Impact assessment of the investment:

Novel Topical Vegetable, Cotton Virus and Whitefly Protection (VG16037)

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Hort Innovation

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Executive summary

What the report is about

Ag Econ conducted independent analysis determine the economic, social, and environmental impact resulting from delivery of the vegetable project *Novel Topical Vegetable, Cotton Virus and Whitefly Protection (VG16037)*. The project was funded by Hort Innovation over the period February 2018 to November 2022 using the vegetable research and development levy, contributions from the Australian Government, and co-investors including the Cotton Research and Development Corporation (CRDC). The project was delivered by The University of Queensland (UQ).

The analysis applied a five step analytical process to understand the impact pathway and collect supporting data.

Contracts	Hort Innovation	Activities	RD&E costs	So what?
Milestones	Researchers	Outputs	Adoption curve	
Final reports	Growers	Outcomes	Adoption benefits	
	Supply chain	Impacts	NPV, BCR, IRR, MIRR	

Research background

VG16037 progressed the development of biodegradable clay particles (BioClay) as a topical delivery mechanism for double-stranded ribonucleic acid (dsRNA). DsRNA is a relatively new generation crop protection technology that can be used to control targeted pathogens and pests using a cellular mechanism called RNA interference (RNAi). Building on years of UQ research with commercial partners Nufarm, the product was trialled in multiple glasshouse and field trials for *Tomato spotted wilt virus* (TSWV) in capsicum and *Zucchini yellow mosaic virus* (ZYMV) in zucchini, and in insectary trials for silverleaf whitefly (SLW) in cotton. Preliminary dsRNA constructs were also designed for *Cotton leaf curl disease* (CLCuD).

Key findings

The nominal investment cost of $4.74 million (31% vegetable R&D levy and Government matching) was adjusted for inflation (ABS, 2024) and discounted (using a 5% real discount rate) to a 2023-24 present value (PV) of costs equal to $6.58 million.

Through a logical framework process, including discussing the project key stakeholders and reviewing project documentation, the project impact pathway was identified. The process highlighted a clear pathway through which VG16037 (as part of the longer-term BioClay R&D by UQ and Nufarm) has the potential to improve the management of key pests and diseases.

A discounted cashflow model was developed to evaluate the impact of reduced yield loss from TSWV and ZYMV in vegetable crops, as well as the potential for lower-cost SLW management in cotton production. The earlier stage of research into CLCuD meant there were too many uncertainties to quantify the impact with confidence.

The baseline results showed a PV benefit of $32.60 million, with an impact benefit cost ratio (BCR) of 4.96:1.

Most notably, the results showed a high potential impact in reducing the productivity losses associated with TSWV and ZYMV in vegetables, which currently rely on the suppression of insect vectors, with often ineffective results. In contrast, SLW has existing control methods in cotton that are effective at suppressing the pest and associated risk. As such, a benefit would be most likely if BioClay-RNAi product is cheaper than existing control methods, or these become unavailable or ineffective. As the exact price of BioClay-RNAi is uncertain, there was a high level of uncertainty of the benefit for SLW control in cotton.

Sensitivity testing identified a relatively wide potential impact range of between 1.10:1 and 22.54:1, with 90% of results falling between 2.72:1 and 11.88:1. Despite the underlying uncertainties in some of the modelling projections (notably the price of the BioClay-RNAi product), the sensitivity analysis gave a high level of confidence that the overall investment and the vegetable levy investment will generate a positive impact over the 30 year analysis period. For the cotton industry, however, a positive impact from improved SLW control is less certain with 38% of modelled scenarios returning a BCR greater than 1:1.

While this impact assessment focussed solely on the viruses and pest directly researched in VG16037, there is a longer term and potential much larger benefit for BioClay-RNAi technology to provide crop protection for a broader range of pests, diseases and crops. Through AS22003, BioClay-RNAi is already being expanded to target a wider range of horticultural pests, and once the first BioClay-RNAi product is successfully commercialised, subsequent products may follow quickly.

The key findings of the VG16037 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment; cost-benefit analysis; vegetable; cotton; BioClay; dsRNA; RNAi; potyvirus; tospovirus; silverleaf whitefly

Figure 1. Summary of impact assessment findings

VG16037 Novel topical crop protection

RD&E activities

Total RD&E costs:

- $4.74 million (nominal value)
- 31% Veg R&D levy and Government matching, and 69% CRDC, Nufarm and UQ cash and in-kind.

Research activities:

- Progress the development of BioClay for the topical application of double stranded ribonucleic acid (dsRNA) to directly attack key plant pests and pathogens affecting vegetable and cotton production.
- The product was trialled in multiple glasshouse and field trials for *Tomato spotted wilt virus* (TSWV) in capsicum and *Zucchini yellow mosaic virus* (ZYMV) in zucchini, and in insectary trials for silverleaf whitefly (SLW) in cotton.
- Preliminary dsRNA constructs were also designed for *Cotton leaf curl disease* (CLCuD).

Extension activities:

- 7 x Scientific papers:
- 23 x Presentations to academic audiences

Outcomes

Outcomes:

- Increased research knowledge and skills relating to production and application of dsRNA for control of ZYMV in zucchini and TSWV in capsicum, with efficacy of up to 50%. Regulatory approval and scaled production are required for commercial availability and adoption. ZYMV and TSWV BioClay crop protection products estimated to be available from 2030.
- BioClay delivered dsRNA enabled complete SLW population control in cotton. Follow on field trials were commenced in India to translate the VG16037 insectary trials to field conditions for cotton. A BioClay product for SLW control in cotton is estimated to be available from 2032.
- Following the success of of VG16037, further BioClay trials were commenced through AS22003 refining the product for crop protection against SLW and other insects in horticultural protected cropping systems.

Impacts

Industry economic impacts:

- Reduced risk of productivity losses associated with key horticultural and cotton production viruses (notably TSWV and ZYMV) and pests (notably SLW).

Environmental impacts:

- Reduced synthetic chemical usage to manage virus vectors and other pests, thereby reducing off target impacts.

Socio-economic impacts:

- Support vegetable and cotton industry spillovers including employment and economic stimulant to local communities

Total attributable benefits and impact:

- Present value (PV @ 5% discount) RD&E costs of $6.58 million.
- PV estimated benefits of $32.60 million from 2030 and 2053.
- Net PV (NPV) of $26.02 million.
- Benefit cost Ratio (BCR) of 4.96:1 with a 90% confidence of a BCR between 2.72:1 and 11.88:1.

Introduction

Evaluating the impacts of levy investments is important to demonstrate the economic, social and environmental benefits realised through investment to levy payers, Government and other industry stakeholders. Understanding impact is also an important step to inform the ongoing investment agenda.

Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of up to 15 randomly selected Hort Innovation RD&E investments (projects) each year. In line with this ongoing program, Ag Econ was commissioned to deliver the *Horticulture Impact Assessment Program 2020-21 to 2022-23* (MT21015).

