Horticulture Impact Assessment Program:

Appendix 12: Probisafe – Development of biocontrol agents to inhibit pathogen growth (VG16005 Impact Assessment)

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What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in *VG16005: Probisafe – Development of biocontrol agents to inhibit pathogen growth (VG16005 Impact Assessment).* The project was funded by Hort Innovation over the period November 2016 to May 2019.

Methodology

The investment was first analysed qualitatively within a logical framework that included activities and outputs, outcomes and impacts. Actual and/or potential impacts then were categorised into a triple bottom line framework. Principal impacts identified were then considered for valuation in monetary terms (quantitative assessment). Past and future cash flows were expressed in 2019/20 dollar terms and were discounted to the year 2019/20 using a discount rate of 5% to estimate the investment criteria and a 5% reinvestment rate to estimate the modified internal rate of return (MIRR).

Results/key findings

The investment in VG16005 has contributed to potential improvements in food safety for Australian leafy green vegetables that may reduce future incidence of foodborne illness and improve consumer health and wellbeing. Further, the investment may contribute to increased profitability and maintained market access for Australian vegetable producers.

Investment Criteria

Total funding from all sources for the project was $1.09 million (present value terms). Though a number of economic and social impacts were identified, the project team identified the need for further investment and there was no evidence of current commercial use of *Probisafe*. Thus, the future potential impacts of investment in VG16005 were not valued in monetary terms within the scope of the current assessment.

Conclusions

The investment in VG16005 has contributed positively to potential improvements in food safety for Australian leafy green vegetables. Any future evaluation of the impacts of further investment to validate, optimise and commercialise *Probisafe* should take the investment in VG16005 into account. Estimated benefits then would be partially attributable to the VG16005 investment.

Keywords

Impact assessment, cost-benefit analysis, VG16005, Probisafe, biocontrol, vegetables, leafy green vegetables

Introduction

Horticulture Innovation Australia Limited (Hort Innovation) required a series of impact assessments to be carried out annually on a number of investments in the Hort Innovation research, development and extension (RD&E) portfolio. The assessments were required to meet the following Hort Innovation evaluation reporting requirements:

- Reporting against the Hort Innovation's current Strategic Plan and the Evaluation Framework associated with Hort Innovation's Statutory Funding Agreement with the Commonwealth Government.
- Annual Reporting to Hort Innovation stakeholders.
- Reporting to the Council of Rural Research and Development Corporations (CRRDC).

Under impact assessment program MT18011, the first series of impact assessments were conducted in 2019 and included 15 randomly selected Hort Innovation RD&E investments (projects). The second series of impact assessments (current series), undertaken in 2020, also included 15 randomly selected projects worth a total of approximately $7.11 million (nominal Hort Innovation investment). The second series of projects were selected from an overall population of 85 Hort Innovation investments worth an estimated $44.64 million (nominal Hort Innovation investment) where a final deliverable had been submitted in the 2018/19 financial year.

The 15 investments were selected through a stratified, random sampling process such that investments chosen represented at least 10% of the total Hort Innovation RD&E investment in the overall population (in nominal terms) and was representative of the Hort Innovation investment across six, pre-defined project size classes.

Project *VG16005: Probisafe – Development of biocontrol agents to inhibit pathogen growth* was randomly selected as one of the 15 investments under MT18011 and was analysed in this report.

General Method

The impact assessment follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some universities. The approach includes both qualitative and quantitative descriptions that are in accord with the impact assessment guidelines of the CRRDC (CRRDC, 2018).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, outcomes, and actual and/or potential impacts. The principal economic, environmental and social impacts were then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. Where impact valuation was exercised, the impact assessment used cost-benefit analysis as its principal tool. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the impact compared to those that were valued. The impacts valued are therefore deemed to represent the principal benefits delivered by the project. However, as not all impacts were valued, the investment criteria reported for individual investments potentially represent an underestimate of the performance of that investment.

