm that there are seed viability issues? What are they? How large is the problem? Which crops are particularly problematic?	50%	100%	
ii. Can there be improvements made in seed storage practices on-farm? Are the technologies available to fix these problems or do new technologies need to be developed?	50%	100%	Required if gaps identified during project
iii. Are technologies developed during VG15021 for on-farm seed viability screening potentially useful for industry? How do they compare to currently used technologies and those identified in the literature review?	50%	100%	
iv. Are there gaps in current technologies on-farm for real time grading of seed for viability pre planting? What opportunities are there in Australian field robotics and precision agriculture to help growers into the future?	50%	100%	Required if gaps identified during project
v. Could a long-term program to optimise seed quality (via pollen quality) and seed longevity (via maternal plant health) through environmental growth optimisation at the seed production phase solve certain grower issues?			Required if gaps identified during project
vi. Are there other solutions, such as engaging new seed suppliers or working with suppliers to supply better quality seeds to growers?			Required if gaps identified during project
Vegetable seed longevity review			
Is there information in the literature to categorise vegetable crops as having short- to long-lived seeds?	50%	100%	
Is a future project to classify key Australian vegetable lines as short to long-lived useful for industry?			Required if information is inadequate
Literature review of techniques to assist growers in maximising seed vitality on-farm			
Are techniques identified in the literature useful and realistic for Australian growers? How do techniques compare against each other?	50%	100%	
Are future projects to validate techniques required for Australian growers and under Australian conditions?			Required if gaps identified during project

*The project leader (Kochanek) will report progress and discuss future opportunities with Levy payers from the Australian vegetable industry and Hort Innovation at project completion (post final report submission).

Outputs

(1) The detailed industry review component that identified grower needs and opportunities is attached as ‘**Output 1**’. This includes (a) a detailed summary of grower issues, (b) outcomes from the on-farm seed storage review to explore whether poor seed storage may contribute to poor seed quality, (c) grower recommendations towards overcoming on farm seed quality issues.

In summary, 10 vegetable growers and 2 industry affiliates (vegetable transplant and canning industry representatives) were interviewed during a field day or on-farm visits in the key growing areas of the Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW) (Plates 1-5). Many growers described quality seeds at their most important farm input and seed issues included poor germination percentage and non-uniform emergence, disease transmission via seeds, varietal impurity, non-uniform seed size, damage to seeds and ‘seed enhancements’ such as priming, pelleting and hot water treatments reducing seed quality rather than enhancing it. Seed supplier concerns, lack of lines bred or grown for Australian conditions, disease resistance not holding up, inadequate or inaccurate seed packet labelling and long lead-in times for seed delivery were identified as additional issues of concern. Grower recommendations for seed related issues are summarized in the Evaluation and Discussion Section.



Plate 1. Grower Jeff McSpeddin from the Bathurst NSW growing area was interviewed on farm by the report author, Dr Jitka Kochanek, in March 2017. Matt Plunkett from the Greater Sydney Local Land Services generously organized and participated in grower visits.



Plate 2. Matt Plunkett and Jitka Kochanek interviewed grower Michael Willott at Ravenswood Farm in the Bathurst NSW vegetable growing area. Various crops were sown as seed which had been sold as the wrong variety and thus could not be harvested.



Plate 3. NSW extension officers Bill Dixon and Peter Conasch from the Greater Sydney Local Land Services providing a tour of the Sydney Basin demonstration farm with the report author.



Plate 4. Seedling producer John Vella, Matt Plunkett and Jitka Kochanek during on site interviews at Leppington Seedlings in the Sydney Basin, NSW.



Plate 5. On farm grower interview with grower Brock Sutton at Sutton Farms in the Lockyer Valley, Qld. Brock is shown demonstrating his farm sowing machinery to Jitka and her UQ research team (January 2017).

(2) The literature review provides information about R&D solutions or recommendations towards the development of

such solutions is attached as '**Output 2**'.

Tests and technologies to grade seed quality were reviewed in the literature survey, including:

- (a) Destructive tests that are used in accredited laboratories around the world and new tests that are emerging from research facilities (Section 3),
- (b) Currently available machinery to process seeds for improved quality (Section 4) and
- (c) New non destructive technologies that use innovative computer-assisted analysis systems for real time automation of seed quality grading (Section 5). Included is a summary of future R&D recommendations for Industry (Section 5.5).

Section 6 reviewed factors that determine the germination and vigour peak that can be attained by a seed lot and that influences the rate at seeds subsequently deteriorate. Specifically, genetic effects, pre-harvest parental effects, seed maturity effects and postharvest handling and storage conditions that influence seed viability, deterioration rate and longevity are comprehensively reviewed. Recommendations for future project R&D investments are provided in Section 6.3.

(3) Extension and communication to Levy Payers from project VG16028 is via:

- (a) **Output 3** – an information sharing field day in the Sydney Basis, organized by NSW extension officers from the Greater Sydney Local Land Services and completed in March 2017 (Plate 6). We are especially grateful to Bill Dixon and Matthew Plunkett who were so generous with their time and help towards VG16028.
- (b) **Output 4*** – Industry Article 1: Industry needs and recommendations from VG16028 survey will be summarised, introduction to VG15021 in the Vegetables Australia magazine and/or the Hort Innovation magazine (Aug 2017).
- (c) **Output 5*** - Industry Article 2: Technology & future project recommendations from VG16028 will be summarised in the Vegetables Australia magazine and/or the Hort Innovation magazine (Aug 2017).
- (d) **Output 6*** - Industry Technical Bulletin: Optimized seed storage conditions needed to ensure maximum seed viability is maintained during seed storage and on farm. Location of publication to be confirmed (completed before mid 2018).
- (e) **Output 7** – More information pertaining to grower issues and R&D needs will be collected in Sep 2017 – March 2018 to inform the 2018 R&D Strategy meeting (Output 8). Growers will be encouraged to send information to a designated email and information will be collated prior to the 2018 meeting.
- (f) **Output 8** - A date is scheduled for autumn 2018 to discuss R&D strategies with key Levy payers towards future project development.

* Drafts will be reviewed by Hort Innovation prior to publication in industry magazines or bulletins.



Plate 6. An information sharing field day in the Sydney Basis was organized by NSW extension officers from the Greater Sydney Local Land Services in March 2017. Here the report author is presenting to growers as part of the field day. Grower interviews followed this presentation.

(4) New research collaboration: A relationship has been formed with researchers at The Australian Centre for Field Robotics (ACFR) at the University of Sydney and their input sought with a view to a potential collaboration to progress

non destructive and cost effective techniques to screen viable seed via future R&D Levy investment. The report author met with team members in Sydney in March 2017 (Plate 7).