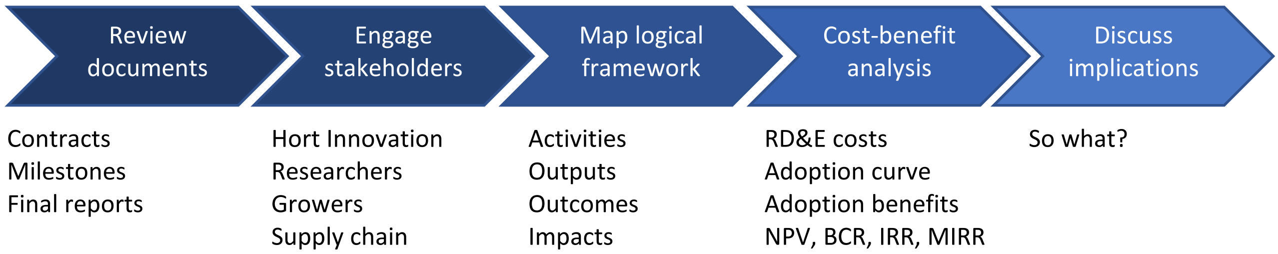
Novel Topical Vegetable, Cotton Virus and Whitefly Protection (VG16037) was randomly selected in the 2022-23 sample. This report presents the analysis and findings of the project impact assessment.

The report structure starts with the general method of analysis used, followed by the RD&E background and an outline of the impact pathway in a logical framework, then describes the approach used to quantify the identified costs and benefits including any data gaps and limitations to the analysis, presents the results including from the sensitivity analysis, and finally discusses any implications for stakeholders.

General method

The impact assessment built on the impact assessment guidelines of the CRRDC (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach is as follows:

1. Review project documentation including project plan, milestone reports, outputs and final report.
2. Discuss the project delivery, adoption and benefits with the Hort Innovation project manager, project researcher/consultant, growers and other relevant stakeholders (see *Stakeholder consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including activities, outputs, and outcomes to identify the principal economic, environmental, and social impacts realised through the project
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.



The analysis identified and quantified (where possible) the direct and spillover impacts arising from the RD&E. The results did not incorporate the distributional effect of changes to economic equilibrium (supply and demand relationships) which was beyond the scope of the MT21015 impact assessment program. A more detailed discussion of the method can be found in the *MT21015 2022-23 Summary Report* on Hort Innovation project page Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015).

Project background

Crop protection is a significant cost in Australian vegetable production, averaging 5% of total costs (ABARES 2018). Major challenges in crop protection include pesticide toxicity, increasing resistance, a lack of natural resistance genes, and public concern around genetically modified crops.

Pest and disease management was identified as a key impediment to improved productivity in the Vegetable Industry Strategic Investment Plan (SIP) 2017–2021, and prioritised for investment under *Outcome 3 Productivity: Increased farm* *productivity and decreased production costs through better utilisation of resources, adaptation to climate, reduced impact of pests and diseases and better utilisation of advanced technologies on the farm*.

Double-stranded ribonucleic acid (dsRNA) pesticides are a relatively new generation crop protection technology that can be used to control targeted pathogens and pests, using a cellular mechanism called RNA interference (RNAi). RNAi inhibits the target pathogen or pests' ability to create essential proteins (CropLife 2021). RNAi can be applied as a topical spray to the plant, either on its own or in combination with conventional crop protection products, or can be genetically engineered into crops to enable the plant to create its own defence mechanism. Topical sprays are absorbed into the plant but do not alter the plant genome (non-GM with regards to the plant), whereas RNAi genetically engineered into the plant is transgenic genetic modification. A major obstacle to the topical application of dsRNA has been the very high instability of naked dsRNA.

From 2012 to 2016 UQ, with commercial partner Nufarm, researched the topical application of dsRNA using novel biodegradable clay particles (BioClay). BioClay is a complex of layered double hydroxide (LDH) particles that is topically applied to a plant. Combining the dsRNA with LDH allows the dsRNA to persist on the surface of the plant, and extends the period of protection against target pests and pathogens for up to 30 days, with no impact on plant growth or yield, no toxic residue, and no alteration to the plant genome. The research had successfully demonstrated the efficacy of BioClay for delivering dsRNA to directly target viruses, rather than indirectly targeting the viruses through their insect vectors. Field research required to further advance the technology to commercialisation.

Through VG15008 (QDAF 2016) a two day workshop was held to understand the priority viruses for further RD&E, with potoviruses and tospovoruses identified as having the greatest negative economic effect on the vegetable industry due to being the most geographically widespread and damaging.

Novel Topical Vegetable, Cotton Virus and Whitefly Protection (VG16037) was commissioned to build on the UQ research to further progress the product development and commercialisation of the BioClay topical spray for control of potoviruses and tospoviruses in horticulture. In addition, the opportunity was also identified to collaborate with the cotton industry to concurrently research a BioClay-RNAi solution for control of Whitefly (a common pest and viral vector in both cotton and horticulture) and cotton leaf curl disease (CLCuD).

VG16037 aligned with the Vegetable SIP 2022-2026 through:

- Outcome 1: Industry supply, productivity and sustainability. Strategy 2. Identify and support opportunities to improve productivity and sustainability through effective integrated pest and disease management (IPDM).

Project details

VG16037 provided funding to UQ from 2018 to 2022 (Table 1).

Table 1. Project details

Project code	VG16037
Title	Novel topical vegetable, cotton virus and whitefly protection
Research organization(s)	The University of Queensland (UQ) (Lead research organisation) Department of Agriculture and Fisheries, Queensland (QDAF) Nufarm (Commercial partner)[1]
Project leader	Neena Mitter (UQ)
Funding period	February 2018 to November 2022
Objective	Minimise the economic impact of pest infestation on vegetables (and on cotton) through the development of an innovative topical protection medium, BioClay.

Logical framework

The impact pathway linking the project's activities and outputs, and their assessed outcomes and impacts have been laid out in a logical framework (Table 2).

[1] Nufarm relinquished the commercial rights, with all intellectual property now held by UQ, with conversations ongoing to engage with a new commercial partner.