Background & Rationale

Background

Pre-packaged leafy greens have become very popular with consumers. In 2018/19 Australia produced 6.7 million tonnes of horticultural products worth an estimated $14.37 billion. Leafy salad vegetable production was approximately 67,039 tonnes worth $396.3 million (roughly 3% of the total value of horticulture production) (Hort Innovation, 2020). Almost 98% of leafy salad vegetable production goes to the Australian domestic market. However, since fresh produce undergoes minimal processing and, in most cases, is eaten raw, there are inherent food safety risks. In February 2016, an outbreak of *salmonellosis* was linked to a range of vegetable products (salad leaves and sprouts) supplied by farms in Victoria (Victoria State Government, 2016). A consumer level recall of associated products was undertaken but consumers, retailers and the Australian leafy greens industry across multiple states and territories were affected (Food Regulation Secretariat, 2016). Pathogens such as *Salmonella*, *E. Coli*, and *Listeria monocytogenes* have caused disease outbreaks in leafy green vegetables (lettuce and spinach), tomatoes, cucumbers and sprouts around the world and these four vegetable types have been consistently responsible for foodborne illnesses (Turner, 2018).

Pathogens can contaminate vegetables either pre- or post-harvest. Pre-harvest sources of contamination may include soil, faeces, irrigation water, dust, insects, inadequately composted manure, wild or domestic animals, and human handling (Olaimat & Holley, 2012). Post-harvest sources of contamination may include harvesting equipment, transport containers and equipment, insects, dust, wash water, ice, processing equipment, and human handling (Beuchat, 2002). Low level pathogen contamination can be difficult to detect and/or control and the methods available to remove or kill pathogens (e.g. washes, chlorine treatments, etc.) are only partially effective. Thus, the vegetable industry, through RD&E funded by Hort Innovation, has been investigating biocontrol strategies to inhibit foodborne pathogens (specifically *Salmonella Typhimurium* and *Listeria monocytogenes*) on salad vegetables.

Rationale

A previously funded Hort Innovation project, VG09075, investigated biocontrol strategies to inhibit foodborne pathogens on salad vegetables. Around 900 naturally occurring, harmless lactic acid bacteria (LAB) were selected and screened for antimicrobial activity against *Listeria* and *Salmonella*. Some of the LAB were able to reduce *Listeria* and *Salmonella* growth by up to 99.9% after seven days of storage. Project VG16005 (*Probisafe – Development of biocontrol agents to inhibit pathogen growth*) was funded to confirm the activity of the most promising biocontrol LAB (termed *Probisafe*) and identify optimal conditions for their application at lab-scale and in industry trials.

Project Details

Summary

Project Code: VG16005
Title: *Probisafe – Development of biocontrol agents to inhibit pathogen growth*
Research Organisation: Uniquest Pty Ltd and the University of Queensland
Principal Investigator: Deon Goosen
Period of Funding: November 2016 to May 2019

Objectives

The objectives of the investment were to:

1. Develop natural biocontrol bacteria (*Probisafe*) for industry application to control pathogen growth on vegetables.
2. Evaluate the safety of biocontrol agents.
3. Evaluate commercial probiotic delivery using vegetables.

Logical Framework

Table 1 provides a description of VG16005 in a logical framework.