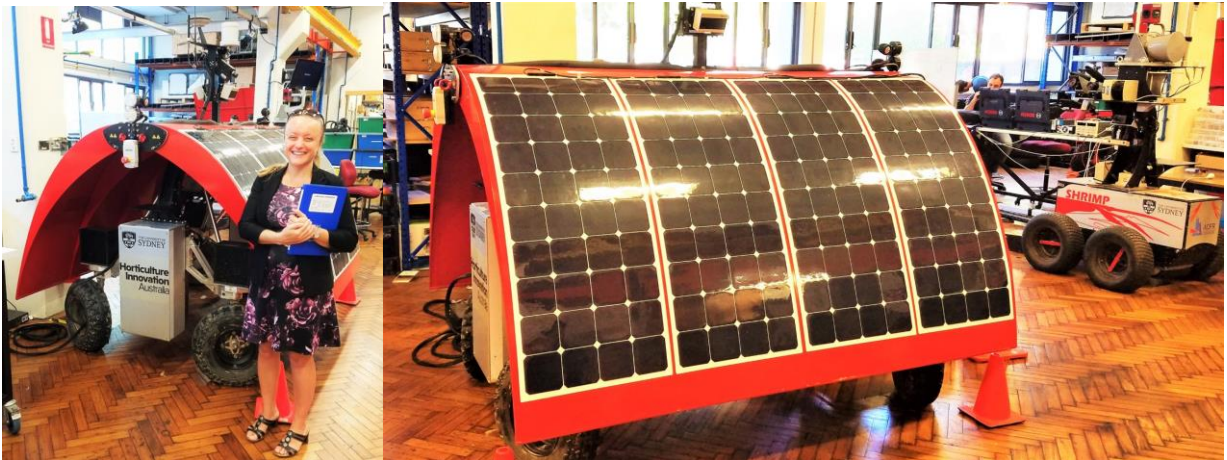


Plate 7. A relationship has been formed with researchers at The Australian Centre for Field Robotics (ACFR) at the University of Sydney. The report author is shown standing beside their infamous 'Ladybird' mobile ground robot.

(5) Recommendations for development of novel technologies via new R&D investment/s, are summarised in the Evaluation and Discussion and Recommendations sections. A date is scheduled for autumn 2018 to discuss R&D strategies with key Levy payers towards future project development.

Outcomes

1. PROJECT RESULTS AND OUTCOMES

All intended outcomes were successfully achieved, as shown in the Monitoring and Evaluation (M&E) Plan in Table 2. This includes recommendations for new R&D investment/s towards the development of novel technologies with the potential for real time grading to maximize vegetable seed quality and a long-term program to optimise seed quality at the seed production and postharvest phase, to ensure seeds are of maximal quality before they reach the grower and then maintain quality on farm.

Table 2. The Monitoring and Evaluation (M&E) Plan for project VG16028 documenting the activity and output schedule and the outcomes and/or next steps arising from each activity.

Project Activities and Outputs	Complete	Outcomes and next steps
Grower needs & future technology development		
i. Do growers confirm that there are seed viability issues? What are they? How large is the problem? Which crops are particularly problematic?	Yes	Outcomes from the grower survey to be communicated via an industry bulletin
ii. Can there be improvements made in seed storage practices on-farm? Are the technologies available to fix these problems or do new technologies need to be developed?	Yes	Opportunity identified for future R&D - to be discussed at 2018 strategy meetings*
iii. Are technologies developed during VG15021 for on-farm seed viability screening potentially useful for industry? How do they compare to currently used technologies and those identified in the literature review?	Yes	Growers not keen on technology, prefer to outsource to seed laboratories
iv. Are there gaps in current technologies on-farm for real time grading of seed for viability pre planting? What opportunities are there in Australian field robotics and precision agriculture to help growers into the future?	Yes	Literature review completed. Opportunity identified for future R&D - to be discussed at 2018 strategy meetings. Findings communicated via industry bulletin
v. Could a long-term program to optimise seed quality (via pollen quality) and seed longevity (via maternal plant health) through environmental growth optimisation at the seed production phase solve certain grower issues?	Yes	Opportunity identified for future R&D - to be discussed at 2018 strategy meetings*
vi. Are there other solutions, such as engaging new seed suppliers or working with suppliers to supply better quality seeds to growers?	Yes	Opportunity identified for future R&D - to be discussed at 2018 strategy meetings*
Vegetable seed longevity review		
Is there information in the literature to categorise vegetable crops as having short- to long-lived seeds?	Yes	Literature review completed
Is a future project to classify key Australian vegetable lines as short to long-lived useful for industry?	Yes	Opportunity identified for future R&D - to be discussed at 2018 strategy meetings*
Literature review of techniques to assist growers in maximising seed vitality on-farm		
Are techniques identified in the literature useful and realistic for Australian growers? How do techniques compare against each other?	Yes	Literature review completed
Are future projects to validate techniques required for Australian growers and under Australian conditions?	Yes	Opportunity identified for future R&D - to be discussed at 2018 strategy meetings*

*The project leader (Kochanek) will report progress and discuss future opportunities with Levy payers from the Australian vegetable industry and Hort Innovation in autumn 2018 at a strategy meeting with key Levy payers with a view to planning future R&D project development and investment.

2. ECONOMIC, SOCIAL AND ENVIRONMENTAL IMPACTS THAT HAVE RESULTED OR MAY RESULT INTO THE FUTURE FROM THE PROJECT

The detailed and integrated program logic model for VG16028 is provided as Table 3.

Table 3. Program Logic for project VG16028.

Broader goals Long-term goals: HIA, Australian Veg Industry & Government	<u>Government</u> Enhanced productivity & adding value <u>Australian Vegetable Industry & HIA</u> Market and Value Chain Development • Develop promising novel technologies (2.4.2) • Give Australian products a competitive advantage over imports (2.3.4) Improved Farm Productivity, Resource Use & Management • Transformational R&D to enhance the productivity of the Australian Vegetable industry (3.1) • Reduce the costs of inputs such as labour, fuel, energy, fertiliser and other costs (3.5) • Biosecurity - Proactively manage biosecurity risks to industry productivity (3.6) Knowledge and recommendations communicated to Industry • Communication to growers and other industry stakeholders through multiple networks for increased industry engagement (4.2) Meeting consumer needs both domestically and internationally • Maintain a positive image of the industry through society benefits (1.4)
End-of-program outcomes (i.e. with future R&D investment)	• New technology development ○ New technologies and products with new uses may arise from this project, ○ For example, The Australian Vegetable Industry may choose to invest in the development of technologies to non-destructively grade seeds for high viability, which can then provide royalties to the Vegetable Levy from IP and sale of technologies. • Significant productivity boost from enhanced seed quality, for example ○ Higher profits via enhanced crop establishment and uniformity resulting in improved crop growth and harvest outcomes, ○ Reduced costs of production via enhanced resource efficiency, for example, through less resource wastage when poor seed viability no longer hinders product quality, ○ Enhanced breeding programs since successful germination and growth of difficult new lines will open currently unusable germplasm, providing a competitive advantage and reduced risk (e.g. new germplasm can be vital during disease outbreaks and into the future if climatic extremes escalate), ○ Reduced biosecurity risk, for example, if non-destructive technologies are developed that can detect diseases that would otherwise be transmitted by seeds. • Spill-over benefits for society ○ By overcoming early crop losses a myriad of potential spill-over benefits for society can be obtained such as improved resource use efficiency on-farm, reduced biosecurity risks and less resource wastage, ○ High quality seeds mean that essential farm inputs and investments - such as labour, fertilisers, irrigation, mechanisation and crop protection materials - are not lost or wasted, as can be the case if poor seed quality results in crop failure,

