Industry-specific impact assessment program: Banana

Impact assessment report for project *The cause and management of crown rot of banana* (BA13011)

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Contents

Tables

Figures

Executive Summary

What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in project BA13011 titled "*The cause and management of crown rot of banana*". The project was funded by Hort Innovation over the period June 2015 to March 2018.

Methodology

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

Results/key findings

The investment in BA13011 has produced valuable knowledge about the cause and management of crown rot in bananas that is likely to have led to reduced incidence and/or severity of crown rot and rejection of export consignments. This, in turn, will contribute to increased profitability for some Australian banana producers.

Investment Criteria

Total funding from all sources for the project was $0.78 million (present value terms). The investment produced estimated total expected benefits of $4.65 million (present value terms). This produced an estimated net present value of $3.87 million, a benefit-cost ratio of 5.98 to 1, an internal rate of return (IRR) of 22.98% and a modified IRR of 9.18% over 30-years at a discount rate of 5% and a reinvestment rate of 5%.

Conclusions

A number of economic, environmental, and social impacts were identified also, but not valued as part of the current assessment. Thus, given the impacts not valued, combined with conservative assumptions made for the principal economic impacts valued, it is reasonable to conclude that the investment criteria reported may be an underestimate of the actual performance of the BA13011 investment.

Keywords

Impact assessment, cost-benefit analysis, BA13011, banana, crown rot, crown-end rot, disease management

Introduction

All research and development (R&D) and marketing levy investments undertaken by Horticulture Innovation Australia Limited (Hort Innovation) are guided and aligned to specific investment outcomes, defined through a Strategic Investment Plan (SIP). The SIP guides investment of the levy to achieve each industry's vision. The current industry SIPs apply for the financial years 2016/17 – 2020/21.

In accordance with the Organisational Evaluation Framework, Hort innovation has the obligation to evaluate the performance of its investment undertaken on behalf of industry.

This impact assessment program addresses this requirement through conducting a series of industry-specific ex-post independent impact assessments of the almond (AL), banana (BA), citrus (CT) and onion (VN) research, development and extension (RD&E) investment funds.

Twenty-nine RD&E investments (projects) were selected through a stratified, random sampling process. The industry samples were as follows:

- Nine AL projects were chosen worth $5.84 million (nominal Hort Innovation investment) from an overall population of 21 projects worth an estimated $10.78 million,
- Eight BA projects worth $3.02 million (nominal Hort Innovation investment) from an overall population of 24 projects worth approximately $16.72 million,
- Eight CT projects worth $5.40 million (nominal Hort Innovation investment) from a total population of 35 projects worth $15.78 million, and
- Four VN projects worth $2.40 million (nominal Hort Innovation investment) from an overall population of 8 projects worth $3.89 million.

The project population for each industry included projects where a final deliverable had been submitted in the five-year period from 1 July 2014 to 30 June 2019. The projects for each industry sample were chosen such that the investments represented (1) at least 10% of the total Hort Innovation RD&E investment expenditure for each industry, and (2) the SIP outcomes (proportionally) for each industry. Four projects had been randomly selected as part of a related Hort Innovation project (MT18011) and were included in the samples for the AL industry (AL14006 and AL16004) and the CT industry (CT15006 and CT15013). This left 25 unique projects randomly selected for evaluation under MT19012.

Project BA13011: *The cause and management of crown rot of banana* was randomly selected as one of the 25 unique MT19012 investments and was analysed in this report.