Table 1: Logical Framework for Project VG16005

Activities	*Development of natural biocontrol bacteria (Probisafe) for industry application* • The *Probisafe* bacterial strains used in the project were isolated from fruits and vegetables in previous Hort Innovation project VG09075 (completed in 2011). • The LAB strains that showed preliminary inhibition against *Salmonella Typhimurium* in the initial screening then were tested in controlled laboratory trials to confirm anti-*Salmonella* activity. • Two selected LAB isolates were cultured and prepared and then inoculated into shredded iceberg lettuce for different treatment times (1, 5, 15, and 30 minutes). The lettuce samples then were incubated for seven days and the populations of biocontrol strains determined on days 0, 3 and 7. • Another two LAB isolates were used to individually inoculate shredded iceberg lettuce at three different inoculation levels). The lettuce samples then were incubated for seven days and the populations of biocontrol strains determined on days 0, 3 and 7. • Five selected LAB strains were individually inoculated onto whole leaf salads (baby spinach and rocket), shredded iceberg lettuce, shredded cabbage and carrot to test for inhibition of *S. Typhimurium* growth. Samples then were incubated for seven days and the populations of biocontrol strains determined on days 0, 3 and 7. • The effects of recommended ($\leq 5^oC$) and abuse storage temperatures on the growth and survival of selected biocontrol strains and *Salmonella* on minimally processed vegetables were observed at 4^oC and 12^oC. • Several new *Probisafe* growth media were designed and tested (using food grade ingredients) for commercial settings. • The three most promising strains of *Probisafe* were grown in the food grade mediums and then harvested. • Iceberg lettuce samples, prepared and supplied by the project's industry partner, were inoculated with *Probisafe* strains and then for seven days and the populations of biocontrol strains determined on days 0, 3 and 7. • Lettuce samples were prepared with three different species of candidate biocontrol LAB strains and packaged under modified atmosphere packaging.

	• After storage at 8°C for five days, the samples were sent to Symbio Laboratories (Brisbane, QLD) for detection of four types of biogenic amines commonly found in food. • Twelve strains of candidate biocontrol LAB strains were submitted to Macrogen (Seoul, Korea) for whole of genome sequencing. • A survey of genes linked to virulence and antibiotic resistance was performed on the genome sequences of the 12 strains. *Evaluation of commercial probiotic delivery using vegetables* • Probiotic strains in the form of freeze-dried powder provided by two different companies were tested (three strains from company A, ten strains from company B). • Commercial probiotic suspension was added into baby spinach by soaking. Enumeration of probiotic bacteria was completed on days 0, 3 and 7 of storage after soaking. • Stocks of six probiotic strains were prepared and tested in the presence of three types of salad dressing: French, Italian and Balsamic (Praise, NSW). Five strains also were tested in the presence of simulated gastric and intestinal juice. • Two commercial probiotic strains in the form of freeze-dried powder were added to ready-to-eat baby spinach leaves purchased from Coles. A control sample without probiotics also was prepared. Enumeration of probiotic counts was conducted 0, 3 and 7 days after treatment. • Samples of the probiotic treated baby spinach were sent to Symbio Laboratories for analysis to ensure microbiological safety. • A sensory panel then was recruited and a sensory evaluation of baby spinach with added commercial probiotics was conducted. • 40 people participated in the sensory trials at the University of Queensland. • Three commercial probiotic strains (two from company A, one from company B) were selected for an industry trial due to their good survival in baby spinach during laboratory trials. • Baby spinach leaves were prepared and supplied by the project's industry partner and probiotic bacteria were added at the factory of the fresh-cut producer. • A number of extension activities, including radio interviews, online media stories, industry meetings/presentations, conference presentations, and articles were completed over the life of the project.
Outputs	*Development of natural biocontrol bacteria (Probisafe) for industry application* • 25 LAB isolates were found to have strong inhibition zones against *S. Typhimurium.* • The assessment of *Probisafe* isolates on cut lettuce under different treatment times found that the inoculation resulted in LAB counts that remained relatively unchanged over seven days of storage for all four treatment times. These results suggested that LAB isolates attach very well in lettuce, even under short contact times. • Assessment of the effects of different concentrations of *Probisafe* strains on lettuce quality found that the initial populations of LAB strains affected the pH of lettuce samples and, consequently, lettuce appearance. Increasing the initial bacterial concentration resulted in the reduction of lettuce's pH. • Testing of *Probisafe* strains on ready-to-eat whole and cut leafy vegetables found that growth of *S. Typhimurium* was inhibited by several promising strains on shredded cabbage, carrot and lettuce. However, *S. Typhimurium* was not inhibited by *Probisafe* strains in baby spinach and rocket. • When tested at different temperatures (4°C and 12°C), bacteria populations for most biocontrol strains remained at similar levels after seven days storage at 4°C. However, populations tended to increase when stored at 12°C. • Concentrations of *S. Typhimurium* decreased in all samples over seven days at 4°C. However, when stored at 12°C, *Salmonella* counts increased significantly.

