Impact assessment of the investment:

Development of molecular markers for fusarium wilt resistance in banana (BA17006)

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Hort Innovation

Previous page image from BA17006 Final Report

Disclaimer:

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Executive summary

What the report is about

Ag Econ conducted independent analysis to determine the economic, social, and environmental impact resulting from delivery the banana project *BA17006 Development of molecular markers for fusarium wilt resistance in banana*. Delivered by the University of Queensland over the period March 2019 to March 2021, the project was funded by Hort Innovation using the banana research and development levy and contributions from the Australian Government.

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

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

Research background

Fusarium wilt, caused by the fungal pathogen *Fusarium oxysporum f*. sp. *cubense (Foc)* is the most significant challenge facing Australia's $502 million (Hort Innovation 2023a) banana industry. Foc includes several pathotypes, or races, with Tropical Race 4 (TR4) posing the greatest risk due to the susceptibility of the Cavendish variety that makes up nearly 97% of Australian production. TR4 was found in one of Australia's main banana growing regions in March 2015 and as at July 2023 had spread to 8 banana plantations. Genetic resistance has been identified as the only viable option for control.

BA17006 initiated work to develop molecular markers associated with sources of genetic resistance to fusarium wilt (Foc) in banana lines Calcutta 4, Pisang Jari Buaya (PJB) and SH3362 (all with known Foc resistance from previous research). The project built on nearly 20 years of research into the interaction of banana and Foc, which had included the identification a Foc resistance marker for the subspecies Malaccensis. The research established a first generation (F1) line by supporting the identification of additional Foc resistance markers, BA17006 aimed to support a more efficient selection of suitable resistant germplasm for introduction into Australia and thereby decrease the risk presented by Foc (particularly TR4).

Key findings

The analysis identified the pathway through which BA17006 can support socio-economic impact for Australia's banana industry and local communities. A review of available data and discussions with stakeholders allowed the quantification of this impact regarding the potential for increased industry value from a more rapid development of Foc resistant varieties that meet agronomic and consumer standards.

The analysis estimated total expected benefits of $1.89 million (2022-23 present value (PV) using a 5% discount rate) accruing between 2036 and 2052, compared to total funding from all sources of $0.56 million (2022-23 PV) between 2019 and 2021. When combined, these generated a positive RD&E impact with a net present value (NPV) of $1.33 million, an estimated benefit-cost ratio (BCR) of 3.39 to 1, an internal rate of return of 11% and a modified internal rate of return of 9%.

The long timeframe to achieve the benefits was reflective of the early stage of research conducted in BA17006, and the timeframe associated with required subsequent research to identify and refine the Foc markers and incorporate these into varietal development programs. This long timeframe also introduced a relatively high level of uncertainty in some variables.

Sensitivity analysis allowed this uncertainty to be tested, and (as expected) showed a potentially wide range in the results. Testing changes in all the variables across 1000 simulations of the model generated a BCR ranging from less than 0.01:1 (a negative impact with benefits below costs) and 17.26:1 (a high impact), with 69% of results having a BCR greater than 1:1.

This sensitivity testing gave a moderate level of confidence in a positive impact being generated; however, it is important to consider that the results only quantified one of the identified impacts (increased industry value from increased speed with which improved Foc resistant varieties will become available). Additional socio-economic impacts identified through the logical framework were not able to be quantified due to data limitations (identified in the analysis), but have the potential to further increase the impact above that identified in this analysis.

The key findings of the BA17006 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment, cost-benefit analysis, banana, *Fusarium oxysporum*, TR4, resistance, breeding, molecular marker

Figure 1. Summary of impact assessment findings

BA17006 Molecular markers for fusarium wilt

Hort Innovation | The University of Queensland Australia | Queensland Government Department of Agriculture and Fisheries

RD&E activities

Total RD&E costs:

- $0.42 million (nominal value)
- 62% R&D levy and Government matching, and 38% UQ and QDAF in-kind.

Research activities:

From March 2019 to March 2021:

- Continue research into Fusarium Wilt (Foc) Tropical Race 4 (TR4) resistance in the Malaccensis subspecies
- Establish first generation (F1) populations of wild diploid banana lines Calcutta 4, PJB and SH3362 and assess for resistance when challenged with Foc Subtropical Race 4 (Foc SR4).
- Collaborate with international organisations: Bayer Crop Science (Germany), Guangxi Academy of Agricultural Sciences (China), and banana breeding programs IITA (Africa), CIRAD (France) and Embrapa (Brazil).
- Undertake communication and extension activities including presenting research findings at Australian (2019 & 2021) and international (China 2019 & Malaysia 2021) events.

Outcomes

Project outcomes:

- Calcutta 4 and SH3362 derived F1 populations segregated for resistance and susceptibility when challenged with Foc SR4, indicating that both lines are likely heterozygous for resistance to Foc SR4.
- PJB crosses were not obtained due to infrequent occurrence of flowering and poor pollen production.
- The previously identified Malaccensis molecular market was improved to be placed closer to the actual Foc resistance gene.

Supported longer term supported outcomes:

- Further research to identify of Calcutta and SH3362 Foc markers and refine refined Malaccensis, Calcutta 4, and SH3362 Foc markers to ultimately identify the specific resistance genes.
- Enable resistance markers or genes to be incorporated into banana varietal development including conventional breeding and cisgenic development.

Impacts

Economic impacts:

- Increased industry value from a more rapid development of Foc resistant varieties that meet agronomic and consumer standards.
- Reduce the cost to develop Foc resistant banana varieties particularly in conventional breeding programs.

Socio-economic impacts:

- A more reliable supply of fresh and affordable bananas, supporting consumption with associated health and wellbeing benefits.
- Greater security for the economies and communities in banana producing regions.

Total impact:

- Present value (PV @ 5% discount) RD&E costs of $0.56 million.
- Expected PV benefits of $1.89 million between 2036 and 2052.
- Net PV (NPV) of $1.33 million.
- Benefit cost Ratio (BCR) of 3.39:1 with a 69% of results having a BCR greater than 1:1.

AgEcon Research, Development & Extension Services

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.