	○ This promotes industry with a positive and sustainable image in the public eye.
Intermediate outcomes	The project leader will report progress and discuss future opportunities with Levy payers from the Australian Vegetable Industry and Hort Innovation at project completion. Possible future projects, as identified from grower interviews: • Development of technologies for non-destructive real time grading of seed for viability pre planting ○ For example, to ensure variety/cultivar purity, seed uniformity in terms of size and germinability, seeds free from disease, seeds that maintain their viability across seasons etc. • Classification of key Australian vegetable lines as short to long-lived ○ To aid growers and allied industries in seed storage decision-making. • Improvements to and increased knowledge about seed storage practices for growers to maintain optimal seed quality. • A long-term program to optimise seed quality and seed longevity for growers. • Development of Australian Standards for seed quality that must be adhered to by seed suppliers. • Programs to produce seeds in Australia and develop lines specifically for Australian conditions (e.g. Centre for Vegetable Excellence in southern Qld).
Immediate outcomes (July 2017)	Provide recommendations to Industry for development of novel technologies and/or practical solutions for future R&D investment consideration. The primary objective will be to ensure seeds supplied to growers are of a high quality (or the grower can seek compensation and/or pay a lower price). Two information fact sheets or industry bulletins summarising findings from industry, literature and future technology reviews will be distributed to Industry at project completion.
Influence activities	Activities to 'set the scene' delivered • Growers interviewed in Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW) • Seed issues and problem crops identified and collated • Recommendations to overcome key issues identified and collated such as: ○ Engage new seed suppliers, ○ Develop new varieties specifically for local conditions, ○ Centre for Vegetable Excellence (e.g. in southern Qld) for genetic improvement, ○ Development of Australian Standards that must be adhered to by seed suppliers, ○ Need for better/truthful labelling on seed packaging, ○ Development of technologies to non-destructively grade seeds for high viability. • Literature review has identified promising non-destructive techniques to assist growers in maximising seed vitality on-farm.
Foundational activities	Funding obtained for VG16028, building upon project VG15021. Relationships developed with (a) Leading growers in key Australian vegetable growing areas (i.e. Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW)); (b) Researchers at The Australian Centre for Field Robotics (ACFR) at the University of Sydney, QUT Australian Centre for Robotic Vision and QDAFF Society of Precision Agriculture with a view to possible future collaboration towards development of technologies identified in VG16028; and (c) Extension officers from the Greater Sydney Local Land Services.

In summary, longer term outcomes from VG16028 promise:

a. New technology development

New technologies and products with new uses may arise from this project. VG16028 provides recommendations for development of novel technologies via new R&D investment/s with the potential for real time grading of seed for viability pre planting but also the option to ensure seeds are of maximal quality even before they reach the grower and maintain their quality on-farm.

b. Significant productivity boost for growers

Project VG15021 showed that enhanced crop establishment technologies could realistically be adopted by c. 50% of the vegetable industry within 7-8 years. Key financial or social benefit estimates that align with VG16028 are shown below:

Higher profits via enhanced crop establishment, growth and yield: (a) Enhanced crop establishment: Project VG15021 showed that seed costs account for c. \$260m p.a. for the Australian vegetable industry. Assuming expensive and problem lines account for 10% of seed stock, a 20% increase in germination of problem lines accounts for \$5.2m p.a., while \$5 extra produce harvested for each extra germinated seed provides \$52m p.a. (b) Enhanced crop productivity. Assuming a conservative 2% increase in total yield with better seed viability outcomes for 50% of the levied vegetable industry provides \$18.5m p.a.

Reduced costs of production via enhanced resource efficiency. For example, assuming labour accounts for 17% of total costs and a 2% reduction in labour costs, this accounts for \$6.3m annually for 50% of the industry; assuming fertiliser costs account for 9% of total costs and a 3% reduction in their use, this accounts for cost savings of \$5m p.a. for 50% of industry.

Enhanced breeding programs: Successful germination and growth of difficult new lines will open currently unusable germplasm, providing a competitive advantage and reduced risk (e.g. new germplasm can be vital during disease outbreaks and into the future if climatic extremes escalate).

c. Spill-over benefits for society

This project aims to overcome early crop losses for industry, which have a myriad of potential spill-over benefits for society. One key benefit to society is improved resource use efficiency on-farm, hence less resource wastage. High quality seeds mean that essential farm inputs and investments - such as labour, fertilisers, irrigation, mechanisation and crop protection materials - are not lost or wasted, as can be the case if poor seed quality results in crop failure.

Evaluation and discussion

Grower Survey - Issues and Recommendations:

To identify grower needs and opportunities, 10 vegetable growers and 2 industry affiliates (vegetable transplant and canning industry representatives) have been interviewed during a field day or on-farm visits in the key growing areas of the Lockyer and Fassifern Valleys (Qld), Sydney Basin and Bathurst (NSW). A summary of the key points raised within the survey:

All growers reported seed viability, purity and/or quality issues

- Many growers described quality seeds at their most important farm input
 - Without quality seeds all other resources are wasted,
 - Growers are happy to pay extra for high quality seeds.
- Some growers have resorted to importing their own seeds because Australian seed suppliers do not meet the quality and quantity standards needed.
- Growers commonly observed seed viabilities of < 85% – ideally 98% viability is the target.
- Currently vegetable growers are price takers of seeds – ideally would like to become price setters.
- Growers and other seed users (e.g. transplant suppliers) are often forced to use seeds even if they are of poor quality because they need that specific variety to meet market demands.

Seed issues

- Poor germination percentage and non-uniform emergence
 - Identified in certain varieties of sweetcorn, cabbage, cauliflower, lettuce, beetroot and other crops.
- Disease transmission via seeds
 - Overseas seed production was perceived as a potential biosecurity threat,
 - Growers suspect many diseases are entering production systems via infected seeds,
 - Diseases of concern were *Botrytis spp.* fungus, verticillium wilt fungus (*Verticillium spp.*), *Alternaria spp.* fungus, *Rhizoctonia spp.* fungus, black rot bacteria (*Xanthomonas spp.*) and cucumber green mottle mosaic virus (*Tobamovirus genus*).
- Varietal impurity
 - For example, non-hybrid seeds are mixed into hybrid lines, multiple varieties/cultivars are mixed together or the entirely wrong variety is supplied to the grower.
- Non-uniform seed size
 - Larger seeds were perceived to have higher vigour,
 - Uniform seed size is needed for optimal machinery performance (e.g. to avoid sowing of 2 seeds into one location).
- Damage to seeds
 - Cleaning practices often damage seeds; better cleaning practices are needed.
- Seed enhancements need improvement
 - Techniques such as priming, pelleting and hot water treatments need to be improved,
 - Presently many reduce seed quality rather than enhance it.

Other key issues

- Seed supplier insincerity was a key issue
 - Behaviour is 'unprofessional' from many seed suppliers towards growers,
 - For example, the grower must just 'accept what they get' even if seed quality is poor and compensation is rarely provided (e.g. Terranova, SPS, Claus, Fairbanks, Syngenta),
 - Truth in labelling is needed as often the grower cannot trust what is written on the packet, e.g. 95% germination is on the packet but only 70-80% of seeds germinate,
 - Some seeds are sourced from inappropriate locations, such as developing countries, hence seed quality is poor OR from inappropriate climates so seeds/crops have poor outcomes in Australia (e.g. deserts of California, cool regions of New Zealand).

- Lines are generally not bred or grown in conditions that resemble Australian conditions hence do not perform well in Australian conditions.
- Large companies (e.g. Bayer, Monsanto, Syngenta) have bought many of the local/smaller companies with consequences for Australian growers
 - The Australian market is too small to justify investment in breeding programs for Australian conditions,
 - Massive skills gap within the market,
 - Many breeding programs (including international) have been shut down by these companies.
- Disease resistance is not holding up in many available lines.
- Labelling needs more information and that information needs to be accurate.
- New lines are not being made available on the Australian market.
- Lead-in times for seed are very long, seeds are not available on-hand.