	• Most lettuce samples maintained good visual quality during seven day storage at 4^{o}C. Lettuce stored at 12^{o}C remained unchanged for three to four days, however, after that period the lettuce lost crispness and became soft. • The temperature results showed that *S. Typhimurium* survived when lettuce was stored at 4^{o}C but supressed its proliferation whereas storage at 12^{o}C stimulated growth of the pathogen. These findings emphasised the importance of storing fresh-cut vegetables at cold temperatures of $\leq$ 5^{o}C. • Compared to laboratory trials, the effectiveness of LAB isolates against *S. Typhimurium* varied in lettuce systems. • Out of a total of 28 LAB isolates tested, the highest *Salmonella* reductions occurred in lettuce samples treated with strains 109, 733, 774, 820 and 845. • Strains 109, 774 and 845 appeared to have good potential as biocontrol agents in fresh produce. Cut lettuce samples with these three strains maintained good quality during storage at the recommended temperature (4^{o}C). • Strains 109, 774 and 845 have the potential to be applied in washing solutions for fresh-cut lettuce for supressing *Salmonella* growth. • *Probisafe* strains were successfully grown in normal, food-grade media. The highest levels were achieved using formula D (containing glucose, yeast extract and potassium phosphate). Thus, the three most promising *Probisafe* strains were cultured in formula for industry trials. • The growth of *Probisafe* bacteria in lettuce and the corresponding changes in lettuce appearance in the industry trial were similar to those of laboratory trials. • Testing for biogenic amines on *Probisafe* treated lettuce showed that concentrations of two out of four common amines were below the detection limit. The other two amines were detected. However, there are no Food Standards Australia New Zealand (FSANZ) limits for these amines in vegetables. The study concluded that the addition of selected LAB strains and storage for five days at 8^{o}C did not result in elevated biogenic amine levels that might endanger health. • Genome sequencing to investigate virulence found that the majority of highly specific virulence genes were not found in the LAB genomes. None of the toxin genes of *L. monocytogenes* and *S. aureus* and the superantigens had matches in the LAB genomes. • The study concluded that there was no reason to suspect that *Probisafe* strains have potential safety issues with regard to virulence genes, since these genes also are present in other, regularly consumed and safe probiotic and fermentation bacteria. • Also, based on genome sequence information, it was determined that there was not a high risk of transfer of antibiotic resistance genes from the LAB strains to other bacteria. *Evaluation of commercial probiotic delivery using vegetables* • Vegetables offer a healthy, vegan alternative for delivering probiotics to consumers. • Testing of commercial probiotics showed that the count for all strains was reduced from day zero to day seven after treatment. However, the reduction was variable between strains. • Several of the probiotic strains tested met the minimum levels required by the European Union of 10^{7} CFU[1]/g in food products. Thus, their application in commercial bagged salads is feasible. • The study also found that the addition of salad dressing (which is typically acidic) during the consumption of probiotic-fortified salads did not adversely affect the survival of the probiotics.

[1] CFU: Colony-Forming Unit

	• All probiotic strains survived well in the presence of simulated intestinal juice. The results showed that baby spinach as a probiotic carrier provides as much protection from gastric acid as would be expected from current, milk-based probiotic food. • Results of sensory trials conducted at the University of Queensland showed that the sensory quality of baby spinach was not adversely affected by the addition of the two commercial probiotic strains tested. • Industry trials of the commercial probiotics found that results were similar and in agreement with the laboratory trials. Therefore, application of probiotics in commercial bagged salads in non-lab, industry settings is feasible.