General Method

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

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

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

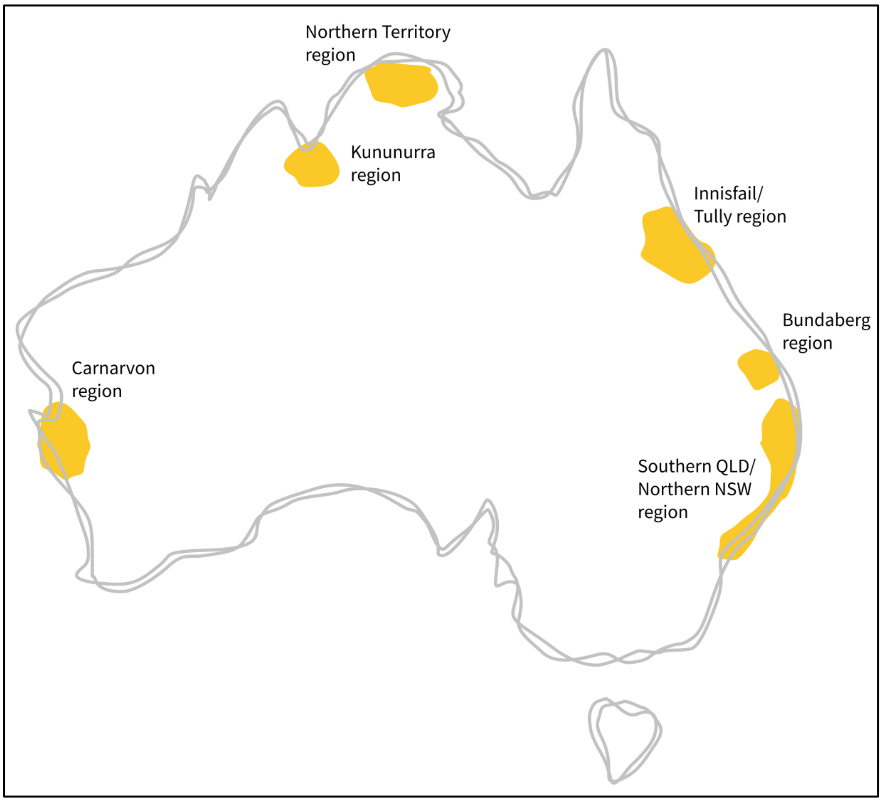
Background & Rationale

Background

The Australian Banana Industry

Bananas have been grown in Australia since the 1880s. Today, bananas are grown in subtropical and tropical regions including in Queensland (Qld), northern New South Wales (NSW), the Northern Territory (NT) and Western Australia (WA) (Hort Innovation, 2020). On average, Qld accounts for approximately 90% of the total area of bananas grown and over 95% of total Australian production (10-year average[1]). Figure 1 shows Australia's banana growing regions and Table 1 provides a summary of the data for production of bananas for both Australia and Qld.

Figure 1: Australia's Banana Growing Regions



Source: https://australianbananas.com.au/Pages/all-about-bananas/the-banana-story

[1] Based on area data from the Australian Bureau of Statistics (ABS), series 7121.0 *Agricultural Commodities, Australia* 2009/10 to 2018/19 and production data from the Australian Banana Growers' Council (ABGC)

Table 1: Production Statistics for the Australian and Qld Banana Industry (year ended 30 June 2010 to 2019)

Australia											
Year ended 30 June	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**10yr Avg.**
Total area (ha)	12,497	13,296	15,484	15,348	12,879	11,788	16,612	14,021	12,477	11,902	13,630
Area (bearing age) (ha)	11,543	11,196	13,496	14,218	12,085	10,936	15,610	13,274	11,551	10,962	12,487
Production[(a)] (t)	309,505	330,980	202,423	339,922	370,176	370,989	395,878	413,660	388,265	371,915	349,371
Yield (t/ha)	26.8	29.6	15.0	23.9	30.6	33.9	25.4	31.2	33.6	33.9	28.0
Gross value ($m)	488.1	316.0	466.8	490.7	341.3	455.0	409.0	538.5	487.6	490.9	448.4
QLD											
Year ended 30 June	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**10yr Avg.**
Total area (ha)	10,869	11,480	13,576	13,886	11,356	10,101	15,794	13,182	11,502	10,829	12,258
Area (bearing age) (ha)	10,083	9,727	11,810	12,986	10,726	9,446	14,933	12,597	10,693	10,030	11,303
Production[(b)] (t)	270,358	287,553	177,135	310,468	328,548	320,442	378,709	392,562	359,425	340,294	316,549
Yield (t/ha)	26.8	29.6	15.0	23.9	30.6	33.9	25.4	31.2	33.6	33.9	28.0
Gross value ($m)	448.3	283.1	415.4	456.5	322.8	440.8	401.2	525.8	472.0	468.3	423.4