Table 2. Project logical framework detail

RD&E activities

- The two components of the BioClay platform, dsRNA, and Clay, were designed, modified, engineered, and synthesised to industry relevant parameters.
- The genes which are critical to potyviruses (particularly *Zucchini yellow mosaic virus* (ZYMV)), tospoviruses (particularly *Tomato spotted wilt virus* (TSWV)), and SLW survival were selected using a software program targeting multiple isolates and addressing issues of off -targets.
- Spray application of BioClay was validated through multiple glasshouse and field trials for ZYMV and TSWV using zucchini and capsicum as hosts respectively.
- In the case of SLW, BioClay was developed to target all stages of SLW (eggs, nymphs, and adults). Artificial diet assays were conducted to screen ~100 gene targets. Insectary trials on cotton were conducted with BioClay application resulting in significant egg and nymph mortality. It was shown that dsRNA can enter into leaves of different host plants, moves systemically in both directions and also is taken up by whitefly feeding on the treated plants.
- A dsRNA production system, including high resolution analytics, was optimised for small and medium scale requirements.
- In partnership with Nufarm clay manufacture was undertaken as a major component with modifications made to better align for cost and regulatory frameworks. A draft regulatory framework was also developed.
- For *Cotton leaf curle disease* (CLCuD), the project identified CLCuD-causing begomovirus and betasatellite species most likely to enter Australia. Genomic information was collected from public and private repositories and genomic regions suitable for dsRNA targeting were identified. The absence of CLCuD in Australia prohibited local testing (and validation) of designed dsRNA constructs. Discussion and planning were initiated with a partner organisation for testing BioClay against CLCuD-causing complexes in the glasshouse, and possibly in the field, where the disease is prevalent.
- Map scale-up activities to progress proof-of-concept to commercialisation.

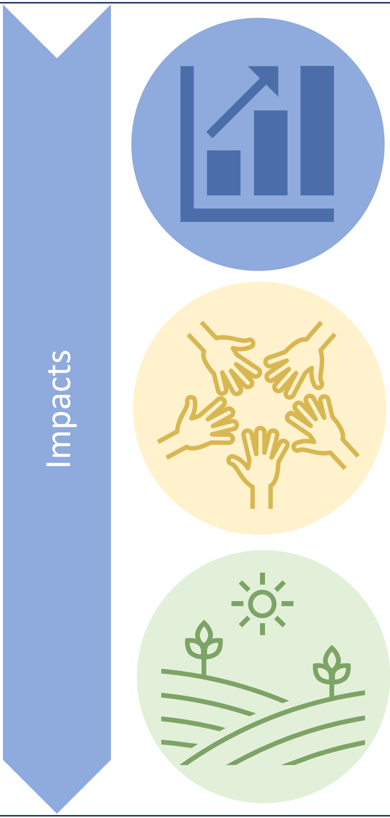
RD&E outputs

- **BioClay-RNAi**
  - Modified BioClay composition to deliver RNAi as a spray technology for the management of potyviruses (particularly ZYMV), tospoviruses (particularly TSWV), ready to progress to regulatory approvals and commercial production.
  - Proof of concept data generated for BioClay based RNAi control of SLW, ready for insectary trials and field trials.
  - RNAi constructs designed for CLCuD.
- **Protocols/Tools**
  - Bioinformatics-based software to design constructs to target viruses and SLW developed
  - Suitable methods for scaled up dsRNA expression and analytics developed.
  - Incursion management plan for cotton leaf curl disease incorporation the use of BioClay
- **Extension.**
  - 7 x Scientific papers:
  - 23 x Presentations to academic audiences
- **Research capacity.**
  - 3x PhDs, and one honours student trained through the project.

Outcomes

End of project outcomes

- **Potyviruses and Tospoviruses**
  - Increased research knowledge and skills relating to production and application of dsRNA for potyvirus (notably ZYMV in zucchini) and tospovirus (notably TSWV in capsicum) control. Preliminary field trials demonstrated protective efficacy of 50%, suggesting that BioClay is effective in controlling ZYMV and TSWV under field conditions. Large scale commercial trials commenced in the follow on project AS22003 with a particular focus on protected cropping. AS22003 also seeks to expand BioClay-RNAi products for control of SLW in horticultural crops (from the initial cotton focus in VG16037), thrips (TSWV vector and sucking pest), and two-spotted red spider mite. While the ZYMV and TSWV products are the most advanced, a new commercial partner needs to be engaged, as well as regulatory approval and scaled production for the commercial availability and adoption. Stakeholder estimated commercial availability between 2028 and 2030.
- **SLW**
  - Increased research knowledge and skills relating to topical application of dsRNA for SLW control. Novel gene targets were identified for control of SLW. BioClay-RNAi use was shown to enable complete SLW population control by causing mortality of eggs, nymphs and to a lesser extent adults in multiple insectary trials on cotton. Trials demonstrated no bee population mortality caused by the SLW dsRNA, highlighting the benefits of specificity and limited environmental impact. Follow on field trials were commenced in India to translate the VG16037 insectary trials to field conditions, funded through the Australia-India Strategic Research Fund (AISRF), with additional SLW trials being undertaken in horticultural protected cropping systems through AS22003. While there are more uncertainties given the earlier stage of research relative to potyviruses and tospoviruses, stakeholders have estimated a potential commercial availability of a SLW product for use in cotton between 2030 to 2034.
- **CLCuD**
  - Increased research knowledge and skills relating to topical application of dsRNA for CLCuD control. RNAi constructs designed but not tested for functionality, requiring future research in controlled settings (likely offshore with CLCuD not present in Australia), before progressing to field trials, regulatory approval and commercialisation. Given the very early stage of the research and higher number of uncertainties, no estimate could be made regarding this timeline or impact.
  - Increased industry knowledge and skills relating to the risk profile of CLCuD for Australia, and the options for risk management to reduce the risk of CLCuD including through BioClay.
- **Industry capacity**
  - In addition to specific research knowledge and skills identified above, the work conducted through VG16037 helped to attract additional collaboration and investment opportunities to further strengthen Australian-led BioClay research capacity and international competitiveness. New investment opportunities include fungal pathogens in horticulture and cotton, and canegrubs and soldier fly in sugar, with international collaboration interest from American (University of California Riverside, and University of California Berkley), and European (University of Ghent) and Ecuadorian (ESPOL) universities. VG16037 also supported increased collaboration with Indian researchers through the follow-on research into SLW control funded through the AISRF.



By progressing the development of novel BioClay-RNAi crop protection options for the vegetable and cotton industries, VG16037 will help to reduce the risk posed by key pests and diseases, specifically:

- [Economic] Reduced productivity losses, including from reduced plant marketable yield and reduced costs in controlling key pests and diseases.
- [Socio-economic] Support/increase vegetable and cotton industry spillovers including employment and economic stimulant to local communities (The CIE 2023).
- [Social] Supporting improved productivity and reduced costs/kg in the supply of fresh and affordable domestic vegetables, in turn supporting lower prices and associated increased vegetable consumption and improved health and wellbeing benefits (Angelino et al, 2019, Mujcic et al, 2016, Stanaway et al 2022).
- [Social] Reduced health and wellbeing costs to farm staff including psychological stress and strains on business and community relationships related to biosecurity events (CSIRO 2020 and CSIRO 2021).
- [Environmental] Reduced environmental impacts that result from chemical use to manage the impact of viruses and their vectors and other pests, including potential impacts on off-target plant and animal species, with implications for long term ecosystem health (Australian Gov. 2021).

Project costs

The project was funded by Hort Innovation, using the vegetable and cotton research and development levies and contributions from the Australian Government, with additional funding from the Cotton Research and Development Corporation (CRDC) research partner UQ, and commercial partner Nufarm (Table 3). Overhead costs were added to the direct project cost to capture the full value of the RD&E investment.