Grower recommendations to overcome key issues

- Engage new seed suppliers
 - Bring in new companies that are willing to do breeding in Australia or at least under climatic conditions similar to those in Australia,
 - It was perceived that there are not enough seed producers/suppliers so if a bad season hits the growers 'gets what they get'.
- Develop new varieties specifically for local conditions
 - Seed production in Australia was seen as a high priority by most growers,
 - Overseas seed production was perceived as a potential biosecurity threat.
- Centre for Vegetable Excellence (e.g. in southern Qld)
 - Genetic improvement was viewed as a key priority,
 - Growers suggested that the biggest industry suppliers of key crops in Australia be involved to develop varieties for the Australian climate and market needs.
- Development of Australian Standards for seed quality
 - Development of 'A' and 'B' grade seed standards that give the grower a choice to pay more for premium 'A grade' seeds or pay less for poorer 'B grade' seed lots,
 - Must be adhered to by seed suppliers; penalties for seed suppliers if seed quality parameters on the label are not met.
- Need better/truthful labelling on seed packaging.
- Screening trials
 - Engage a body such as the DPI or UQ to undertake screening trials with seed companies and engage growers to do final proof-of-concept trials for new varieties.
- Development of technologies to non-destructively grade seeds for high viability
 - Growers suggested that the Vegetable Industry could invest in the development of these technologies and royalties from IP and sale of technologies would return into the Vegetable Levy,
 - Possible partnerships with providers such as GRDC who face similar problems,
 - Maintenance of IP in Australia a key priority,
 - Machinery itself bought and owned by seed suppliers.

Other key points

- A long-term program to optimise seed quality (via pollen quality) and longevity (via maternal plant health) through environmental growth optimisation at the seed production phase was viewed highly favourably by growers
 - Viewed as a real opportunity to maximise seed quality for the Australian vegetable industry,
 - Kochanek was the first researcher to discover this phenomenon (Kochanek *et al.*, 2010, 2011) and will engage growers at project conclusions to determine feasibility of this research.
- The UQ-developed 'seed pouch' and app to destructively determine seed quality on-farm was not deemed useful for growers
 - Growers would prefer to outsource such services to seed testing laboratories and/or have confidence in quality from seed suppliers in the first place.
- Seed storage practices on-farm

- Most growers store seeds for <1 year, generally in air-conditioned rooms, hence seed deterioration on-farm was generally not a major issue,
- Nonetheless some growers kept discontinued lines or excess seeds between seasons,
- Hence the final project report will make recommendations to industry about optimal seed storage conditions to optimise seed longevity.
- A future project that classifies key Australian vegetable varieties/cultivars as short to long-lived was deemed useful for industry
 - Seeds of some varieties were noted to live longer than others within a crop,
 - Knowing inherent seed longevity for a given line would mean fewer repeat germination tests and an ability to keep lines between seasons,
 - Industries that could particularly benefit are, for example, baby leaf cut lettuce and spinach industries, sweet corn and beetroot canning industries and others.

Literature Review Recommendations:

Levy payers across industry identified that seed viability, purity and/or quality issues are a major concern, hence the literature review has compiled R&D solutions or provided recommendations towards the development of such solutions.

The definition of a high quality seed lot from grower surveys is one that is disease-free and genetically pure, with high germination (>95%) and uniform seedling establishment and with seed sizes and shapes that fit well into existing machinery.

1) Promising non destructive technologies for real time grading of seed quality

The most promising technologies to grade seed quality non destructively, in real time and across most of the areas of concern for growers were reviewed in the literature. Innovative computer-assisted analysis systems to grade seed quality in real time - based on external and internal seed attributes such as surface texture and colour, light reflectance and fluorescence, seed size, shape, density and more – are emerging and promising to be faster, easier and more accurate than traditional seed viability analysis by technicians or rudimentary seed grading machinery (Cantliffe, 2003; Dell'Aquila, 2009; Huang *et al.*, 2015). The review covered computer vision, electronic nose and thermal imaging techniques and various optical analysis techniques, including infrared spectroscopy, hyperspectral imaging, chlorophyll fluorescence, X-ray imaging and biospeckle laser techniques. Of these, those that quantify seed optical properties and thermal dynamics were deemed the most useful to address grower needs.

Hyperspectral imaging was identified as the most useful technology because it combines spectroscopic imaging and computer vision to simultaneously determine interior and exterior seed qualities. Its rapid data acquisition capacity and ability to gather multiple complex attributes at high resolution simultaneously and under variable conditions makes it the most promising technology for conveyor belt commercial-scale uses. It is also the only currently available technology able to deal with specific seed sorting realities and complexities, such as overlapping and clumped seeds and distinguishing between seeds with similar sizes, colours and shapes. The main limitation hindering commercial use of hyperspectral imaging has been the huge amount of data it generates, which slows and overcomplicates the seed classification process. This is now being overcome by researchers selecting specific effective wavebands to build more simple imaging systems that are slightly less accurate but still meet the quality requirements of the grower (ElMasry & Sun, 2010; Dumont *et al.*, 2015; Fahlgren *et al.*, 2015; Rahman & Cho, 2016).

Thermal imaging was also identified as a promising technology for automated non destructive seed sorting, being a highly sensitive, non-contact and affordable technique with a high resolution in spectral and spatial dimensions and that is completely safe for the seed and user. Currently, the drawbacks limiting its usefulness for real time seed sorting are its requirement for a long data acquisition window of around 15 seconds, need for environmental stability and inability to sort clustered or overlapping seeds; on a conveyor belt this would mean stopping the production line to gather seed quality data. However, given that thermal imaging is a much newer technology than hyperspectral imaging, thus without the R&D background, thermal imaging limitations may be overcome with future R&D investment (Kranner *et al.*, 2010; Dumont *et al.*, 2015; Rahman & Cho, 2016).

R&D Challenges and Future Direction

Future R&D will need to overcome seed lot complexity and variability if new technologies to grade seed quality in real time for growers are to become a reality. Artificial intelligence is already used in horticulture and agriculture for simple and repetitive on farm tasks such as weed management (Ball *et al.*, 2015) and yield prediction (Underwood *et al.*, 2016). Thus, given that seeds are complex and variable living organisms, seed quality grading success will come with building upon simple systems. A future project to develop such technologies may require, for example:

- Time to learn intricacies of seed lots for each crop or line of interest, such as subtleties in seed external appearance and internal chemical and physical composition. Indeed, these traits will vary between seasons and crops and sometimes between varieties or cultivars of a single crop.
- Time to learn how seed features relate to biological attributes that are important for growers, such as in-field seed viability and vigour to ensure uniform seed emergence and crop growth,
- A long phase of evaluation and validation for each new trait to be assessed and sorted, with significant learning needed to correlate the image-extracted traits to biologically relevant quality attributes of seeds (Fahlgren *et al.*, 2015),
- For each new application or crop line a new process of learning and expertise building will be needed to ascertain the meaning of measurements and to put them into the correct biological context (Braga *et al.*, 2005).

Complex traits may require a multi-step sorting process with several techniques used one after the other or multiple techniques used simultaneously to grade seed quality to the precision required by industry (Pannico *et al.*, 2015). Indeed, this may even entail combining currently used seed sorting machines with novel techniques, such as new hyperspectral imaging techniques with presently used gravity tables (Hansen *et al.*, 2017).