Outcomes	• Two large fresh-cut salad producers have shown interest in probiotic vegetables and have expressed that they are willing to start trials of probiotic application in their salad products.
	• A new category of salad products is anticipated to be released to market in the future.
	• Though the initial findings demonstrated that there is potential to use Probisafe bacteria to inhibit the growth of harmful bacteria and deliver probiotics via vegetables, the project team recommended that further investment be funded to:
	  o Undertake large scale industry trials of probiotic applications.
	  o Optimise the application method (soaking, spraying, etc.) for *Probisafe* strains.
	  o Commercialise a freeze-dried *Probisafe* product.
	  o Obtain appropriate FSANZ approval for application of commercial probiotics and *Probisafe* strains in foods.
	  o Undertake investigations on the effects of *Probisafe* on the sensory properties and nutritional quality of salad products during shelf-life.
	  o Testing of *Probisafe* strains for antibiotic resistance profiles.
	• Additional information on the status of *Probisafe*, and the potential addition of commercial probiotics to vegetables, since the completion of project VG16005 was sought from UniQuest Pty Ltd. However, no response was received during the evaluation period.

Impacts	• Potentially, contribution to improved food safety for fresh vegetable products known to be hosts for *Salmonella* leading to reduced incidence of foodborne illnesses. • Potentially, improved profitability for some Australian vegetable producers through reduced risk of foodborne illnesses leading to less variable consumer demand and/or reduced product recalls. • Potentially, increased consumer health and wellbeing through future consumption of probiotic vegetable products. • Potentially, some contribution to maintained market access for Australian vegetable products through improved food safety. • Potentially, reduced post-harvest vegetable treatment costs because of reduced need for pathogen disinfection treatments. • Potentially, some contribution to maintained social licence to operate for some Australian vegetable producers due to improved food safety, increased community wellbeing and reduced use of chemical disinfestation treatments.

Project Investment

Nominal Investment

Table 2 shows the annual investment (cash and in-kind) in project VG16005 by Hort Innovation. There were no other investors in this project.

Table 2: Annual Investment in the Project VG16005 (nominal $)

Year ended 30 June	Hort Innovation ($)	Others ($)	Total ($)
2017	397,893	0	397,893
2018	238,736	0	238,736
2019	159,157	0	159,157
Totals	795,786	0	795,786

Source: VG16005 Project Agreement and Variation documents supplied by Hort Innovation 2020

Program Management Costs

For the Hort Innovation investment the cost of managing and administrating the Hort Innovation funding was added to the Hort Innovation contribution for the project via a management cost multiplier (1.162). This multiplier was estimated based on the share of 'payments to suppliers and employees' in total Hort Innovation expenditure (3-year average) reported in the Hort Innovation's Statement of Cash Flows (Hort Innovation, various years). This multiplier was then applied to the nominal investment by Hort Innovation shown in Table 2.

Real Investment and Extension Costs

For the purposes of the investment analysis, investment costs of all parties were expressed in 2019/20 dollar terms using the Gross Domestic Product deflator index (Australian Bureau of Statistics, 2020). No additional costs associated with project extension were incorporated as the project included a high level of industry participation and a number of extension activities. Results were communicated to vegetable growers and other industry stakeholders (e.g. consultants, researchers and investors) as part of the project.

Impacts

Table 3 provides a summary of the principal types of potential impacts delivered by the project. Impacts have been categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Principal Potential Impacts from Project VG16005

Economic	• Contribution to improved food safety for fresh vegetable products known to be hosts for *Salmonella* leading to reduced incidence of foodborne illnesses. • Improved profitability for some Australian vegetable producers through reduced risk of foodborne illnesses leading to less variable consumer demand and/or reduced product recalls. • Some contribution to maintained market access for Australian vegetable products through improved food safety. • Reduced post-harvest vegetable treatment costs because of reduced need for pathogen disinfection treatments.
Environmental	• Nil
Social	• Increased consumer health and wellbeing through future consumption of probiotic vegetable products. • Some contribution to maintained social licence to operate for some Australian vegetable producers due to improved food safety, increased community wellbeing and reduced use of chemical disinfestation treatments.