Nominal investment

Table 3. Project nominal investment

Year end 30 June	Hort Innovation managed costs		Hort Innovation overheads[1] ($)	Other funding ($)[2]	Total nominal cost ($)
	Hort Innovation (VG levy and Gov't matching)	CRDC (cotton levy and Gov't matching)			
2018	69,756	139,193	40,676	298,174	547,800
2019	130,345	139,193	44,834	384,636	699,007
2020	278,705	139,193	72,640	596,349	1,086,886
2021	567,896	0	85,023	810,399	1,463,318
2022	0	0	0	0	0
2023	361,431	0	61,854	515,769	939,053
Total	**1,408,132**	**417,579**	**305,027**	**2,605,326**	**4,736,064**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Vegetable Fund Annual Reports, averaging 17% for the VG16037 funding period (2018-2023). As CRDC funds were managed by Hort Innovation, the Hort Innovation overhead and administrative costs were applied to the total cash investment (Hort Innovation plus CRDC).
2. Other funds from UQ and Nufarm included cash and in-kind salaries of key staff, field trials, equipment, product manufacturing, and consumables. These were provided in the contract as a lump sum, so have been apportioned yearly based on Hort Innovation and CRDC cash costs.

Present Value of investment

The nominal total investment cost of $4.73 million identified in Table 3 was adjusted for inflation (ABS 2024) into a real investment of $5.51 million (2023-24 equivalent values). This was then further adjusted to reflect the time value of money using a real discount rate of 5% (CRRDC 2018), generating a present value (PV) of costs equal to $6.58 million (2023-24 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

The impact pathways identified in Table 2 were evaluated against available data to determine if their impact could be quantified with a suitable level of confidence.

Data availability to quantify the impact pathways

Potyvirus and tospovirus control

Given the focus of VG16037 on developing a BioClay-RNAi solution for ZYMV (potyvirus) and TSWV (tospovirus) these were assessed to have the highest certainty for commercial availability and were therefore selected for analysis. *VG15008 Viruses of national importance to the vegetable industry* (QDAF 2016) estimated economic losses from potyviruses and tospoviruses for key vegetable industries, providing a robust baseline for a counterfactual ("without investment") scenario with which to compare the benefits of BioClay-RNAi technology.

Whitefly control

Consultation with cotton industry stakeholders provided sufficient data to quantify the current and likely future threat of SLW with regards to SLW prevalence, risk of quality and reputational damage, and current control options. This information was sufficient to develop a counterfactual ("without investment") scenario with which to compare the benefits of BioClay-RNAi technology.

Impacts valued and valuation framework

In line with the above, a model was developed to estimate the reduction in ZYMV and TSWV risk in horticultural production, and SLW risk in cotton production. The model incorporated the following specific impacts.

- [Economic] **Reduced potyvirus (ZYMV) economic losses** in melons, squash and zucchini resulting from reduced plant productivity, and decreased marketable yield. In VG15008 (QDAF 2016) potyviruses were estimated to cause 5% to 10% production losses in vegetable cucurbits (excluding cucumbers), with ZYMV being one of the two primary potyviruses causing the damage, and having a particular effect on melons, squash and zucchini.
- [Economic] **Reduced tospovirus (TSWV) economic losses** in capsicum, tomato and lettuce resulting from reduced plant productivity, and decreased marketable yield. In VG15008 (QDAF 2016) TSWV was estimated to cause 5% production losses in capsicum, tomato and lettuce production (field and glasshouse).
- [Economic] **Reduced SLW economic losses in cotton**. In contrast to virus control in vegetables, where BioClay-RNAi is expected to be the first product for direct control of viruses, SLW risks to Australian cotton production (primarily through SLW residue causing "sticky cotton") are currently well managed by growers through the use of 1-2 applications of chemical pesticides. As such, the availability of BioClay-RNAi for SLW control is unlikely to result in a reduction in "sticky cotton" risk for cotton growers unless existing products become ineffective or unavailable. While some SLW products are used for the control of other cotton insect pests, it is possible that the BioClay-RNAi product could replace some existing control options if the cost was cheaper. While the exact cost of the BioClay-RNAi product is not yet known, stakeholders have stated that it should be equal to or cheaper than existing insecticides. A range of prices was included exiting SLW control options and the BioClay-RNAi product to estimate a potential benefit.

Impacts unable to be valued

Additional impacts were not quantified as they were found to have a weaker impact pathway, or a lack of supporting data.

- [Economic] **Reduced economic losses from SLW (and other insects) in vegetable production**. While VG16037 research into SLW focused on cotton production, SLW is also a major pest in horticulture including as a virus vector (Tomato torrado virus, Cowpea mild mottle virus) (QDAF 2016), and through direct productivity damage (AUSVEG 2017). However, in contrast to ZYMV and TSWV, no data was identified to quantify the scale of losses of SLW. Furthermore, while follow on research AS22003 is investigating the potential for BioClay-RNAi products to control SLW (and other insect pests) in vegetable production, the early stage of this research limits the ability to confidently quantify the RD&E outcomes, product availability and production impact.

- [Social] **Supporting increased vegetable consumption with improved health and wellbeing**. Fresh, affordable, and locally grown are three of the key drivers in Australian consumer purchasing behaviour for fruit, vegetable and nuts (Kantar, 2022). By reducing production losses through improved crop protection, BioClay-RNAi technology has the potential to decrease the average cost of production, and thereby support lower consumer prices, and increased vegetable consumption. This in turn would generate health and wellbeing benefits associated with vegetable consumption (Angelino et al 2019, Mujcic et al 2016). While this analysis quantified the initial supply side impacts for industry production and value (first round impacts) in line with the CRRDC Guidelines (2018), the flow-on effects with regards to price and consumption changes (second round impacts) require equilibrium models that are beyond the scope of this analysis, and generally beyond the scope R&D impact assessment program (CRRDC 2018).
- [Socio-economic] **Support/increase vegetable and cotton industry spillovers**. The CIE (2023) highlighted the flow-on (spillover) effects of the vegetable industry as a source of employment and economic stimulant to regional communities. Similar analyses have been done for the cotton industry (Powell & Chalmers 2008). By supporting increased industry productivity and sustainability, VG16037 supports a corresponding increase in spillovers to local vegetable and cotton communities. While this analysis quantified the direct impacts for industry production and value, the flow-on effects require additional analysis using economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018). Increased resilience also relates to avoided health and wellbeing costs associated with biosecurity events. These health and wellbeing effects, such as avoided or reduced psychological stress that can affect growers and their communities, may be more profound than the direct economic impact (CSIRO, 2020 and CSIRO 2022). The CSIRO research also noted that health and wellbeing affects are harder to quantify than economic impacts, which is consistent with the lack of data identified through this analysis.
- [Environmental] **Reduced environmental impacts**. There is a recognised link between farm chemical use and harmful off-target effects on rivers, the ocean, the atmosphere, animals and plants if not managed safely (Australian Gov. 2021). The availability of BioClay-RNAi products that are virus-pest specific, non-GM, and naturally degrading reduces the need for synthetic chemical control options to manage viruses, their vectors, and other pests, and thereby reduces potential environmental impacts of crop protection. However, no existing chemical control exists for viruses, and horticulture growers will likely continue to control for sap-sucking insect vectors (which can cause direct damage in addition to viral transmission). Similarly in cotton, chemicals used for SLW are often also applied for the control of other pests, so the extent of potential reduced chemical use is unclear until BioClay-RNAi products are developed for a broader range of insects.