(2) Maximising Seed Viability and Longevity for Industry

Section 6 of the literature survey determined that scarce research has been undertaken into understanding vegetable seed viability and longevity characteristics or how these seed quality traits can be maximised through pre- and post-harvest cultural practices.

Thus key areas for future R&D investment identified in this review include:

(a) A definitive classification of key vegetable crops as short to long lived to inform storability decisions for seed producers and vegetable growers. This would entail a holistic comparison of the most economically important cultivars and varieties for the Australian vegetable industry.

(b) Significant opportunity to improve vegetable seed viability and longevity by optimising:

(i) The pre-harvest crop growing environment. This work would follow on from the author's ground-breaking research that was the first to determine that paternal and maternal plant health plays a combined and cumulative role in significantly improving seed viability and longevity. Future research would identify those conditions that optimise pollen quality and maternal health for industry's most economically important cultivars and varieties with a view to significantly improving seed viability and longevity for the grower.

(ii) The timing of seed harvest. Future research would identify optimal seed collection windows for industry's most economically important cultivars and varieties to maximise seed viability and longevity at harvest and thus for the grower in the longer term.

The review also highlighted the need for appropriate seed storage conditions to ensure maximum seed viability is maintained during seed storage and on farm. A technical bulletin will communicate this information to industry over the coming months.

Concluding Remarks

The next steps for project VG16028 will be grower consultation to prioritise R&D activities. Since each challenge requires unique solutions, grower seed quality issues have been divided into six Pillars: germination, viability, seed aging, uniform emergence and vigour (Pillar 1), seed-borne disease (2), varietal impurity (3), damage to seeds (4), seed mass, fill and density (5) and seed size, uniformity of size and shape of seeds (6). Levy payers will be consulted via a strategy meeting in 2018 to ascertain which of the six seed quality Pillars are their first priority. Future R&D activities will thus follow.

Recommendations

CONTEXT FOR RECOMMENDATIONS

Growers require high quality seed for long term crop performance and management on farm. Hence the Australian vegetable industry tendered project VG16028 to (a) identify grower seed quality issues and (b) provide recommendations for future R&D investment into technologies, activities or techniques that can evaluate and improve seed viability prior to planting on farm. The University of Queensland (UQ) Plant Growth and Productivity Optimisation team delivered the project.

At project onset a review of Australian vegetable industry needs from face-to-face grower surveys identified pressing on farm seed quality issues that rob the grower of profits. Growers described quality seeds as their most important farm input.

Key seed quality issues

- Poor germination percentage and non-uniform emergence,
- Seed-borne disease transmission – potentially critical biosecurity issue if seeds are imported from overseas,
- Varietal impurity,
- Non-uniform seed size,
- Damage to seeds,
- ‘Seed enhancements’ reducing seed quality (e.g. priming, pelleting and hot water treatments),
- Other concerns: certain seed supplier insincerity, lack of lines bred or grown for Australian conditions, disease resistance not holding up, inadequate or inaccurate seed packet labelling, long lead-in times for seed delivery.

A global review of new technologies, opportunities and/or future program activities to overcome the identified seed quality issues was then completed using information from industry, literature and with input from research allies with the capacity to develop the most promising technologies.

RECOMMENDATIONS TO INDUSTRY

1. Development of Australian Standards for seed quality
 - Address the critical need for better and/or truthful labelling on seed packaging,
 - Give the grower a choice to pay more for premium ‘A grade’ seeds and less for poorer ‘B or C grade’ seeds,
 - Must be adhered to by seed suppliers - penalties if seed quality parameters on the label are not met.
2. Development of technologies to non-destructively grade seeds in real time for high viability
 - Machinery would be bought and owned by seed suppliers; royalties from IP and sale of technologies would return into the Vegetable Levy,
 - A comprehensive literature review compared emerging artificial intelligence (AI) technologies for grading seed quality to currently available destructive tests and machinery for processing seeds,
 - Artificial intelligence technologies promise to be far superior to currently available technologies for real time seed quality grading automation, ensuring the high precision and accuracy required by growers,
 - Of the new technologies, hyperspectral imaging (HSI) was the most promising. Using a combination of spectroscopic imaging and computer vision, HSI is able to simultaneously determine interior and exterior seed qualities while being the only technology reviewed that is able to deal with seed sorting realities and complexities (e.g. overlapping and clumped seeds, distinguishing between seeds with similar sizes, colours and shapes),
 - Thermal imaging was also identified as a promising technology for automated non destructive seed sorting but is a newer technology hence requires more R&D prior to being useful commercially,

- Researchers at The Australian Centre for Field Robotics (University of Sydney) were identified as potential collaborators to deliver technologies with the UQ team via future R&D Levy investment,
- Technology development could be in partnership with providers who face similar problems (e.g. Grains Research and Development Corporation).

3. A long-term R&D program to improve vegetable seed viability and longevity for industry

- Growers unanimously agreed that programs to better understand and maximise vegetable seed viability and longevity presented real opportunities to improve seed standards for industry,
- The literature survey determined that scarce research has been undertaken into understanding how vegetable seed viability and longevity can be maximized,
- The UQ team has the capacity to deliver this R&D for industry.

Three significant R&D opportunities were identified

(i) A long term R&D program to determine the influence of environmental conditions and planting times of parent lines to maximise seed quality for industry's most economically important lines. This would follow on from ground-breaking UQ research that has determined that pollen and maternal plant health can be enhanced by optimising growing conditions prior to seed harvest, with a cumulative flow-on effect that then significantly improves seed viability and longevity.

(ii) Identify optimal seed collection windows for industry's most economically important cultivars and varieties. Currently immature or over-mature seed harvesting is resulting in poor seed quality and more information is needed to address this issue.

(iii) Classify the most economically important vegetable lines as short to long lived to inform storability decisions for seed producers and vegetable growers. Seeds of a given crop or line can be classified as short to long lived, however scarce research has been undertaken into understanding these trends for vegetables.

4. Programs to develop new varieties for local conditions

- Developing new varieties for local conditions was a high priority for most growers,
- Discussions are needed to ascertain best strategy forward. Strategies suggested by growers:
 - (i) Engaging seed suppliers who are willing to undertake breeding programs in Australia or under climatic conditions similar to those in Australia, as a means of insurance against bad seasons, and/or
 - (ii) Creation of a Centre for Genetic Improvement to undertake this research in Australia, possibly as a collaboration between growers, researchers, breeders and seed suppliers.

The next steps

- Growers have been invited via two industry bulletins to submit more seed quality information directly to the UQ team (seedqualitystudy@uq.edu.au),
- Following this second phase of data gathering, Levy payers will be invited to a strategy meeting in autumn 2018 to prioritise seed quality issues and future R&D activities to bring the greatest benefits and profitability across the Australian vegetable sector,
- Since sister project VG15021 is already developing transformational technologies for the vegetable industry to optimise seed quality, the two projects combined will build a holistic approach to seed quality assurance for vegetable growers and future mechanisation, field robotics and/or precision agriculture will ideally be optimised simultaneously.

Scientific refereed publications

None to report.

Intellectual property/commercialisation

No commercial IP was generated.

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Appendices and attachments

- Output 1 – GROWER INTERVIEWS: Key issues and recommendations from face-to-face grower interviews
- Output 2 – LITERATURE REVIEW: On farm seed viability and ways to overcome key issues
- Output 3 – Industry Bulletin #1: Turning seed quality failure into consistent success: How widespread is the problem?
- Output 4 – Industry Bulletin #2: Turning seed quality failure into consistent success: The R&D journey begins

BULLETIN 1

TURNING SEED QUALITY FAILURE INTO CONSISTENT SUCCESS: HOW WIDESPREAD IS THE PROBLEM?