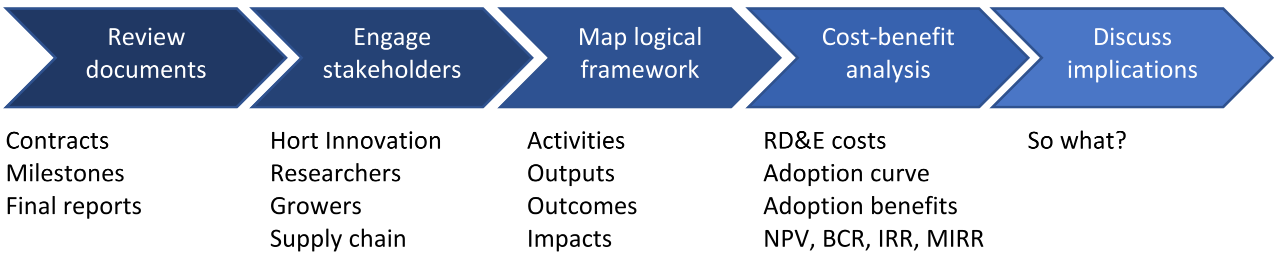
Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of 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).

Project *BA17006 Development of molecular markers for fusarium wilt resistance in banana* was randomly selected as one of the 15 investments in the 2021-22 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 was 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 stakeholders (see *Stakeholder Consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including activities, outputs, 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 2021-22 Summary Report* on the Hort Innovation project page Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015).

Project background

Fusarium wilt or Panama disease, caused by the fungal pathogen *Fusarium oxysporum f.* sp. *cubense (Foc)* is the most significant challenge currently facing Australia's $502 million (Hort Innovation 2023a) banana industry. Foc includes several pathotypes, or races.

In Australia Ladyfinger and Ducasse production (3% of Australian production) is affected by Race 1 strains of the Foc fungus whereas Cavendish production (97% of production) has until recently (2012) only been affected by Subtropical Race 4 when grown in sub-optimal conditions, particularly in its most southern growing regions of southeast Queensland and northern NSW. In contrast, cavendish is highly susceptible to Tropical Race 4 (TR4). In Australia TR4 had been confined to the Northern Territory (NT) after effectively wiping out the regions banana industry after first discovered in 1997. In March 2015 TR4 was detected in Australia's primary Cavendish growing region in north Queensland (N QLD), and as of July 2023 TR4 had spread to 8 banana plantations.

Once present in a plantation Foc cannot be eradicated; the fungus persists in the soil, with no know effective control. Genetic resistance has been identified as the only viable option for control and consequently the identification of disease resistant varieties has been of the highest priority for the Australian banana industry. This was reinforced in the banana industry's subsequent 2017-2021 SIP (Hort Innovation 2017), which highlighted the ongoing need to focus investments in plant protection through Outcome 1 – New varieties introduced and improved pest and disease management that improve varietal diversity and biosecurity.

Studies at the University of Queensland into the interaction of banana and Foc had been ongoing since 1994 with funding from the banana R&D levy[1], Australian Research Council (ARC) Linkage Grants, the Bill and Melinda Gates Foundation (BMGF), and the International Institute for Tropical Agricutlure (IITA). Over this time, knowledge and tools were developed that allowed the identification of a molecular marker associated with Foc resistance in the *Musa* subspecies Malaccensis which had been subsequently adopted in selecting for Foc resistance in the IITA program in East and West Africa, the Honduran Foundation for Agricultural Research (FHIA) breeding program, and the Brazilian Agricultural Research Corporation (Embrapa) breeding program. However, the Malaccensis molecular market cannot be used to identify Foc resistant cultivars that were developed using other progenitors. For example Pisang Jari Buaya (PJB) and Calcutta 4 parental lines have demonstrated Foc resistance, but due to their genetic differentiation, Calcutta 4 and PJB may have developed to carry Foc resistance genes different to those in Malaccensis. As such, it was recognized that the identification of the Calcutta 4 and PJB resistance markers (and ultimately genes) would greatly benefit future breeding programs and industry sustainability.

BA17006 was established to continue the research into Foc resistance, with a focus on initiating studies into the genetics of resistance in PJB and Calcutta 4, with the aim of obtaining molecular markers for additional sources of resistance for use in marker assisted selection for banana breeding programs, and for subsequent introduction into Australia.

Project details

Drawing on its existing knowledge and capacity, the University of Queensland was selected as the lead delivery partner, with the project running from 2019 to 2021 (Table 1).

Table 1. Project details

Project code	BA17006
Title	Development of molecular markers for fusarium wilt resistance in banana
Research organization(s)	The University of Queensland (UQ) (lead) Queensland Department of Agriculture and Fisheries (QDAF) (supporting) Northern Territory Department of Primary Industry and Resources (NTDPIR) (supporting)
Project leader	Elizabeth Aitken (UQ)
Funding period	March 2019 to March 2021
Objective	Initiate work to develop closely linked molecular markers associated with sources of genetic resistance to Foc obtained from wild diploid banana to allow efficient selection of suitable resistant germplasm for introduction into Australia.

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] Including BA09057, BA10020 and BA10024.

Table 2. Project logical framework

RD&E activities

- **Banana Diploid Lines**
  - Up to four clumps of clonal accessions of Calcutta 4, PJB and SH3362 (with known TR4 and SR4 resistance from previous research e.g. Chen et al (2019)) were already established at the QDAF research facility at Redlands, QLD, as well as susceptible diploids of Malaccensis origin.
  - Additional diploid plants known to have resistance to Foc were planted in the field to support future research.
- **F1 populations with Calcutta 4 as a Foc resistant parent.** The seed from a cross between Malaccensis 848 (susceptible) and Calcutta 4 (resistant) undertaken in 2018, was used to generate an F1 population of 22 plants, with multiple clones produced from each plant. Two clones of each accession were field planted in September 2019, while the remaining clones were set aside for glasshouse pot plant trials with *Foc* SR4.
- **F1 populations with SH3362 as a resistant parent.** The seed from a cross between a susceptible Malaccensis line and the resistant SH3362 undertaken in 2019, was used to generate a population of 20 F1 plants. Single clones of each accession were field planted in August 2020, while the remaining clones were set aside for glasshouse pot plants trials with *Foc* SR4.
- **F1 populations with PJB as a Foc resistant parent.** Attempts to use PJB as a female parent in the crosses were unsuccessful and when left to allow open pollination to occur no seed was produced.
- **Ongoing studies into Foc resistance in Malaccensis.** Support broader IITA/BMGF research to identify a more defined region on banana chromosome 3 for the Foc resistance in Malaccensis lines.
- **Extension activities**
  - Present research posters for the Australian Banana Congress 2019 and 2021.
  - Present at the Guangxi Academy of Agricultural Sciences in China 2019.
  - Speak at the Australian Banana Scientific Symposium, Brisbane 2021.
  - Present at the Malaysia National Banana Congress 2021.