Data and assumptions

The required data relating to the impact pathway was collected from the project documents and other relevant resources (Table 4). Where available, actual data was applied to the relevant years, with estimates applied for any data gaps and projections into the future based on analytical techniques (for example correlations and trend analysis), or stakeholder estimates, or both. A data range was incorporated to reflect underlying risk and uncertainty. This was particularly relevant where estimates were needed due to data gaps, and where projections were made into the future. These ranges were then analysed through sensitivity testing (see *Results*).

Table 4. Summary of data and assumptions for impact valuation

Variable	Value	Source & comment
General data and assumptions		
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
BioClay-RNAi product available for ZYMV and TSWV control	2030 (± 2 years)	Large scale commercial trials commenced in AS22003, with a focus on protected cropping. Subsequent regulatory approval and scaled production will be required for the commercial availability and adoption of BioClay control of Potyviruses (ZYMV) and Tospoviruses (TSWV), estimated by researchers to occur between 2028-2032.
Cost of BioClay-RNAi product	$54/ha/spray (-70%, +4%)	Discussions with researchers that the cost would be equal to or lower than existing crop protection products. A broad price range for existing pesticide and fungicide product costs was taken from Gross Margins for pumpkin, lettuce, capsicum, and zucchini (AgBiz 2017, NSW DPI 2013). A potential BioClay-RNAi product cost was estimated based on the 25th percentile, 50th percentile, and 75th percentile.

Efficacy of BioClay-RNAi product in virus/pest risk reduction	50% (-20%, +60%)	VG16037 trials demonstrated efficacy of 50%. Stakeholders noted a goal of achieving efficacy of up to 80% through ongoing product R&D (such as through AS22003 and the AISRF research). A lower bound of 40% was applied reflecting the possibility that larger scale commercial trials generate lower results than small-scale controlled trials.
Adoption speed of BioClay-RNAi product	Max adoption 7 years from first availability (± 2 years)	Estimate based on the VG16037 proposal stating an expectation that the technology will have become an integral part of optimised crop protection from 5 years after availability, with a conservative 5-9 years to maximum adoption applied.
Maximum adoption level	75% of industry (± 33%)	Conservative estimate in consultation with stakeholders.
Yield related costs for horticultural crops	$0.27/kg (± 63%)	Avoided virus yield losses in horticulture increases the marketable yield, which in turn incurs additional costs in bringing the product to market (notably packing and freight). These costs were identified for zucchini, capsicum, tomato, and lettuce from industry gross margins (AgBiz 2017, NSW DPI 2013).
Outcome attribution to VG16037	38%	Attribution of benefits to VG16037 is based on a cost share of the total research program including preceding work starting 2012 and follow on work to achieve a commercially adoptable product. See *Appendix A. RD&E costs*.
RD&E counterfactual	50% (± 50%)	The extent to which the investment would be undertaken without Hort Innovation investment. Given the high proportion of private grants and commercial partner investments, it was assessed as moderately likely that the investment would have occurred without Hort Innovation.
ZYMV (potyvirus) in melons, squash (pumpkins), and zucchini		
Production of ZYMV at risk crops (melons, squash/pumkins, zucchini)	Melon: 224,227 t Pumpkin: 117,040 t Zucchini: 38,734 t	Projected forward based on a 10 year average 2014-2023 from the Australian Horticulture Statistics Handbook (Hort Innovation 2024).
Production area of ZYMV at risk crops (melons, squash/pumkins, zucchini)	Melon: 7217 ha Pumpkin: 5817 ha Zucchini: 2421 ha	Industry production (above) from the Australian Horticulture Statistics Handbook (Hort Innovation 2024) was combined with yield data from Agricultural Commodities (ABS 2022) and industry gross margin budgets (NSW DPI 2013) to estimate total production area.
Unit price of ZYMV at risk crops (melons, squash/pumkins, zucchini)	Melon: $1.01/kg Pumpkin: $0.86/kg Zucchini: $2.27/kg	10 year average 2014-2023 from the Australian Horticulture Statistics Handbook (Hort Innovation 2024), adjusted for inflation (ABS 2024). See *Appendix A Industry Data* for more detail.
ZYMV losses	4% (-56%, +78%)	VG15008 (QDAF 2016) estimated 5% to 10% production losses in vegetable cucurbits (excluding cucumbers), due to potyviruses including Papaya ringspot virus- type W (PRSV-W), Watermelon mosaic virus (WMV) and ZYMV. PRSV-W and ZYMV were identified as the two primary viruses causing damage. Based on VG15008, this analysis estimated that of the total 5% to 10% losses, 33% to 67% was attributed to ZYMV.
BioClay-RNAi sprays per season per hectare	Melons: 4.9 (± 43%) Pumpkin: 3.2 (± 56%) Zucchini: 2.1 (± 33%)	VG16037 highlighted a residual effect of up to 30 days for BioClay-RNAi. A range of 20-30 days was assumed for the analysis. This was applied to the season length for each crop to generate an estimate of the number of sprays required per season per hectare.
TSWV (tospovirus) in capsicum, tomato, and lettuce		
Production of TSWV at risk crops (capsicum, tomato, lettuce)	Capsicum: 73,734 t Tomato: 457,629 t Lettuce: 132,931 t	Projected forward based on a 10 year average 2014-2023 from the Australian Horticulture Statistics Handbook (Hort Innovation 2024).