Public versus Private Impacts

Impacts identified in this evaluation are both private and public in nature. If *Probisafe* is successfully commercialised and adopted by industry, private benefits are likely to be realised by Australian vegetable producers through reduced variability of consumer demand, maintained market access and, potentially, reduced post-harvest vegetable treatment costs and/or maintained social licence to operate. Some public benefits may occur and include reduced public healthcare costs from reduced incidence of foodborne illnesses and improved consumer health and wellbeing.

Distribution of Private Impacts

The potential impacts on the Australian vegetable industry from investment in project VH16005 will be shared along the vegetable supply chain with input suppliers, growers, processors, transporters, wholesalers, retailers and consumers all sharing impacts produced by the project. The share of impact realised by each link in the supply chain will depend on both short- and long-term supply and demand elasticities in the pear market.

Impacts on Other Australian Industries

No direct impacts to industries other than the Australian vegetable industry were identified. However, there may be gains to food-based commodity industries via potential future spill-overs from the increase in knowledge and scientific capacity or from other applications for *Probisafe* or similar products.

Impacts Overseas

No significant or direct overseas impacts were identified. However, the knowledge created by the project and shared through international scientific and industry networks may results in some positive impacts for vegetable industries overseas where similar food-borne pathogen issues in leafy green vegetables are relevant.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The project findings and related impacts will contribute to Rural RD&E Priority 1 and to Science and Research Priority 1.

Table 4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy 6. Resources 7. Advanced Manufacturing 8. Environmental Change 9. Health

Sources: (Commonwealth of Australia, 2015) and (Australian Government, 2015)

Alignment with the Vegetable Strategic Investment Plan 2017-2021

The strategic outcomes and strategies of the vegetable industry are outlined in the Vegetable Strategic Investment Plan 2017-2021[2] (Hort Innovation, 2017). Project VG16005 primarily addressed Outcome 1 (Strategy 1.2, 1.5 and 1.6) with some contribution to Outcome 2 (through Strategy 2.3) and Outcome 3 (Strategy 3.4 and 3.8).

[2] For further information, see: https://www.horticulture.com.au/hort-innovation/funding-consultation-and-investing/investment-documents/strategic-investment-plans/

Valuation of Impacts

The investment in VG16005 demonstrated that there is potential for the use of *Probisafe* bacteria to inhibit the growth of harmful bacteria and deliver probiotics via vegetables. A number of potential future economic and social impacts were identified, including contributions to improved food safety leading to reduced incidence of foodborne illnesses, increased profitability for some Australia vegetable producers, maintained market access, and improved consumer health and wellbeing. However, the project team noted that additional RD&E investment is required to further validate, optimise and commercialise *Probisafe* for commercial use in Australian leafy green vegetables. Thus, based on the need for further investment and no evidence of current commercial use of *Probisafe*, the future potential impacts of investment in VG16005 were not valued in monetary terms within the scope of the current assessment.

Any future evaluation of the impacts of further investment in *Probisafe* should take the investment in VG16005 into account. Estimated benefits then would be partially attributable to the VG16005 investment.

Results

All past costs were discounted to 2019/20 using a discount rate of 5%. No impacts were valued in monetary terms; thus, the investment criteria reported were limited to the Present Value of Costs (PVC). To ensure consistency with other Hort Innovation project analyses and reporting, the PVC was reported for the length of the project investment period plus 30 years from the last year of investment (2018/19) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