RD&E outputs

- **Calcutta 4 and SH3362 derived F1 populations** that segregated for resistance and susceptibility when challenged with Foc SR4.
- **Malaccensis Marker**. A more defined region on banana chromosome 3 was identified as the resistance trait location in .
- **Expanded genetic material with known Foc resistance.** These include the new lines known as Tjau lagada; Tuu gia and Pisang Gajih Merah, as well as three further clones of PJB have been planted. Five clones of the original susceptible Malaccensis line 848 were also planted for future research.

Outcomes

End of project outcomes

- **New knowledge and resources generated** to progress the development of molecular markers associated with sources of genetic resistance to Foc in wild diploid banana.
  - Calcutta 4 and SH3362 derived F1 populations that segregated for resistance and susceptibility when challenged with Foc SR4 indicated that both Calcutta 4 and SH3362 are likely heterozygous for resistance to Foc SR4 and not homozygous for resistance. This outcome supports future research in evaluating the F2 generation against Foc SR4, and Foc TR4, to provide confirmation of the underlying genetics of resistance in these lines and the identification of associated markers for Foc resistance in Calcutta 4 and SH3362.
  - PJB crosses were not obtained due to infrequent occurrence of flowering and poor pollen production. However, the observation that some pollen was produced warranted further attempts to make crosses using this useful line.
  - The previously identified Malaccensis molecular market was improved, with a more defined region on banana chromosome 3 identified as the Foc resistance trait location. This supported follow-on work through international collaborations to identify the gene/s conferring resistance and develop an associated gene-specific molecular marker.
- **Maintained and improved industry research capacity relating to banana genetics and Foc.**
  - Contributed to improved RD&E capacity by:
    - Supporting the continuity of existing research and personnel by filling a funding gap in the broader IITA led Foc molecular marker research funded through the BMGF (2014-2018 and 2019-2022).
    - Funding a post-doc researcher in molecular mapping, plant genetics, and bioinformatics techniques.
  - Strengthened collaboration and knowledge transfer activities between UQ and QDAF, as well as with international organisations the French Agricultural Research Centre for International Development (CIRAD), Bayer Crop Science, IITA, the Brazilian Agricultural Research Corporation (Embrapa), Colorado State University, and Guangxi Academy of Agricultural Sciences, supporting improved outcomes for Australian and international banana growers.

Longer term outcomes

- Inform further research into Foc resistance markers and genes:
  - Inform the identification of Calcutta and SH3362 Foc (TR4 and SR4) markers through the screening of F2 populations.
  - Inform research into refined Malaccensis, Calcutta 4, and SH3362 Foc markers, to ultimately identify the specific resistance genes.
- Enable resistance markers or genes to be incorporated into banana varietal development, including:
  - Traditional breeding programs (international). The Malaccensis marker was already being used in the FHIA and Embrapa breeding programs to screen for Foc resistance. The use of Calcutta 4 and SH3362 markers (once developed) would support improved confidence by allowing screening for multiple progenitors. Given the complexities of traditional breeding programs, the timeline for results is potentially up to 15 years (Stakeholder pers comm).
  - Varietal development using advanced methods, such as in cisgenics, where a Foc resistance gene (once identified) could be incorporated into an agronomically acceptable banana variety that also meets consumer preferences. The timeline for the commercial availability of cisgenic Foc resistant varieties could be around 5 years once commenced (Stakeholder pers comm). Commercial viability (and therefore adoption) would also be dependent on regulatory distinction between cisgenic and transgenic which have historically been grouped together under Genetically Modified Organism (GMO). GMOs have been met with caution by both consumers and regulators in Australia and internationally.

Impacts

Through the end of project outcomes, and the support for the longer term outcomes, the research conducted in BA17006 has the potential to generate the following **economic impacts**:

- [Economic] Reduce the timeline by which commercially viable (with regards to yield and quality) Foc resistant banana varieties are made available to Australian and global banana producers.
- [Economic] Reduce the cost to develop Foc resistant banana varieties particularly in conventional breeding programs.

These in turn would support **spillover socio-economic benefits**:

- [Socio-economic] Greater banana industry productivity and production security means a more reliable supply of fresh and affordable bananas, supporting banana consumption with associated health and wellbeing benefits (Mengstu et al 2021, Mujcic et al 2016).
- [Socio-economic] A reduce biosecurity risk for industry supports greater resilience for banana growing economies and communities in Australia, including Tully, Innisfail, Lakeland, and the Atherton Tablelands in Queensland; Darwin in the Northern Territory; the Coffs Harbor and Northern Rivers regions of New South Wales; and the Carnarvon region in Western Australia; and also globally.

Project costs

The project was funded by Hort Innovation, using the banana research and development levy and contributions from the Australian Government, with in-kind funding from research partners UQ and QDAF (Table 3). Where relevant, overhead and extension 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 project costs ($)	Hort Innovation overheads[1] ($)	UQ and QDAF ($)[2] project costs	Total nominal ($) investment costs
2019	50,000	8,503	34,741	93,244
2020	100,000	15,565	69,483	185,047
2021	77,284	11,681	53,699	142,699
Total	**227,284**	**35,753**	**157,923**	**420,960**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Banana Fund Annual Reports (Hort Innovation 2023a), averaging 15.9% for the BA17006 funding period (2019-2021).

2. Other funds from UQ and QDAF were provided in the contract as a lump sum of in-kind salaries, so have been apportioned yearly based on Hort Innovation cash costs.

Present Value of investment

The nominal total investment cost of $0.41 million identified in Table 3 was adjusted for inflation (ABS, 2023) into a real investment of $0.48 million (2022-23 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 $0.56 million (2022-23 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 was evaluated against available data to determine if their impact could be quantified with a suitable level of confidence. From this process, one impact was selected for valuation.

Impacts valued and valuation method

[Economic] Reduced timeline by which commercially viable (yield and quality) Foc resistant banana varieties are made available to Australian banana producers.

To quantify this impact, a framework was developed to quantify and compared a counterfactual ("without BA17006" scenario) and a "with BA17006" scenario.