Production area of TSWV at risk crops (capsicum, tomato, lettuce)	Capsicum: 3209 ha Tomato: 6041 ha Lettuce: 8683 ha	Industry production (above) from the Australian Horticulture Statistics Handbook (Hort Innovation 2024) was combined with yield data from Agricultural Commodities (ABS 2022) and industry gross margin budgets (NSW DPI 2013) to estimate total production area.
Unit price of TSWV at risk crops (capsicum, tomato, lettuce)	Capsicum: $2.93/kg Tomato: $1.63/kg Lettuce: $1.58/kg t	10 year average 2014-2023 from the Australian Horticulture Statistics Handbook (Hort Innovation 2024), adjusted for inflation (ABS 2024). See *Appendix A Industry Data* for more detail.
TSWV losses	5% (± 50%)	VG15008 (QDAF 2016) estimated 5% production losses in greenhouse and field grown capsicum from TSWV. In addition to capsicum, tomato and lettuce crops were identified as being the three primary crops affected by TSWV (with no specific data for tomato and lettuce losses). This analysis estimated total production losses across the three crops of 5% (± 50%).
BioClay-RNAi sprays per season per hectare	Capsicum: 3.3 (± 29%) Tomato: 3.3 (± 29%) Lettuce: 2.2 (± 26%)	VG16037 highlighted a residual effect of up to 30 days for BioClay-RNAi. A range of 20-30 days was assumed for the analysis. This was applied to the season length for each crop to generate an estimate of the number of sprays required per season per hectare.
SLW in cotton		
Total cotton production area	400,000 ha	10 year average total hectares planted to cotton (including irrigated and dryland hectares), *The Australian Cotton Yearbook (Greenmount Press, 2013-2023).*
Area impacted by SLW	35%	Estimate from stakeholder consultation key pest prevalence in the major cotton growing regions of S QLD and N NSW (Revell 2022).
Current SLW crop protection applications	1-2 / ha	Previous analysis conducted on SLW control in cotton (Revell 2022) and additional stakeholder consultation.
Current cost of SLW crop protection products	$53/application/ha (± 55%)	Previous analysis conducted on SLW control in cotton (Revell 2022) including the primary SLW control options Skope, Pegasus, Admiral, Movento, Applaud, Starkle, and Exirel.
Number of chemical sprays replaced by BioClay-RNAi product	0.75 (± 55%)	Estimate in discussion with stakeholders. Replacement only occurs if the price of BioClay-RNAi (estimated range of $16-$56/spray) is below the price of existing control options (estimated range of $43-$66/spray).

Results

The analysis identified total PV costs (PVC) of $6.58 million (2023-24 PV) between 2017-18 and 2022-23, and estimated PV benefits (PVB) of $32.60 million (2023-24 PV) accruing between 2029-30 and 2052-53 (Table 5). When combined, these costs and benefits generate a net present value (NV) of $26.02 million, an estimated benefit-cost ratio (BCR) of 4.96 to 1, an internal rate of return (IRR) of 14% and a modified internal rate of return (MIRR) of 9%. In the baseline results, the reduced risk of TSWV accounted for 89% of benefits, the reduced risk of ZYMV accounted for 11% of benefits, and the reduced SLW pest management costs accounted for less than 1% of benefits.

Table 5. Impact metrics for the total investment in project VG16037

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	6.58	6.58	6.58	6.58	6.58	6.58	6.58
PVB ($m)	0.00	0.00	2.86	12.97	21.16	27.57	32.60
NPV ($m)	-6.58	-6.58	-3.72	6.39	14.58	20.99	26.02
BCR	0.00	0.00	0.43	1.97	3.22	4.19	4.96
IRR	Negative	Negative	Negative	10%	13%	14%	14%
MIRR	Negative	Negative	1%	8%	9%	9%	9%

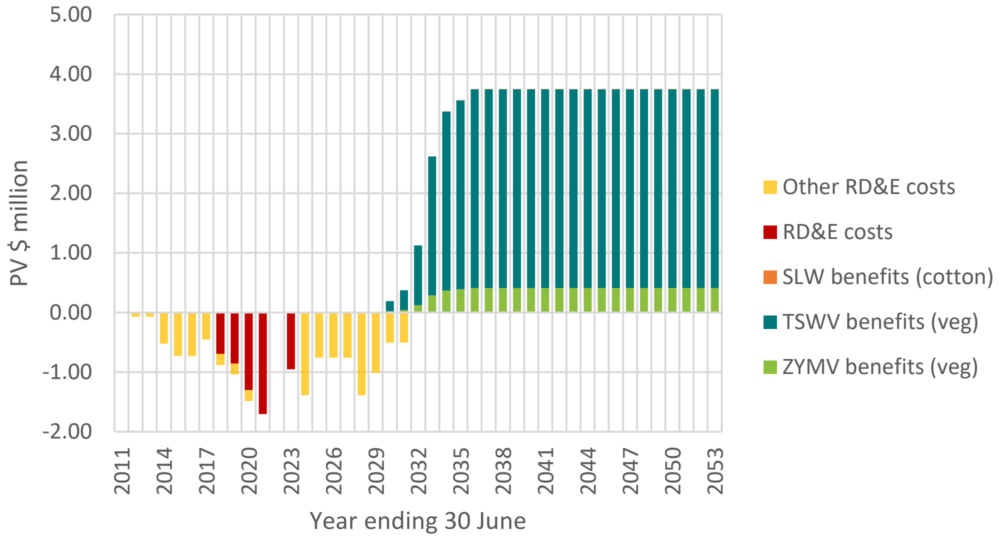
Given the investment included both cotton and vegetable industry levies, the results can be broken down into individual industry costs and impacts. The Hort Innovation contributed 77% of levy cash costs with nearly 100% of baseline results being generated in the vegetable industries. As a result, the attributable impact of the vegetable levy investment is increases to a BCR of 6.42:1 (Table 6).

Table 6. Impact metrics for the Hort Innovation attributable investment in project VG16037

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	5.07	5.07	5.07	5.07	5.07	5.07	5.07
PVB ($m)	0.00	0.00	2.86	12.97	21.16	27.57	32.60
NPV ($m)	-5.07	-5.07	-2.22	7.89	16.08	22.50	27.52
BCR	0.00	0.00	0.56	2.56	4.17	5.43	6.42
IRR	Negative	Negative	0%	12%	14%	15%	16%
MIRR	Negative	Negative	2%	9%	10%	10%	10%

Figure 2 shows the annual undiscounted benefit and cost cash flows for VG16037.

Figure 2. Annual cash flow of undiscounted total benefits and total investment costs

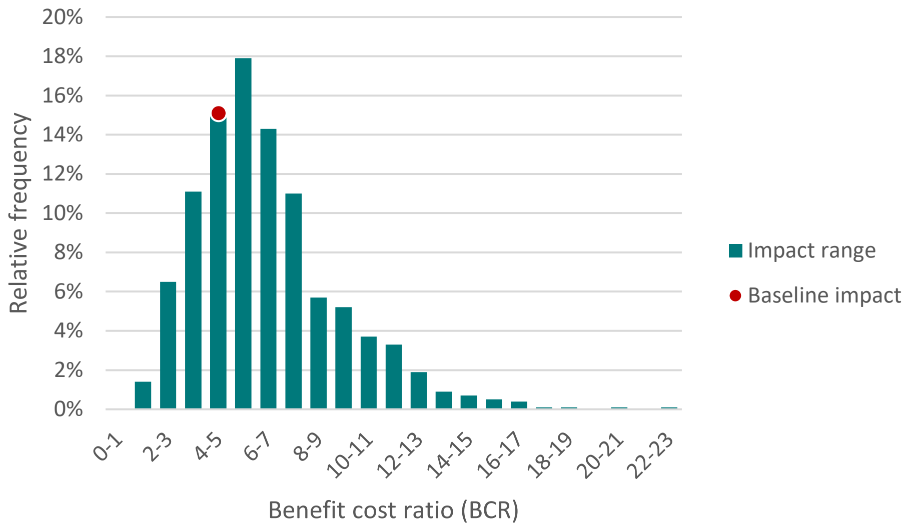


Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling variables, the potential model variation was estimated and drivers of variation identified. The sensitivity testing used @Risk stochastic modelling to incorporate the combined effect of changing all variables across their full ranges over 1000 simulations. This process showed:

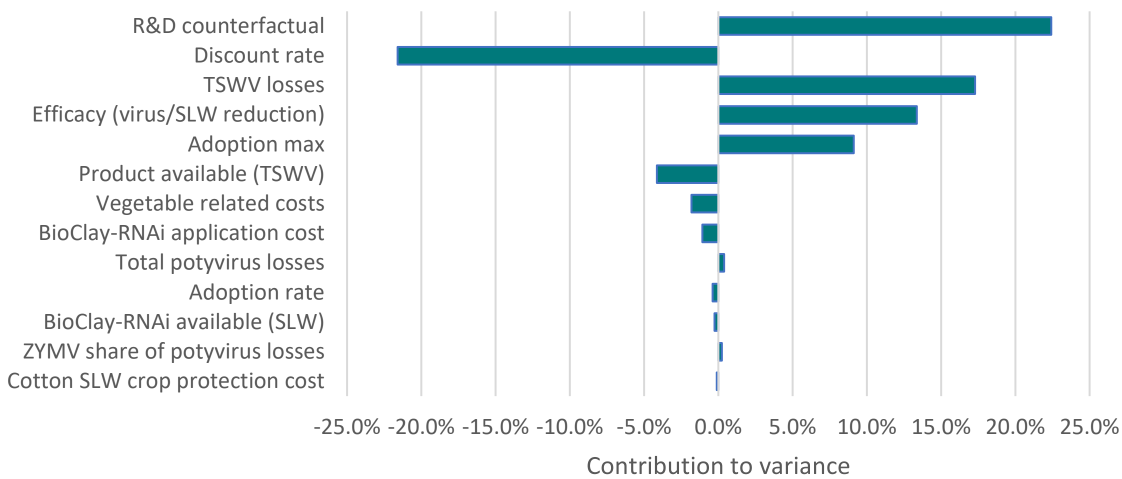
- **Impact variation (Figure 3)**. Compared to the baseline BCR or 4.96:1, the 1000 simulation showed a potential BCR range of between 1.10:1 and 22.54:1, with 90% of results falling between 2.72:1 and 11.88:1 (i.e. excluding the low probability tails), and a simulation average of 6.43:1 (above the baseline results). These results give a high level of confidence that the investment will generate a positive impact. For the cotton industry, comparing 23% of total costs to the SLW cotton benefit, a positive impact is less certain with 38% of modelled scenarios returning a BCR greater than 1:1.

Figure 3. Impact variation over 1000 simulations.



- **Contribution to variance (Figure 4)**. Contribution to variance is a measure of how much a variable contributes to the total variance of an output. Contribution to variance also shows whether a variable is positively or negatively correlated with impact. A negative contribution to variance, with bar extending to the left, indicates that this input has a negative effect on BCR: increasing this input will decrease the impact. The R&D counterfactual (the extent to which the research would have occurred without Hort Innovation investment) had the largest contribution to variation (22%) reflecting the uncertainty over this figure and the subsequent wide value range applied. The R&D counterfactual showed a positive correlation to impact, with higher attribution to Hort Innovation resulting in higher impact for VG16037. The discount rate showed a similarly large contribution to variance (22%), but with a negative correlation to impact. The breakeven discount rate is reflected in the IRR (16%), or the MIRR (10%) if we assume that generated cashflows are reinvested at the risk-free discount rate. The baseline TSWV losses had the third highest contribution to variance (17%) primarily because this was the largest impact area (making up 89% of total benefits). The Efficacy of the BioClay-RNAi product in reducing virus and SLW pressure had the fourth highest contribution to variance (13%), reflecting the larger potential upside from discussion with stakeholders. A breakeven efficacy of 18% needed to achieve a positive overall impact (keeping all else equal), compared to the 50% achieved in the VG16037 trials and the 60% to 80% targeted for the commercial product. The maximum adoption (as a percent of industry production) had the fifth highest contribution to variance (9%), with a minimum adoption of 15% required to achieve a positive impact. Other variables had a contribution of less than 5% each.

Figure 4. Contribution to variance



Implications and learnings

VG16037 progressed the development of an RNAi crop protection solution through the topical application of BioClay. The logical framework demonstrated a relatively clear impact pathway for the commercial availability and benefits of BioClay-RNAi in reducing the risk of key TSWV and ZYMV in vegetables. This was supported by reasonable data from industry resources and previous research; however, some of the data sources were point-in-time estimates that were quite dated (for example the disease impact survey and industry gross margins) and would benefit from being updated to support a more robust understanding of VG16037 impact, and improved industry analysis more generally.

In terms of VG16037 RD&E funding, Hort Innovation contributed 77% of total levy cash costs, with CRDC contributing 23%. In contrast, the baseline benefits showed nearly 100% of benefits generated in the vegetable crops. The difference in benefits largely reflected the higher level of uncertainty with regards to the relative cost of the BioClay-RNAi product. While stakeholders were able to give a general estimate of the BioClay-RNAi product cost, being equal to or cheaper than existing pesticides, this still left a potentially wide cost. This uncertainty had particularly large implications for BioClay-RNAi use in suppressing SLW in cotton, where adoption was assessed to be dependent on cost savings relative to existing control options. As a result, sensitivity testing (around the assumed variable ranges) showed a positive impact for horticulture in 100% of modelled scenarios, whereas for cotton a positive impact was achieved in just 38%.

It is important to note, however, that while this impact assessment focussed solely on the viruses and pest directly related to the VG16037 research (TSWV, ZYMV, & SLW), there is a longer term and much larger potential benefit for BioClay-RNAi technology to provide crop protection for a broader range of pests, diseases and crops. Through AS22003, the product use is already being expanded to a wider range of horticultural pests, and researchers expect that once the first BioClay-RNAi product is successfully commercialised, subsequent products will be developed relatively quickly. This longer-term and potentially much larger benefit will draw on the background R&D processes and knowledge developed through VG16037 and preceding research, thereby generating further impact for the investments in this area.

Stakeholder consultation

Where possible, Ag Econ sought to engage multiple stakeholders across key areas of the logical framework and impact pathway to augment existing information and data sources, and reduce any uncertainty or bias from individual stakeholders. All stakeholders were engaged through telephone or online meetings, with follow up emails as necessary. Consultation followed a semi-structured approach in line with broad topics relating to the impact pathway and associated data requirements. Table 7 outlines the stakeholders consulted as part of this impact assessment and the topics on which they were consulted.