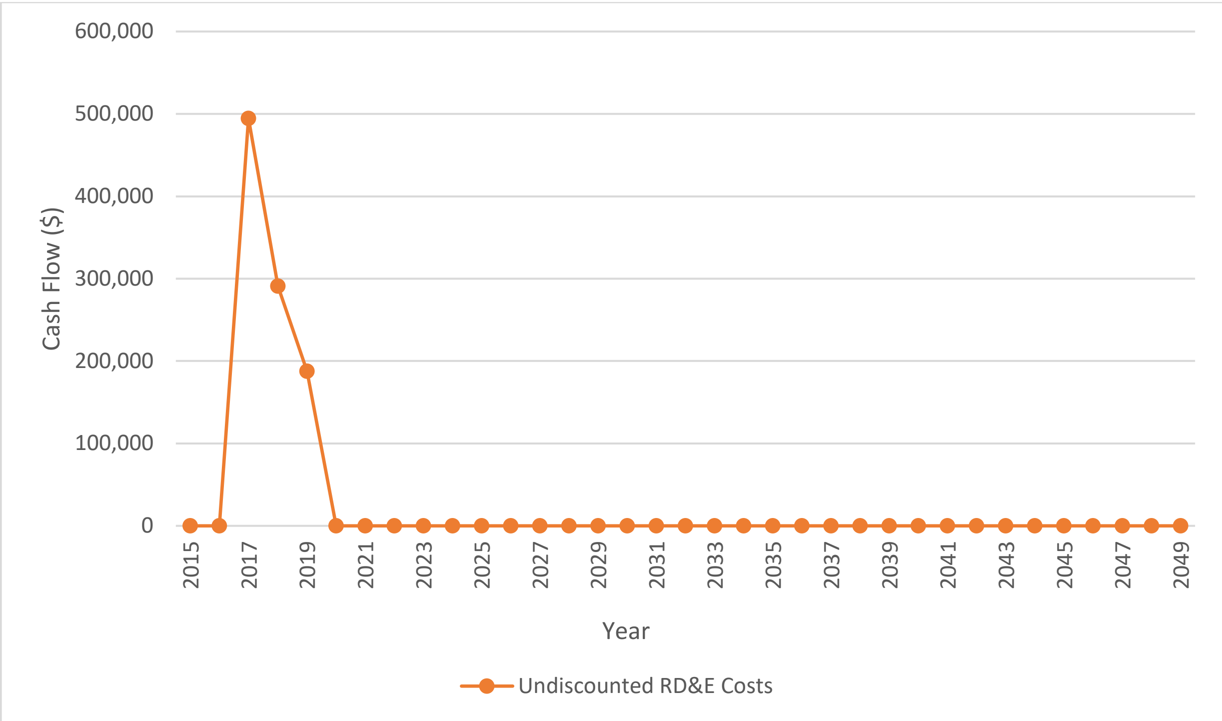
Table 5 shows the investment criteria estimated for different periods of benefit for the total investment. Hort Innovation provided 100% of the project funding.

Table 5: Investment Criteria for Total Investment in Project AP09035

Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Costs ($m)	1.09	1.09	1.09	1.09	1.09	1.09	1.09

The annual undiscounted cost cash flows for the total investment for the duration of VG16005 investment plus 30 years from the last year of investment are shown in Figure 1.

Figure 1: Annual Cash Flow of Undiscounted Total Investment Costs



Conclusion

Total funding from all sources for the project was $1.09 million (present value terms). Though a number of economic and social impacts were identified, the project team identified the need for further investment and there was no evidence of current commercial use of *Probisafe*. Thus, the future potential impacts of investment in VG16005 were not valued in monetary terms within the scope of the current assessment.

The investment in VG16005 has contributed to potential improvements in food safety for Australian leafy green vegetables that may reduce future incidence of foodborne illness and improve consumer health and wellbeing. Further, the investment may contribute to increased profitability and maintained market access for Australian vegetable producers.

Glossary of Economic Terms

Cost-benefit analysis:	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Benefit-cost ratio:	The ratio of the present value of investment benefits to the present value of investment costs.
Discounting:	The process of relating the costs and benefits of an investment to a base year using a stated discount rate.
Internal rate of return:	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Investment criteria:	Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.
Modified internal rate of return:	The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate).
Net present value:	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Present value of benefits:	The discounted value of benefits.
Present value of costs:	The discounted value of investment costs.