The without BA17006 scenario considered:

- "Business as usual". A baseline projection of banana industry value (production, prices) was made based off historical trend data.
- "Increased TR4 spread". While slow, the continued spread of TR4 in QLD highlights the risk faced by industry from this disease. A TR4 spread scenario was added to the baseline to reflect this risk. In this scenario, grower adoption of TR4 resistant varieties is dependent on:
    1. The TR4 resistant varieties meeting minimum agronomic and consumer preference standards. To date, TR4 resistant varieties identified through varietal import and evaluation projects such as BA16001 have been found to be inferior to Williams Cavendish in agronomic and consumer testing. For example, in Australia's previous banana varietal import project (BA16001) 14 of 37 screened varieties showed suitable levels of resistance to TR4 (i.e. a TR4 "screening success rate" of 38%) with screening success for other criteria of 21%. Together, these result in total screening success of 8% or less than 1 in 10 new varieties likely to meet the TR4 resistance, other agronomic and consumer preference criteria. The analysis assumed progress would be made in the search for a combined TR4 resistant, agronomically suitable, and consumer appealing variety albeit at a slow rate due to limitations in the number of varieties that could be imported (resource constraints), combined with the current low "screening success rate" against each of the evaluation criteria.
    2. Williams Cavendish becoming unviable due to increased TR4 spread, at which point the new varieties present an option for continued banana production as long as they can still generate a sufficient grower profit. To replant in TR4 infected areas would also require biosecurity rules to change to allow replanting in TR4 areas.

The "with BA17006" scenario considered:

- The timeline for additional research that is required to identify the Calcutta and SH3362 Foc (TR4 and SR4) markers through the screening of F2 populations, and then further refine the Malaccensis, Calcutta 4, and SH3362 Foc markers (with the ultimate goal of identifying specific resistance genes).
- The rate of improvement in varietal development (regarding TR4 resistance and other agronomic traits, as well as consumer appeal) resulting from the use of resistance markers or genes. While the markers focus on TR4 resistance, the increased efficiency in identifying TR4 resistant varieties not only improves the TR4 and overall screening success rate for Australia's importation program, but also supports an increased breeding focus on and progress towards other agronomic and consumer traits. The analysis focussed on the use of the resistance markers or genes in conventional breeding programs given the existing adoption pathway for Australian banana growers. While cisgenics offers another potential impact pathway, and removes some issues regarding agronomic and consumer appeal (as the resistance gene is added into existing high performing varieties), it also introduces other uncertainties around regulatory and consumer acceptance (given historical issues regarding genetically modified food). Further, cisgenics can only be undertaken once the specific Foc resistance gene is identified. These uncertainties relating to cisgenics were considered too significant to achieve a sufficient level of confidence in the analysis.
- After considering the above, the rate of grower adoption, and economic implications, were considered for the two scenarios outline in the counterfactual: 1) adoption of TR4 resistant varieties once they reach or exceed Williams Cavendish in agronomic and consumer appeal (regardless of the rate of TR4 spread), and 2) adoption of TR4 resistant varieties once Williams Cavendish becomes unviable (due to TR4 spread).

Impacts not valued

The following impacts were not able to be quantified:

[Economic] Reduced cost to develop Foc resistant banana varieties. This impact relates primarily to overseas breeding programs; however, reduced varietal development costs could be passed on to Australian growers through reduced retail costs per plant. Breeding program costs were not available for this analysis, and the scale of potential savings could not be confidently estimated through available data or stakeholder consultation.

[Socio-economic] Increased banana consumption with associated health and wellbeing benefits. There is a recognised link between health and wellbeing benefits of banana consumption (Mengstu et al 2021) and fruit and vegetable consumption more broadly (Angelino et al 2019, Mujcic et al 2016). However, to quantify the benefit of increased banana consumption (or avoided decreases in banana consumption) in the context of cost benefit analysis requires a clear relationship between unit consumption and unit health and wellbeing, as well as a dollar value for unit health and wellbeing changes. These relationships and values could not be confidently estimated through available data or stakeholder consultation.

[Socio-economic] Greater resilience for local economies and communities. The CIE (2023) highlighted the flow-on (spillover) effects of the banana industry for regional economies, particularly around the communities of Tully, Innisfail, Lakeland, and the Atherton Tablelands in Queensland; Darwin in the Northern Territory; the Coffs Harbor and Northern Rivers regions of New South Wales; and the Carnarvon region in Western Australia. While this analysis is a first step in understanding and quantifying the direct effects on industry production and value, the flow-on effects require additional analysis in economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018).

[Socio-economic] Global producer and consumer benefits from reduced Foc risk. While the above impact areas focus on Australian producers, consumers, and communities, the importance of banana production and trade around the globe combined with the ongoing spread of Foc, highlights the potential for significant global benefits from molecular markers for Foc resistance. While Australia does not participate in international banana trade (Hort Innovation 2023a), bananas are are among the most produced, traded and consumed fruits globally (FAO, 2023a). Bananas are produced in more than 135 countries, and are a staple crop for the food security of 400 million people, as well as an essential source of income in many developing countries (FAO, 2023b). TR4 has spread to all the major banana producing regions of Asia, Latin America, and Africa (FAO, 2023c). TR4 poses a significant risk to global banana production and trade given the high level of susceptibility of the dominant Cavendish variety, but also its ability to affect a much broader range of the 1000 banana and plantain cultivars that are of particular importance in developing countries and subsistence agriculture. The potential risk of TR4 has been estimated at $16 billion (ABGC 2019); however, this potentially underestimates the broader cost for consumers and producers in developing economies. Given the significant global risk of Foc and particularly TR4, the development of Foc resistance markers has the potential to generate a large global impact. However, estimating this global impact would require a replication of this Australian modelling across all banana producing countries, including collection and analysis of data on production systems, costs, and TR4 spread. The scale of the necessary data collection and analysis make it beyond the scope of this impact assessment.

Data and assumptions

For the impact where valuation was possible, the necessary data was collected from the project documents and other relevant resources. Where available, actual data was applied to the relevant years, with estimates applied for any data gaps and projections into the future based on identified analytical techniques (for example correlations and trend analysis), or stakeholder estimates, or both. Where estimates were used, a data range was considered to reflect underlying risk and uncertainty, which was further analysed through sensitivity testing (see *Results*). A summary of the key data, assumptions and sources is provided in Table 4.