A six month study has confirmed what vegetable growers already suspected - seed viability, purity and quality issues are prolific and are costing vegetable growers profits through wasted resources and time. The study began with face-to-face grower surveys that identified on farm issues and possible solutions; a comprehensive literature review followed, to pinpoint the newest and best technologies to grade and improve seed quality. The outcome is a series of recommendations for future R&D investment strategies; grower meetings to determine commercialisation and research priorities are scheduled for 2018.

Imagine a scenario where a grower plans to direct sow many hectares of seeds to grow a crop to supply a major supermarket chain across multiple Australian capital cities. The schedule is tight so the complex growing, harvesting, packing and transport logistics are pre-planned weeks to months in advance. The seed packet label promises 98% germination. Knowing how vital this opportunity is for their business, the grower adjusts their sowing rate to accommodate a 93% emergence rate, just to be on the safe side. Many days of soil preparation, weed control and expensive pre-sowing fertiliser applications have provided friable seed beds for germination and seedling growth success. The seeds are sown with the best machinery available, under ideal conditions and with industry best practice irrigation. Then the grower waits. Two weeks pass and only 85% of seeds have emerged. What's more, the emergence is non-uniform – some plants are big, others are tiny - and about 5% of seedlings appear to be of the wrong variety. The grower knows there is no way to meet their supermarket commitment with so few quality plants, so the only option is to renegotiate the commitment – and hope that future business opportunities are not jeopardised.

If you grow vegetables from seeds and the above story of seed quality failure sounds familiar, you are not alone. The Australian vegetable industry recognised a need to tackle on farm seed quality and viability issues and hence tendered the Hort Innovation co-funded project VG16028, *"On farm evaluation of vegetable seed viability using non destructive techniques"* in early 2017. The 6-month study aimed to identify grower seed quality issues and provide recommendations for future R&D investment into technologies, activities or programs that can evaluate and improve seed viability prior to planting on farm. Levy payers and commercialisation partners were the primary audience.

The University of Queensland's Plant Growth and Productivity Optimisation group, led by Dr Jitka Kochanek, were selected to undertake the tender. At project onset, the group conducted face-to-face surveys with growers and industry affiliates across key Queensland and NSW vegetable growing areas. **This bulletin summarises the seed quality issues identified from this grower survey.**

Many growers described quality seeds as their most important farm input because without quality seeds all other resources are wasted. Based on the survey, the definition of a high quality seed lot for the Australian vegetable industry is one that is disease-free and genetically pure, with high germination (>95%) and uniform seedling establishment and with seed sizes and shapes that fit well into seed sowing machinery. "Certain seed suppliers consistently do the right thing by growers, which is great to see," said Dr Kochanek, "Unfortunately, the survey revealed that other seed suppliers regularly do not meet seed quality standards required by growers, but growers must still use these suppliers to obtain specific cultivars or varieties. Regrettably, all growers reported experiences with seed viability, purity or quality issues. In fact, some growers have resorted to importing their own seeds because certain seed suppliers do not meet the quality and quantity standards needed."

Key seed quality issues identified were (a) Poor germination percentage and non-uniform emergence. This was commonly observed in certain varieties of sweet corn, cabbage, cauliflower, lettuce, beetroot and other crops; (b) Disease transmission via seeds. Growers suspect certain diseases are entering production systems via infected seeds. This was flagged as an important potential biosecurity threat, particularly for overseas imported

seeds; (c) Varietal impurity. For example, non-hybrid seeds were mixed into hybrid lines, multiple varieties or cultivars were mixed together or the entirely wrong variety or cultivar was supplied to the grower; (d) Non-uniform seed size. Uniform seed size is needed for optimal machinery performance, such as to avoid sowing two seeds into one location. Further, larger seeds were perceived to have higher vigour; (e) Damage to seeds. Certain cleaning practices were believed to damage seeds; (f) Seed enhancements need improvement. Techniques such as priming and pelleting need to be improved; presently many reduce seed quality rather than enhance it.

Other seed-related concerns raised by growers included (g) Growers were forced to 'accept what they get' from certain seed suppliers, even if seed quality was poor; compensation was rarely provided; (h) A lack of lines bred or grown for Australian conditions; (i) Inadequate or inaccurate seed packet labelling. Often information on the packet was incorrect or misleading, for example the label promised 95% germination but only 70-80% of seeds germinated; (j) Long lead-in times for seed delivery of certain cultivars or varieties.

A follow-up bulletin will detail specific recommendations for future R&D investment strategies from a global review of new technologies, opportunities and future program activities gathered from the industry survey, researcher interviews and from scientific literature. Growers are now invited to submit more seed quality information via email directly to the team (seedqualitystudy@uq.edu.au). Following this second phase of data gathering, a strategy meeting with key Levy payers will be held in southern Qld and central NSW during autumn 2018 to determine the R&D investment direction for further seed quality research activities. All Levy payers are invited so please make a note in your calendar now if you plan to attend!

Footnote: Special thanks are extended to all growers who participated in the survey - the study would not have been possible without this valuable input! We also gratefully acknowledge NSW extension officers from the Greater Sydney Local Land Services and grower Mario Muscat who organised a field day and on farm interviews within the Sydney Basin and Bathurst growing areas.

Want more details? Order the full VG16028 report from the Hort Innovation website at <http://horticulture.com.au/resources/final-report-order-form/>

BULLETIN II

TURNING SEED QUALITY FAILURE INTO CONSISTENT SUCCESS: THE R&D JOURNEY BEGINS

Artificial intelligence technologies to grade seed quality in real time; Australian Standards to guarantee seed quality through accurate labelling; a long-term program to maximise seed viability and longevity through parent plant growth optimisation before seed harvest – these are a snippet of the potential R&D investment strategies that emerged from a six month study, tendered in early 2017 by the Australian vegetable industry and Hort Innovation. Bulletin I revealed findings from grower surveys, confirming seed quality issues are prolific and wasting precious on farm resources. Here, recommendations for future R&D investment to boost seed quality to the high standards required by vegetable growers are collated from a global review of new technologies and opportunities gathered from industry, researcher and literature surveys. Grower meetings to determine commercialisation and research priorities are scheduled for 2018.

For any scale of operation, regardless of the size of the enterprise, crops that are established from seed require excellent seed quality. Substandard seeds propagate a substandard crop and essential farm inputs and investments are wasted, robbing the grower of profits. For vegetable growers, this encompasses economically dominant crops such as corn, beans and carrots.

Tendered in early 2017 to The University of Queensland's Plant Growth and Productivity Optimisation group, the Vegetable Levy and Hort Innovation funded project VG16028 *On farm evaluation of vegetable seed viability using non destructive techniques* confirmed - via grower surveys - that essential seed quality attributes are often not being met and solutions are critically needed. Project leader, Dr Jitka Kochanek, explains survey outcomes, "All growers reported seed quality issues on farm. Poor germination percentage and non-uniform emergence, seed-borne disease, varietal impurity, non-uniform seed size, damaged seeds and so-called 'seed enhancements' that actually reduce seed quality are real issues plaguing vegetable growers in Australia today. Concerns were also raised about inadequate and inaccurate seed packet labelling, a lack of lines bred or grown for Australian conditions and long lead-in times for seed delivery." Thankfully, there are also real solutions and this bulletin summarises recommendations, collated from industry, researcher and literature surveys, towards tackling seed issues via future R&D investment strategies.