Table 7. Stakeholder consultation by theme

Stakeholder details		Consultation topics						
Stakeholder and organisation	**Stakeholder type**	**Related research**	**Research inputs**	**Research outputs**	**Research immediate outcomes**	**Follow on research**	**Stakeholder adoption**	**Impact areas and data**
Ben Callaghan, Hort Innovation, R&D Manager	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Neena Mitter, UQ Centre for Horticultural Science and ARC Research Hub for Sustainable Crop Protection, Director	RD&E practitioner, VG16037 project lead	✓	✓	✓	✓	✓	✓	✓

Glossary of economic terms

Benefit-cost ratio (BCR)	The ratio of the present value of investment benefits to the present value of investment costs.
Cost-benefit analysis (CBA)	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.
Direct Effects	Impacts generated for the funding industry as a result of adoption of the RD&E outputs and recommendations, typically farm level outcomes relating to productivity and risk.
Discounting and Present Values	The process of relating the costs and benefits of an investment to a base year to reflect the time value of money or opportunity cost of RD&E investment. The analysis applies a real discount rate of 5% in line with CRRDC Guidelines (CRRDC 2018) with results sensitivity tested at discount rates of 2.5% and 7.5%.
Economic Equilibrium	Due to a market's underlying supply and demand curves, changes in supply will have an impact on price and vice-versa. The Economic Equilibrium is the point at which market supply and price are balanced. Estimating the magnitude of market response to changes in supply or demand is a complex and demanding task that is considered beyond the scope of most CRRDC Impact Assessments (CRRDC 2018).
Gross Margin (GM)	The difference between revenue and cost of goods sold, applied on a per hectare basis and excluding fixed or overhead costs such as labour and interest payments.
Internal rate of return (IRR)	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.
Modified internal rate of return (MIRR)	The internal rate of return of an investment that is modified so that the cash inflows generated from an investment are re-invested at the rate of the cost of capital (in this case the discount rate).
Net present value (NPV)	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.
Nominal and real values	Nominal values reflect the actual values in a given year (e.g. contracted RD&E expenses). These are converted to real (inflation adjusted) values to make them comparable across time.
Spillover Effects	Impacts generated for stakeholders who did not fund the RD&E, including other agricultural industries, consumers, communities, and the environment.

Abbreviations

CLCuD Cotton leaf curl disease

RD&E Research, Development and Extension

SIP Strategic Investment Plan

TSWV Tomato spotted wilt virus, a tospovirus

ZYMV Zucchini yellow mosaic virus, a potyvirus

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Appendix A. RD&E costs

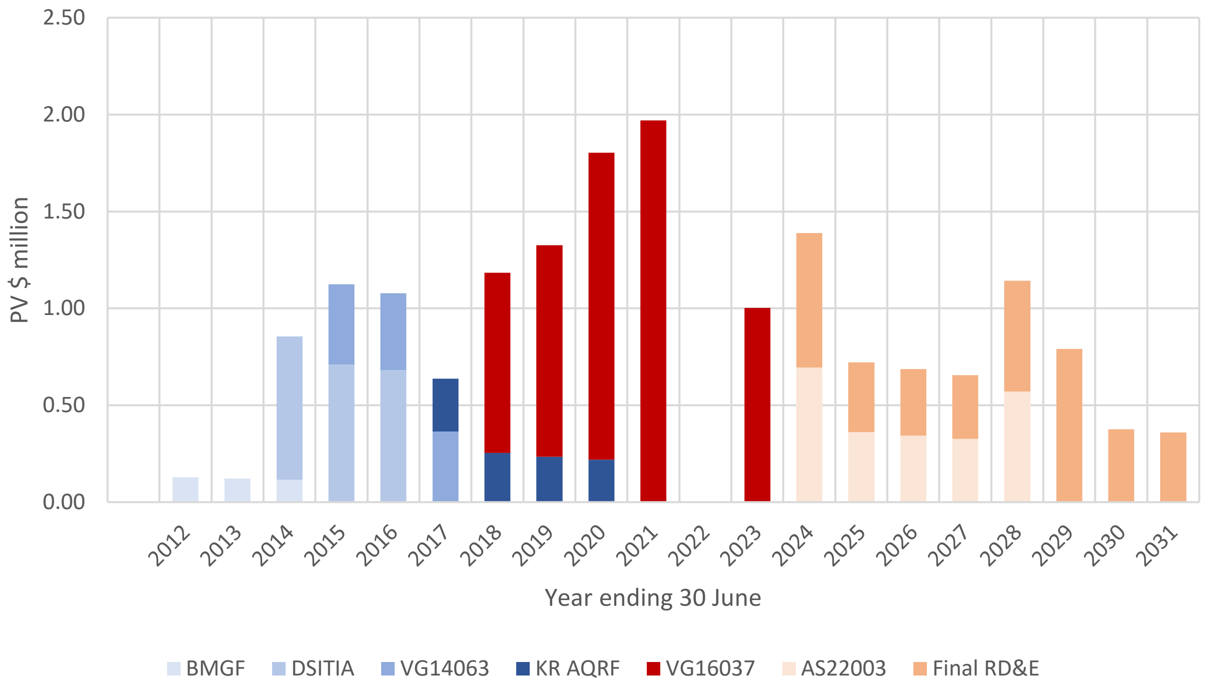
In discussions with stakeholders, six investments were identified as part of the program to deliver a commercially available BioClay-RNAi product for the control of ZYMV and TSWV in vegetable crops and SLW in cotton crops. The cost share of VG16037 (in present value (PV) terms) was used to attribute a share of the total program benefits to the project (Table 8 and Figure 5).

Table 8. Total program cost by investment stage

Investment name	Total PVC ($m)	% Total PVC	Investment period	Average annual PVC ($m)
Bill & Melinda Gates Foundation grant	0.36	2%	2012-2014	0.12
Accelerate partnerships DSITIA (QLD Gov) - BioClay: Novel Spray-on Crop Protection	2.13	12%	2014-2016	0.71
Innovative Solutions to Management of Tospoviruses of Vegetable Crops (VG14063)	1.18	7%	2015-2017	0.39
New horizons with BioClay: Protecting crops from aphids and whiteflies (KR AQRF)	0.98	6%	2017-2020	0.24
Novel topical vegetable, cotton virus and whitefly protection (VG16037)	6.58	38%	2018-2022	1.32
Translating RNAi technology for virus and whitefly management in protected cropping systems (AS22003)	2.30	13%	2024-2027	0.57
Final RD&E for commercial ready product (cotton and horticulture)*	3.82	22%	2027-2030	0.96
Total program	**17.35**	**100%**	**2012-2030**	**0.91**

* Exact figures unavailable. Ongoing cotton work between 2024-2027 estimated to be equivalent to vegetable research in AS22003, with additional work in both vegetables and horticulture equal to the average annual cost of AS22003 until product commercialisation.

Figure 5. Total program cost by investment stage



Ends.