Table 4. Summary of assumptions for impact valuation

Variable	Assumption	Source / comment
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
Industry production (without TR4) (t)	Av 381,000	Actual data used up to 2022 (Hort Innovation 2023a), with projections based on 10 year trend growth of 0.8% per year in the baseline (without TR4 and without molecular markers) scenario.
Industry production area (ha)	Av 12,741	Based on actual data for industry production (Hort Innovation 2023a) and average yield in productive areas (ABS 2023b). Projected based on the projection for production (above) and the 5 year average yield per hectare.
Foc TR4 spread (% area)	58% by 2052 (± 60%)	A maximum projected spread of 97% was based on Cook et al (2015). See appendix A for more details.
Farmgate banana price $/kg	1.66 (± 15%)	Historical banana farmgate prices to 2022 were calculated based on Hort Innovation (2023a) and adjusted for inflation (ABS 2023a). Projected prices from 2023 were based off the 5-year (2017-18 to 2021-22) inflation adjusted minimum, average, and maximum.
Timeline for molecular	2034 (± 5 years)	The full R&D timeline from the completion of BA17006 was estimated in

markers to be used for varietal screening		discussion with stakeholders. The timeline includes ongoing research to identify the Calcutta and SH3362 Foc (TR4 and SR4) markers through the screening of F2 populations and then further refine the markers for use in breeding or screening programs. The development of the Malaccensis marker took approximately 20 years (BA17006 final report). Assuming some increased efficiencies building off existing knowledge and resources a reduced timeframe of 10 to 20 years (from BA17006 commencement in 2019) was estimated (baseline 15 years).
Number of varieties imported per year	4 (± 25%)	Varietal imports through levy funded programs have ranged from 23 over 4 years (BA16001) to zero (BA21002). This does not include private importation which would also benefit from the identification of resistance markers. 3 private varieties were imported during BA16001 with (unspecified) multiple varieties being imported in BA21002. A conservative estimate of 3-5 varieties per year was used in projections from 2024.
Without marker TR4 screening success rate	38%	BA16001 TR4 trials resulted in 14 of 37 varieties showing suitable levels of resistance.
With marker TR4 screening success rate	60% (± 17%)	Stakeholder consultation indicates the Malaccensis resistance marker has been placed close to the resistance gene (estimated 99%). Similar levels of success would be expected with the Calcutta 4 and SH3362 markers initiated through BA17006; however, until the marker can be fully aligned to the resistance gene, there would remain some risk of varieties being susceptible. Estimated from 50% to 70% (baseline 60%).
Other evaluation success	21%	In addition to TR4 resistance, new varieties are screened for other disease resistance, desirable agronomic traits (bunch size, weight, height), and consumer preferences. BA16001 trials showed 3 out of 14 varieties with suitable TR4 resistance progressing to pre-commercialisation (despite lower yield performance relative to industry standard Cavendish Williams, see below).
Baseline yield performance (% of Williams Cavendish)	-24% (-68% + 46%)	Trials to date have shown TR4 resistant varieties generating lower yields relative to industry standard Cavendish Williams. BA16001 agronomic performance trails for 6 Cavendish selections with TR4 resistance (GCTCV 215, GCTCV 247, CJ 19, GCTCV 217, GCTCV 105, Asia Pacific #3) showed yield discounts of 8% to 35% (average 24%).
Yield performance improvement with each new variety successfully passing evaluation trials	5% (± 60%)	Due to the limited throughput of varietal import and evaluation to date, there is no trend data to demonstrate progress on yield (or other agronomic or consumer traits) for TR4 resistant varieties. A wide variation in varietal yield performance of TR4 resistant varieties (above) indicates the potential for increased performance over time. To avoid unrealistically high yields into the future, yield projections were capped at the highest trial variety yield of 44.6 t/ha (from BA16001), which is 48% higher than the baseline 5-year industry average of 30 t/ha as at 2023.
Equilibrium production per capita (kg per person)	15 (± 3%)	As Australia's banana industry has no export or import trade (which is assumed to be maintained going forward), large changes in supply have significant price implications. To avoid unrealistic oversupply with improved industry yields, a per capita production cap was applied equal to 15kg/person (based on a 5 year average range of 14.5 to 15.5 kg/person based off Hort Innovation (2023a) production data and ABS (2023c) population data). Projections for Australia's population were taken from CFP (2023).
Adoption timeline for new varieties	5 years (± 40%)	Adoption of available TR4 resistant varieties in plantations unaffected by TR4 was assumed to occur once TR4 resistant yields achieved parity with Williams Cavendish. From this point adoption is estimated to occur within a normal replanting timeline (5-7 years) (QDAF 2018).
Approval threshold for	25% (± 100%)	Stakeholder consultation highlighted that current rules prevent

replanting in TR4 areas (% of industry area loss)		replanting in TR4 infected areas. Given the closed supply of Australian bananas (zero imports) the continued spread of TR4 with associated production loss would likely trigger a review to allow replanting with TR4 resistant varieties (or trigger the importation of bananas, not considered in this analysis). No data or estimate was identified for this trigger level, so a wide assumption of 0% to 50% of production area was applied to reflect the uncertainty.
Replanting costs $/ha	$9,474	One off costs relating to unscheduled crop removal (of dead or diseased crop as a result of TR4) and ground prep and replanting with TR4 resistant varieties before returning to normal cost structure (below) (QDAF 2018), adjusted to 2022-23 values (ABS 2023a).
Average annual variable costs $/kg	$0.99	Annual variable costs across 1 x plant crop and 6 x ratoon crops, including replanting 1/7 of area each year (QDAF 2018), adjusted to 2022-23 values (ABS 2023a).
Outcome attribution	7.5% (± 33%) in 2023 Declining at 2.5% (± 100%) each year	Attribution apportions credit of the final outcome (development of molecular markers) among contributors to the R&D, and therefor considers previous and future R&D that was or will be critical in achieving the final impact. Attribution can be estimated based on R&D cost shares (CRRDC 2018). The research conducted in BA17006 built on the knowledge and skills developed over a long period of research into banana genetics and Foc. The BA17006 Final Report identified a cost share of approximately 15% relative to other funding sourced through the BMGF and the IITA between 2014-2022. This figure does not account for knowledge and skills developed in earlier research such as BA09057, BA10020, and BA10024. In addition, stakeholders noted the requirement for ongoing research to progress the F1 trials conducted in BA17006 and identify and refine the Calcutta 4 and SH3362 Foc markers for use in conventional breeding programs. Considering these broader contributions and ongoing R&D requirements, an attribution of 5% to 10% was estimated. Attribution was estimated to decline at a compound rate of 0% to 5% per year. This low level of attribution decline reflects the foundational importance of molecular markers in identifying Foc resistance, but also the potential for ongoing advances in Foc management, including the development of additional molecular markers for use in breeding and screening
R&D counterfactual	37.5% (± 50%)	The R&D counterfactual considers the extent to which the BA17006 research was dependent on Hort levy funding. Stakeholder discussion and BA17006 documentation notes that the broader UQ research into Foc markers was not historically reliant on funding from Hort Innovation, but instead leveraged international funding from the BMGF and IITA (as discussed above). Stakeholders also noted that ongoing research into the gene or genes associated with the molecular markers was being supported by extensive international funding and collaborations with BMGF, the CIRAD, Bayer Crop Sciences, Guangxi Academy of Agricultural Sciences, and the Colorado State University. The low historical dependence on levy funds, and the wide range of other investors in Foc marker research suggests a high potential for the research to have been funded from other sources. This, however, is offset by funding gaps within the broader program which meant that continuity of key personnel was at risk without additional funding, which was provided through BA17006. A low to moderate R&D counterfactual of 25% to 50% was estimated.