1. Guaranteed seed quality via binding Australian Standards

All growers supported the development of Australian Standards that guarantee a certain level of seed quality, where growers would also have a choice to pay extra for premium 'A grade' seeds and less for poorer 'B or C grade' seeds. "Certain seed suppliers were identified as always doing the right thing by growers, so we would work with these industry leaders first to develop the Standards and then roll the Standards out to all seed suppliers," said Dr Kochanek, "We all recognise that A grade seed quality is not always possible for all varieties and cultivars, but growers have to know what seed quality standard they are getting so they can calibrate their sowing rates accordingly." Once taken up across the seed industry, suppliers could be penalised if seed quality does not match labelling, thereby addressing the critical need for accurate and detailed labelling on seed packaging, as identified in the grower survey.

2. Non destructive, real time grading for high seed viability using artificial intelligence technologies

Although fully automated and integrated robotic systems for horticulture are still some years away, artificial intelligence is already assisting growers with more simple tasks that are highly repetitive, such as weed management, yield prediction and for driverless farm machinery automation. The grading of many seed quality attributes is also a relatively simple and repetitive task hence artificial intelligence (AI) – using innovative computer-assisted analysis systems – is now having success at grading seed quality in real time based on external and internal seed attributes such as surface texture and colour, light reflectance and fluorescence, seed size, shape and density. A comprehensive literature review compared emerging AI technologies for grading seed quality (Table 1 and 2) to currently available destructive tests and machinery for processing seeds, such

as gravity, electrostatic, air, colour and other types of separating equipment. The new AI technologies promise to be far superior to the currently available technologies for real time seed quality grading automation and ensure the high precision and accuracy required by growers. Of the new technologies, hyperspectral imaging (HSI) was the most promising. Using a combination of spectroscopic imaging and computer vision, HSI is able to simultaneously determine interior and exterior seed qualities while being the only technology able to deal with seed sorting realities and complexities such as overlapping and clumped seeds and being able to distinguish between seeds with similar sizes, colours and shapes. Thermal imaging was also identified as a promising technology for automated non destructive seed sorting but is a newer technology hence requires more R&D prior to being useful commercially.

Researchers at The Australian Centre for Field Robotics at the University of Sydney were consulted and identified as potential collaborators to deliver non destructive and cost effective techniques to screen viable seed via future R&D Levy investment.

Table 1. Artificial intelligence systems that use innovative computer-assisted analyses to grade seed quality attributes, as identified from a comprehensive literature review.

Technology	Definition
Computer vision	A form of artificial intelligence that simulates human vision, usually using the visible light spectrum of 380 to 780 nm, to identify and grade seeds based on external image features.
Hyperspectral imaging	Combines the spectral information of spectroscopy with spatial distribution data from computer vision to create a 3D image 'hypercube' that classifies seeds based on their external and internal quality characteristics.
Electronic nose	An instrument that senses and recognises volatile compounds existing in the headspace of a seed lot at parts-per-million to parts-per-billion levels via an array of electronic and chemical sensors.
Infrared spectroscopy	Spectroscopy is a technology that provides a spectral fingerprint for a seed or seed lot by describing the light intensities emerging from its molecules at different electromagnetic wavelengths. Infrared spectroscopy specifically deals with the infrared region of the electromagnetic spectrum.
Chlorophyll fluorescence	Irradiates seeds with electromagnetic radiation of a suitable wavelength and measures the amount fluoresced from the seed coat to indicate seed maturity levels.
Thermal imaging	Uses an infrared camera to capture the thermodynamic properties of seed tissue to provide information about seed quality.
Biospeckle laser	Utilises laser investigative tools for seed analysis.
X-ray	Utilises non destructive radiographic inspection of seed internal and external morphology.

Table 2. Key grower seed quality issues identified during on farm surveys and artificial intelligence technologies that show promise to overcome each issue. A tick denotes a technology has been used by researchers to overcome a particular seed quality issue.

Grower seed quality issue	Computer vision	Hyperspectral imaging	Electronic nose	Infrared spectroscopy	Chlorophyll fluorescence	Thermal imaging	Biospeckle laser	X-ray
Pillar 1: Germination, viability, seed aging, uniform emergence and vigour	✓	✓	✓	✓	✓	✓	✓	
Pillar 2: Seed-borne disease	✓	✓	✓	✓		✓	✓	
Pillar 3: Varietal impurity	✓	✓	✓					
Pillar 4: Damage to seeds	✓	✓	✓	✓				✓
Pillar 5: Seed mass, fill and density				✓				✓
Pillar 6: Seed size, uniformity of size, shape of seeds	✓	✓						

3. Maximising seed viability and longevity through long-term R&D programs

Growers unanimously agreed that programs to better understand and maximise vegetable seed viability and longevity presented real opportunities to improve seed standards for industry.

Three significant R&D themes were identified:

Theme 1: Ground-breaking research at The University of Queensland has determined that pollen and maternal plant health can be enhanced by optimising growing conditions prior to seed harvest, with a cumulative flow-on effect that then significantly improves seed viability and longevity. Thus a long term R&D program would determine the influence of environmental conditions and planting times of parent lines to maximise seed quality for industry's most economically important lines.

Theme 2: Currently immature or over-mature seed harvesting is resulting in poor seed quality and more information is needed to address this issue. Future R&D would identify optimal seed collection windows for industry's most economically important cultivars and varieties.

Theme 3: Seeds of a given crop or line can be classified as short to long lived to inform storability decisions, however scarce research has been undertaken into understanding these trends for vegetable crops. Future R&D would classify the most economically important vegetable lines as short to long lived to inform storability

decisions for seed producers and vegetable growers.

4. New varieties for local conditions

Developing new varieties for local conditions was a high priority for most growers. Growers suggested: (a) Engaging seed suppliers who are willing to undertake breeding programs in Australia or under climatic conditions similar to those in Australia, as a means of insurance against bad seasons, and/or (b) Creation of a Centre for genetic improvement to undertake this research in Australia, possibly as a collaboration between growers, researchers, breeders and seed suppliers.

The next steps

Growers are now invited to submit more seed quality information via email directly to the team (seedqualitystudy@uq.edu.au). We want to hear all your good and bad news stories, as well as suggestions, to plan future activities. Following this second phase of data gathering, the next steps for project VG16028 will be broadened grower consultation: levy payers are invited to a strategy meeting in autumn 2018 to prioritise seed quality issues and future R&D activities to bring the greatest benefits and profitability across the Australian vegetable industry. The date will be confirmed via a third bulletin, released in 2018.

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BULLETIN 1

TURNING SEED QUALITY FAILURE INTO CONSISTENT SUCCESS: HOW WIDESPREAD IS THE PROBLEM?

A six month study has confirmed what vegetable growers already suspected - seed viability, purity and quality issues are prolific and are costing vegetable growers profits through wasted resources and time. The study began with face-to-face grower surveys that identified on farm issues and possible solutions; a comprehensive literature review followed, to pinpoint the newest and best technologies to grade and improve seed quality. The outcome is a series of recommendations for future R&D investment strategies; grower meetings to determine commercialisation and research priorities are scheduled for 2018.