Reference List

Australian Bureau of Statistics. (2020, March 4). *5206.0 - Australian National Accounts: National Income, Expenditure and Product, Dec 2019*. Retrieved June 2020, from Australian Bureau of Statistics: https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5206.0Dec%202019?OpenDocument

Australian Government. (2015). *Science and Research Priorities.* Canberra: Department of Industry, Innovation and Science. Retrieved from https://www.industry.gov.au/sites/g/files/net3906/f/2018-10/science_and_research_priorities_2015.pdf

Beuchat, L. R. (2002, April). Ecological factors influencing survival and growth of human pathogens on raw fruits and vegetables. *Microbes and Infection, 4*(4), 413-423. doi: 10.1016/s1286-4579(02)01555-1

Commonwealth of Australia. (2015). *Agricultural Competitiveness White Paper.* Canberra: Commonwealth of Australia. Retrieved from https://agwhitepaper.agriculture.gov.au/sites/default/files/SiteCollectionDocuments/ag-competitiveness-white-paper.pdf

Council of Rural Research and Development Corporations. (2018). *Cross-RDC Impcat Assessment Program: Guidelines.* Canberra: Council of Rural Research and Development Corporations. Retrieved from http://www.ruralrdc.com.au/wp-content/uploads/2018/08/201804_RDC-IA-Guidelines-V.2.pdf

Food Regulation Secretariat. (2016, November 21). *Investigation into salmonella outbreak in salad products*. Retrieved April 2020, from food regulation: https://foodregulation.gov.au/internet/fr/publishing.nsf/Content/activities-food-safety-risk-management

Horticulture Innovation Australia Ltd. (2016). *Annual Report 2015/16.* Sydney, NSW: Horticulture Innovation Australia Ltd.

Horticulture Innovation Australia Ltd. (2017). *Annual Report 2016/17.* Sydney, NSW: Horticulture Innovation Australia Ltd.

Horticulture Innovation Australia Ltd. (2017). *Vegetable Strategic Investment Plan 2017-2021.* Sydney NSW: Horticulture Innovation Australia Ltd. Retrieved April 2020, from https://www.cherrygrowers.org.au/assets/HortInnovation-cherry-SIP_at_a_glance.pdf

Horticulture Innovation Australia Ltd. (2018). *Annual Report 2017/18.* Sydney, NSW: Horticulture Innovation Australia Ltd.

Horticulture Innovation Australia Ltd. (2020). *Australian Horticulture Statistics Handbook 2018/19 VEGETABLES.* Sydney NSW: Horticulture Innovation Australia Ltd. Retrieved April 2020, from https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/grower-resources/ha18002-assets/australian-horticulture-statistics-handbook/?__FormGuid=a2cd5e51-ecbe-4c53-ae51-a870fc5dfc75&__FormLanguage=

Olaimat, A., & Holley, R. A. (2012, May). Factors influencing the microbial safety of fresh produce: A review. *Food Microbiology, 32*(1), 1-19. doi:10.1016/j.fm.2012.04.016

Turner, M. (2018, November 26). Hort Innovation Variation Agreement - Research P1 VG16005 (CON-000910/2). unpublished.

Victoria State Government. (2016, March 6). *FAQ - Salmonella outbreak associated with some types of salad leaf products.* Retrieved April 2020, from health.vic: https://www2.health.vic.gov.au/about/publications/policiesandguidelines/cho-alert-pre-packaged-salad-salmonella

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Brendan O'Keeffe, Analyst, Hort Innovation

Abbreviations

MIRR	Modified Internal Rate of Return
ABS	Australian Bureau of Statistics
CFU	Colony-Forming Unit
CRRDC	Council of Rural Research and Development Corporations
FSANZ	Food Standards Australia New Zealand
Hort Innovation	Horticulture Innovation Australia Ltd
LAB	Lactic Acid Bacteria
PVC	Present Value of Costs
QLD	Queensland
RD&E	Research, Development and Extension