Results

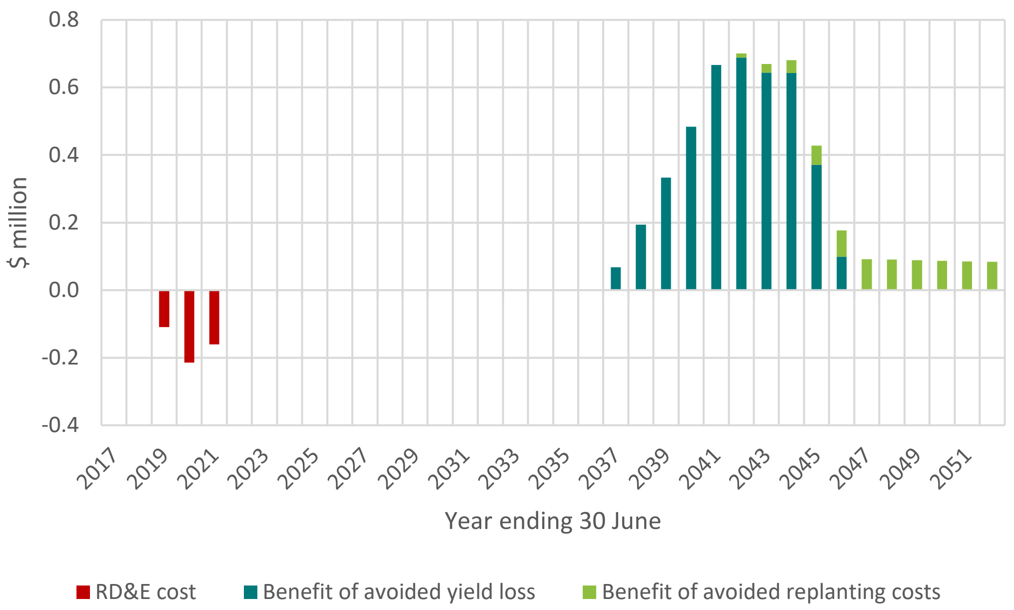
The analysis identified PV costs (PVC) of $0.56 million (2022-23 PV) between 2019 and 2021, and estimated PV benefits (PVB) of $1.89 million (2022-23 PV) accruing between 2036 and 2052 (Table 5). When combined, these costs and benefits generate a net present value (NPV) of $1.33 million, an estimated benefit-cost ratio (BCR) of 3.39 to 1, an internal rate of return (IRR) of 11% and a modified internal rate of return (MIRR) of 9%.

Table 5. Impact metrics for the total investment in project BA17006

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	0.56	0.56	0.56	0.56	0.56	0.56	0.56
PVB ($m)	0.00	0.00	0.00	0.04	1.05	1.78	1.89
NPV ($m)	-0.56	-0.56	-0.56	-0.52	0.49	1.22	1.33
BCR	0.00	0.00	0.00	0.06	1.87	3.18	3.39
IRR	Negative	Negative	Negative	-11%	8%	11%	11%
MIRR	Negative	Negative	Negative	-10%	8%	9%	9%

Figure 1 shows the annual undiscounted benefit and cost cash flows for the total investment of BA17006. Cash flows are shown for the duration of the investment plus 30 years from the last year of investment. The majority of the benefit is derived from the earlier availability of agronomically competitive Foc resistant varieties supporting earlier adoption and avoided industry losses from TR4 spread. From 2042, when the threshold for replanting into TR4 infected areas is reached, there is an additional benefit from reduced replanting costs due to the availability of higher yielding varieties reaching equilibrium production from less planted area.

Figure 1. Annual cash flow of undiscounted total benefits and total investment costs

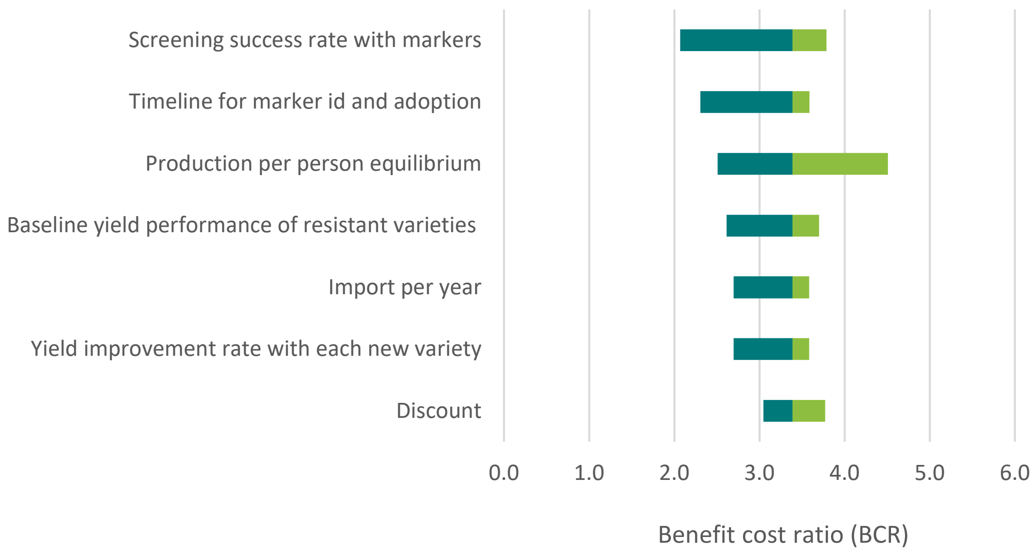


Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling inputs (particularly due to the long forward projections inherent in the impact assessment process), the results were tested for sensitivity to changes in the variable where a potential value range was identified (Table 4).