Imagine a scenario where a grower plans to direct sow many hectares of seeds to grow a crop to supply a major supermarket chain across multiple Australian capital cities. The schedule is tight so the complex growing, harvesting, packing and transport logistics are pre-planned weeks to months in advance. The seed packet label promises 98% germination. Knowing how vital this opportunity is for their business, the grower adjusts their sowing rate to accommodate a 93% emergence rate, just to be on the safe side. Many days of soil preparation, weed control and expensive pre-sowing fertiliser applications have provided friable seed beds for germination and seedling growth success. The seeds are sown with the best machinery available, under ideal conditions and with industry best practice irrigation. Then the grower waits. Two weeks pass and only 85% of seeds have emerged. What's more, the emergence is non-uniform – some plants are big, others are tiny - and about 5% of seedlings appear to be of the wrong variety. The grower knows there is no way to meet their supermarket commitment with so few quality plants, so the only option is to renegotiate the commitment – and hope that future business opportunities are not jeopardised.

If you grow vegetables from seeds and the above story of seed quality failure sounds familiar, you are not alone. The Australian vegetable industry recognised a need to tackle on farm seed quality and viability issues and hence tendered the Hort Innovation co-funded project VG16028, *"On farm evaluation of vegetable seed viability using non destructive techniques"* in early 2017. The 6-month study aimed to identify grower seed quality issues and provide recommendations for future R&D investment into technologies, activities or programs that can evaluate and improve seed viability prior to planting on farm. Levy payers and commercialisation partners were the primary audience.

The University of Queensland's Plant Growth and Productivity Optimisation group, led by Dr Jitka Kochanek, were selected to undertake the tender. At project onset, the group conducted face-to-face surveys with growers and industry affiliates across key Queensland and NSW vegetable growing areas. This bulletin summarises the seed quality issues identified from this grower survey.

Many growers described quality seeds as their most important farm input because without quality seeds all other resources are wasted. Based on the survey, the definition of a high quality seed lot for the Australian vegetable industry is one that is disease-free and genetically pure, with high germination (>95%) and uniform seedling establishment and with seed sizes and shapes that fit well into seed sowing machinery. "Certain seed suppliers consistently do the right thing by growers, which is great to see," said Dr Kochanek, "Unfortunately, the survey revealed that other seed suppliers regularly do not meet seed quality standards required by growers, but growers must still use these suppliers to obtain specific cultivars or varieties. Regrettably, all growers reported experiences with seed viability, purity or quality issues. In fact, some growers have resorted to importing their own seeds because certain seed suppliers do not meet the quality and quantity standards needed."

Key seed quality issues identified were (a) Poor germination percentage and non-uniform emergence. This was commonly observed in certain varieties of sweet corn, cabbage, cauliflower, lettuce, beetroot and other crops; (b) Disease transmission via seeds. Growers suspect certain diseases are entering production systems via infected seeds. This was flagged as an important potential biosecurity threat, particularly for overseas imported

seeds; (c) Varietal impurity. For example, non-hybrid seeds were mixed into hybrid lines, multiple varieties or cultivars were mixed together or the entirely wrong variety or cultivar was supplied to the grower; (d) Non-uniform seed size. Uniform seed size is needed for optimal machinery performance, such as to avoid sowing two seeds into one location. Further, larger seeds were perceived to have higher vigour; (e) Damage to seeds. Certain cleaning practices were believed to damage seeds; (f) Seed enhancements need improvement. Techniques such as priming and pelleting need to be improved; presently many reduce seed quality rather than enhance it.

Other seed-related concerns raised by growers included (g) Growers were forced to 'accept what they get' from certain seed suppliers, even if seed quality was poor; compensation was rarely provided; (h) A lack of lines bred or grown for Australian conditions; (i) Inadequate or inaccurate seed packet labelling. Often information on the packet was incorrect or misleading, for example the label promised 95% germination but only 70-80% of seeds germinated; (j) Long lead-in times for seed delivery of certain cultivars or varieties.

A follow-up bulletin will detail specific recommendations for future R&D investment strategies from a global review of new technologies, opportunities and future program activities gathered from the industry survey, researcher interviews and from scientific literature. Growers are now invited to submit more seed quality information via email directly to the team (seedqualitystudy@uq.edu.au). Following this second phase of data gathering, a strategy meeting with key Levy payers will be held in southern Qld and central NSW during autumn 2018 to determine the R&D investment direction for further seed quality research activities. All Levy payers are invited so please make a note in your calendar now if you plan to attend!

Footnote: Special thanks are extended to all growers who participated in the survey - the study would not have been possible without this valuable input! We also gratefully acknowledge NSW extension officers from the Greater Sydney Local Land Services and grower Mario Muscat who organised a field day and on farm interviews within the Sydney Basin and Bathurst growing areas.

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BULLETIN II

TURNING SEED QUALITY FAILURE INTO CONSISTENT SUCCESS: THE R&D JOURNEY BEGINS

Artificial intelligence technologies to grade seed quality in real time; Australian Standards to guarantee seed quality through accurate labelling; a long-term program to maximise seed viability and longevity through parent plant growth optimisation before seed harvest – these are a snippet of the potential R&D investment strategies that emerged from a six month study, tendered in early 2017 by the Australian vegetable industry and Hort Innovation. Bulletin I revealed findings from grower surveys, confirming seed quality issues are prolific and wasting precious on farm resources. Here, recommendations for future R&D investment to boost seed quality to the high standards required by vegetable growers are collated from a global review of new technologies and opportunities gathered from industry, researcher and literature surveys. Grower meetings to determine commercialisation and research priorities are scheduled for 2018.

For any scale of operation, regardless of the size of the enterprise, crops that are established from seed require excellent seed quality. Substandard seeds propagate a substandard crop and essential farm inputs and investments are wasted, robbing the grower of profits. For vegetable growers, this encompasses economically dominant crops such as corn, beans and carrots.

Tendered in early 2017 to The University of Queensland's Plant Growth and Productivity Optimisation group, the Vegetable Levy and Hort Innovation funded project VG16028 *On farm evaluation of vegetable seed viability using non destructive techniques* confirmed - via grower surveys - that essential seed quality attributes are often not being met and solutions are critically needed. Project leader, Dr Jitka Kochanek, explains survey outcomes, "All growers reported seed quality issues on farm. Poor germination percentage and non-uniform emergence, seed-borne disease, varietal impurity, non-uniform seed size, damaged seeds and so-called 'seed enhancements' that actually reduce seed quality are real issues plaguing vegetable growers in Australia today. Concerns were also raised about inadequate and inaccurate seed packet labelling, a lack of lines bred or grown for Australian conditions and long lead-in times for seed delivery." Thankfully, there are also real solutions and this bulletin summarises recommendations, collated from industry, researcher and literature surveys, towards tackling seed issues via future R&D investment strategies.

1. Guaranteed seed quality via binding Australian Standards

All growers supported the development of Australian Standards that guarantee a certain level of seed quality, where growers would also have a choice to pay extra for premium 'A grade' seeds and less for poorer 'B or C grade' seeds. "Certain seed suppliers were identified as always doing the right thing by growers, so we would work with these industry leaders first to develop the Standards and then roll the Standards out to all seed suppliers," said Dr Kochanek, "We all recognise that A grade seed quality is not always possible for all varieties and cultivars, but growers have to know what seed quality standard they are getting so they can calibrate their sowing rates accordingly." Once taken up across the seed industry, suppliers could be penalised if seed quality does not match labelling, thereby addressing the critical need for accurate and detailed labelling on seed packaging, as identified in the grower survey.

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