Source: ABS Series 7121.0 *Agricultural Commodities, Australia* (2009/10 to 2018/19) and ABS Series 7503.0 *Value of Agricultural Commodities Produced, Australia* (2009/10 to 2018/19)

(a) Production data from the ABGC based on compulsory levies.

(b) Derived from ABS area (bearing age plants) and the Australian average yield for each year.

Crown rot

Crown rot is a postharvest disease which affects bananas in all banana-producing countries. A wide range of organisms are involved in crown rot of bananas but Colletotrichum musae is frequently considered as the most commonly isolated fungus and the most pathogenic one in international literature (Kathy Grice, pers. comm., 2020). The disease usually goes undetected when the fruits are packed for transportation from tropical countries with disease symptoms occurring during shipment, ripening, and storage. The disease, characterized by rot and necrosis, affects tissues joining the fingers with each other, called the crown (Lassois & de Bellaire, 2014).

Major losses generally occur during shipping of bananas to their final market, mainly because of early ripening during shipping (bananas should reach ripening rooms unripe), appearance defects, and storage decay. Such postharvest diseases negatively impact the market value of bananas, especially when they are assessed at the port of arrival or in ripening facilities (Lassois, Jijakli, Chillet, & de Bellaire, 2010).

Rationale

Summer growing conditions in the wet tropics of far north Queensland (FNQ) are associated with a range of pest and disease issues. One such disease is crown rot of banana and managing the disease is largely dependent on in-field crop hygiene, shed sanitation, and the use of registered postharvest fungicides.

In the summer of 2012, the incidence of consignments of crown rot affected fruit received at southern markets was particularly high. Growers believed that none of the existing postharvest fungicides were effectively controlling crown rot of bananas. BA13011: *The cause and management of crown rot of banana* was funded to ascertain the cause of the increase in crown rot incidence.

Project Details

Summary

Project Code: BA13011

Title: *The cause and management of crown rot of banana*

Research Organisation: The Department of Agriculture and Fisheries Qld (DAF)

Principal Investigator: Peter Trevorrow

Period of Funding: June 2015 to March 2018

Objectives

The objectives of the project were to:

1. Identify fungi responsible for crown rot and determine importance in disease cycle.
2. Determine extent of fungicide resistance in the crown rot fungi.
3. Determine the impact of field, shed and supply chain practices on disease management.

Logical Framework

Table 2 briefly describes the activities, outputs, outcomes, and actual and potential impacts of project BA13011 in a logical framework.

Table 2: Logical Framework for Project BA13011

Activities	• A system improvement approach methodology underpinned the project and was used to understand and describe typical banana supply chains, identify the nature of crown rot issues within these chains, and then identify options for improvement. • The process relied heavily on cooperation and communication between the research team and collaborating supply chain businesses. • System improvement plans then were developed in conjunction with the supply chain partners that included new information from research outputs.