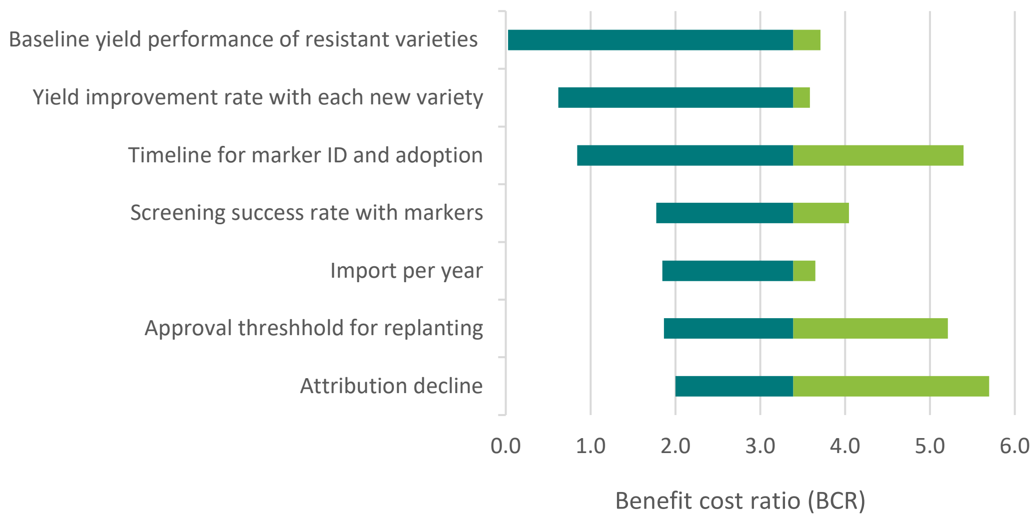
Results were first tested for sensitivity to uniform changes in underlying variables (tested individually), with the top seven variables shown in Figure 3. This highlighted that the results were most sensitive on the downside to 10% changes in the screening success rate with Foc markers (extent to which Foc markers increase the efficiency of varietal development and identification), and the timeline for marker identification and adoption. On the upside the results were most sensitive to a 10% change in the production per person equilibrium (extent to which domestic production is limited by the domestic population due to a lack of exports) (Figure 2).

Figure 2. Sensitivity of the results to a 10% change in variables



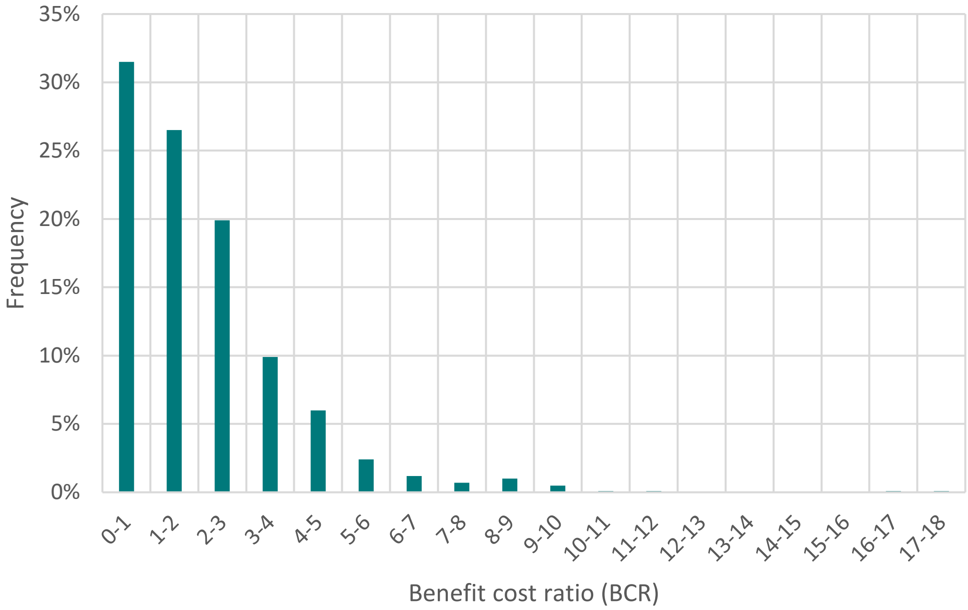
The results were next tested for sensitivity to individual changes across the full value range for each variable to reflect the differences in risk and uncertainty for each variable. The results were most sensitive to the full range of the seven variables shown in Figure 3. The results were particularly sensitive on the downside to the baseline yield performance of resistant varieties, the rate of increase in yield with each new variety, and the timeline for market identification and adoption, all of which had the potential to decrease the impact (BCR) below 1:1. On the upside, the results were most sensitive to the rate of attribution decline, the timeline for market identification and adoption, and the approval threshold for replanting in Foc infected areas.

Figure 3. Sensitivity of the results to changes across the full variable ranges



Finally, the full range of potential impact was estimated using @Risk stochastic modelling to incorporate the combined effect of changing all variables across their full ranges over 1000 simulations. This process showed an impact (BCR) range of between 0.01:1 (benefits lower than costs) and 17.26:1, with a 90% confidence of results between 0.08:1 and 5.21:1, and 69% confidence of a BCR greater than 1:1. The wide range of simulation results reflect the combined effect of the high levels of risk and uncertainty relating to some variables (as reflected in Figures 2 and 3), but give an overall moderate to high level of confidence that the investment will generated a positive impact.