	• A survey of banana producers and supply chain businesses was conducted to enable to research team to better understand the nature and extent of the crown rot problem.
	• The survey was originally planned to include growers from north QLD, NSW, and WA and some of the major banana wholesalers. However, due to time constraints, NSW and WA were omitted from the survey (Kathy Grice, pers. comm., 2020).
	• The purpose of the survey was to define the crown rot problem particularly its frequency, severity, seasonality, current treatments, and the effectiveness of treatment methods.
	• In some cases, growers and wholesalers provided samples collected at the end-point markets that were sent to the diagnostic lab in Mareeba for disease assessment (Kathy Grice, pers. comm., 2020).
	• Based on information from the crown rot survey, supply chains were identified, mapped and benchmarked for practices that influenced the management and control of crown rot.
	• This process further identified the critical control points (CCPs) in the chains for control of crown rot, the current level of knowledge and management of these CCPs and potential practice changes that could be implemented to improve the control of the disease.
	• New or improved practices identified in consultation with the cooperating businesses were then trialled in the partner supply chains.
	• Replicated fruit samples were taken at key points in the packing and distribution process for the identified supply chains:
	  o at farm - after dehanding but prior to the trough/wheel wash,
	  o at farm - post trough/wheel wash, prior to postharvest treatment,
	  o at farm - after postharvest treatment prior to packing, and
	  o at distribution centre – after ripening prior to dispatch to retail.
	• Identified sample cartons were sent in a single consignment from north Qld to Melbourne as part of a commercial consignment subject to standard transport, cold chain and ripening conditions. Air temperature, fruit pulp temperature and relative humidity of the sample cartons were assessed using data loggers.
	• Fruit clusters collected from the farm were control ripened and rated for disease incidence and severity at ‘colour stage 5’ with diagnostic tissue samples taken to confirm the identity of the organisms present by plant pathology staff.
	• Clusters of fruit from the distribution centre/ripening facility were also assessed for disease incidence and severity at ‘colour stage 5’ and diagnostic tissue samples taken.
	• After the initial monitoring activity, discussions were conducted with the partner supply chain businesses to report findings and plan further assessments.
	• Due to the sporadic and season occurrence of a key crown rot organism (*Thielaviopsis musarum*), contact was then made with a broader range of supply chain businesses to coordinate the reporting of aggressive crown rot occurrences and to provide them with diagnostic sample kits so that detailed diagnostics could be performed by project plant pathology staff.
	• This process allowed for the collection of data on incidence and severity for crown rot caused by *T. musarum* and assisted the project team to identify affected producers so that investigations could be conducted into their management practices.
	• Discussions were held at six monthly intervals with the partner supply chain businesses to provide feedback on research results, discuss future activities and identify potential improvements. Changes made as a result of project outputs were recorded.
	• The purpose of monitoring for inoculum in the field was to determine if leaf trash or other components of banana plants were the primary source of inoculum under different field management practices - leaf material (ground/canopy); plant density

	(single v double rows); placement of trash (inter-row v around plants), and if this material influenced the occurrence or incidence levels of the symptoms. • Leaf samples and bunch peduncles were also collected from four properties on the wet tropical coast (FNQ) with different management strategies or varying levels of crown rot reported. • Previous research in on the identification of the causal agent of banana crown rot implicated *Musicillium theobromae* as the primary pathogen. Thus, activities were undertaken within the current project to determine if this was still the case and, if not, to conclude what the causal organisms of crown rot were. • Samples were received and/or collected from backyard grown bananas on the Atherton Tablelands, together with samples from commercial banana growing properties on the wet tropical coast region of far north QLD and northern NSW. • Samples were also obtained from markets or agents in Brisbane, Sydney, Melbourne, and Adelaide when reports of crown rot were received. • Isolations from symptomatic plant material were conducted and the most frequently recovered organisms were sent to the Qld Government's EcoScience Precinct, lodged in the DAF Herbarium, and identified by molecular sequencing where possible. • Previous research had suggested that some of the crown rot causing organisms had developed resistance to the product containing thiabendazole (Tecto®) and it was suggested that this was the result of the use of other products within the same fungicide group (benzimidazoles) that were applied to manage leaf spot disease in banana, particularly on the wet tropical coast up until the mid-1990s. • The project team investigated if a loss of sensitivity was present to the current registered fungicide actives prochloraz and thiabendazole and assessed the extent of the issue across growing regions and for different crown rot causing fungi. • Further, given concerns about resistance and occupational health and safety issues, the project team investigated whether alternative products were available to meet Australian growers' postharvest fungicide needs. • Experiments were conducted to determine if the length of time packed fruit remained in storage (e.g. held on farm, transport, or stored at market) prior to sales would influence the development and severity of crown rot. • The project also investigated whether *M. theobromae* and/or *Fusarium* spp. were, in fact, naturally occurring endophytes within the plant bunch peduncle (stalk). • The project team worked in partnership with major banana supply chain businesses and growers to extend and communicate project findings. Also, results were disseminated through industry communication channels and events such as the Australian Bananas publication, ABGC e-Newsletters, and Banana Industry Roadshows.
Outputs	• A key finding from the crown rot survey was the need to broaden the definition of 'crown rot' from the traditional scientific view to include a broader range of rots and moulds on both the crown and flower remnants in line with the product specification reporting used by the banana market and supermarket chains (Kathy Grice, pers. comm., 2020). • The survey of supply chain businesses revealed that, at some point, every banana supply chain had incidences of crown rot or moulds but that the severity of the problem varied between suppliers, seasons and years. • The incidence of the problem was reportedly higher in summer with lower severity, in contrast to winter where the issue was more infrequent but with a higher severity. • The results also indicated that extended time in the supply chain (residence time) between packing and retail presentation increased the incidence and severity of the disease.