Figure 4. Impact histogram (1000 simulations)



Implications and learnings

Through the development of the logical framework for BA17006 it was evident that the research was early in the impact pathway. This introduced a relatively high level of uncertainty regarding key impact pathway assumptions, particularly including:

- The likely speed and level of TR4 spread throughout Australia's banana growing regions.
- The likelihood, timeline, and additional cost of building on the BA17006 research to develop and sufficiently refine Foc resistance markers for Calcutta 4 and SH3362 (ultimately to be gene specific markers).
- The likelihood and timeline of Foc resistance markers (Calcutta 4, SH3362, and the existing Malaccensis) being integrated into traditional breeding programs, and implications of their use, such as the changes in the speed or cost of breeding programs, or improvements in the achieving higher levels of agronomic and consumer appeal.
- The likelihood, timeline, and cost of using cisgenics to develop Foc resistant varieties that meet agronomic and consumer standards, and the potential for these to be commercially viable given historical barriers regarding genetically modified food. This pathway in particular was considered too uncertain and not included in the analysis.

Detailed sensitivity testing allowed most of this uncertainty to be tested, and (as expected) showed a potentially wide range in the results. Testing changes in all the variables across 1000 simulations of the model generated a BCR of between 0.01:1 (a negative impact with benefits below costs) and 17.62:1 (a high impact), with 69% of results having a BCR greater than 1:1.

The sensitivity testing gave a moderate level of confidence in a positive impact being generated; however, it is important to consider that the results only quantified one of the identified impacts (increased industry value from increased speed with which improved Foc resistant varieties will become available). Additional socio-economic impacts identified through the logical framework were not able to be quantified due to data limitations, but have the potential to further increase the impact above that identified in this analysis. In particular, the potential global impact of molecular markers given the significant economic and nutritional contribution of banana production, particularly in the developing world, and the increasing spread of Foc (particularly TR4) across banana producing regions.

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 6 outlines the stakeholders consulted as part of this impact assessment and the topics on which they were consulted.

Table 6. 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**
Vino Rajandran, Hort Innovation Head of Production R&D	RD&E process owner / manager	✓	✓	✓	✓	✓	✓	✓
Elizabeth Aitken, UQ	RD&E practitioner (BA17006)	✓	✓	✓	✓	✓	✓	✓
Stewart Lindsay, QDAF	RD&E practitioner (BA16001)				✓	✓	✓	✓
Jeff Daniells, (QDAF)	RD&E practitioner (BA21002)				✓	✓	✓	✓
James Dale, Queensland (QUT)	RD&E practitioner (AS20000)				✓	✓	✓	✓

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).
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

ABGC Australian Banana Growers Council

BMGF The Bill and Melinda Gates Foundation

Calcutta 4 wild diploid banana line with known Foc TR4 resistance

CIRAD The French Agricultural Research Centre for International Development

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

Embrapa The Brazilian Agricultural Research Corporation

EPAGRI The Brazilian Agricultural Research and Rural Extension Company of Santa Catarina

FHIA Honduran Foundation for Agricultural Research

Foc *Fusarium oxysporum f*. sp. *Cubense* (Fusarium Wilt or Panama Disease)

IITA The International Institute for Tropical Agriculture

PJB Pisang Jari Buaya (wild diploid banana line with known Foc TR4 resistance)

QDAF The department of Agriculture and Fisheries, Queensland

Race 1 Fusarium Wilt Subtropical Race 1

RD&E Research, Development and Extension

SH3362 banana line from with known Foc TR4 resistance

SIP Strategic Investment Plan

SR4 Fusarium Wilt Sub-tropical Race 4

TBRI Taiwan Banana Research Institute

TR4 Fusarium Wilt Tropical Race 4

UQ The University of Queensland

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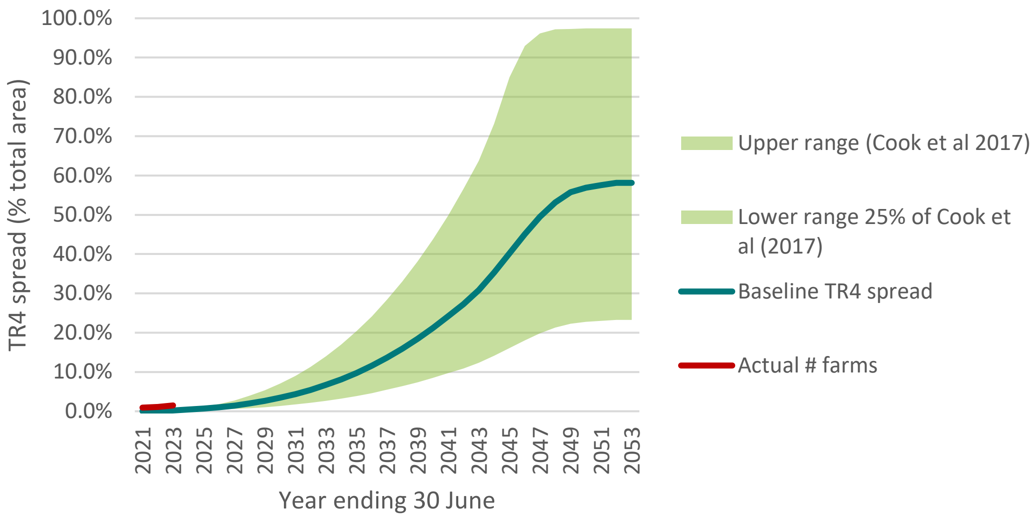
Appendix A Projected spread of *Fusarium oxysporum f*. sp. *cubense (Foc)* Tropical Race 4 (TR4) in Australia

Williams cavendish make up around 97% of Australian industry banana production (Hort Innovation 2023a). This presents a vulnerability for the industry in relation to disease threats, particularly relating to the globally significant disease *Fusarium oxysporum f*. sp. *cubense (Foc)* Tropical Race 4 (TR4) to which Williams Cavendish is highly susceptible. TR4 has been established (and contained) in the Northern Territory since 1997. In 2015, TR4 was discovered on a Queensland farm in 2015, and has since spread to a total of eight QLD farms as of July 2023. Cook et al (2017) estimated the potential rate of spread of TR4 at approximately 97% of production area within 30 years. Given the significance of this assumption relating to the benefit of TR4 resistant varieties, and the ongoing work being undertaken to contain TR4 and mitigate the likelihood of further spread, a lower spread rate at 25% of that estimated in Cook et al (2017) was included in this analysis as a lower range, with an average of the two used in the baseline (Figure 5). While the number of farms with TR4 infection does not directly equate to the % of industry area, this data is also included for comparison of the rate of change.

Figure 5. Projected area of TR4 spread over time used in the analysis, and actual number of infected farms.



Ends.