	• As a result, it was reported that the problem was greater during times of significant oversupply and for market destinations further away from the major production regions, such as Melbourne, Adelaide and Perth. • It was evident during the survey that many growers were unaware of the extent of the problem in the market place. In most cases this was because it was only present at low levels and the issue was only raised in feedback if consignments were rejected or nearly rejected. However, in some cases this was also due to a lack of communication between the market agent and the grower. • Often the market place tolerated a low level of the disease without outright rejection but with a major impact on price. • Consignments from suppliers with a history of the disease were regularly being sold at significant discounts to ensure the produce moved quickly through the chain to reduce the risk of increased residence time in the chain resulting in a rejection at retail. • From the survey it was not possible to identify specific farm management practices that were successful in reducing the disease incidence or severity, although the implementation and use of postharvest fungicides was very low. • Most banana growers surveyed viewed packing facility hygiene as the primary management practice for crown end rot and hygiene and cleaning practices were often significant and extensive, particularly for the larger packing shed facilities. • Across the growers surveyed there was a consistently strong resistance to the implementation of postharvest fungicides based largely on the desire not to increase pesticide use and occupational health and safety concerns around odours and the handling of treated fruit by packers. • Growers also identified the difficulty of retro-fitting appropriate application gear to existing systems. There was a significant desire to explore alternative, non-chemical or biological control options. • From the supply chain assessment, 75 crown samples were received and were assessed visually for the presence/absence of crown rot causing organisms, with isolations carried out on some crowns to determine if the surface moulds could be recovered from the underlying tissue. • Fungi (most commonly *Musicillium theobromae* and *Fusarium* spp.) were only recovered from tissue that was typically symptomatic of crown rot with no fungi recovered from asymptomatic crown tissue. • Various other species of fungi were also recovered and stored for identification and pathogenicity testing to determine their role in the crown end rot complex. The frequency and distribution of fungi did not differ, regardless of where or when they were sampled from within the supply chain. • For the second partner supply chain assessment, two Tully banana producers were selected for supply chain assessments based on contrasting shed management systems (one with management practices in place and one without) and with contrasting reports of crown end rot issues in the marketplace. • The two shed systems were mapped to compare the different system elements. Surprisingly, the grower without management practices had reported no occurrence of crown end rot from the marketplace, whereas the grower with shed management practices reported a history of high crown end rot levels. • Tracked cartons of fruit from the farms were collected at the Melbourne markets after ripening and the data loggers retrieved. • Three fungal organisms commonly associated with crown rot (*M. theobromae, Fusarium* spp. and *Colletotrichum musae*) were recovered from the samples taken at all the sample points on the farm with no postharvest treatment while only *M. theobromae* and *Fusarium* spp. were recovered from the other farm. • Based on the assessment there were differences in the severity and incidence of the symptoms that could be attributed to the different shed management practices in place, with a greater incidence and severity of crown end rot from the farm with

	no postharvest treatment. This contrasted with the producer's own assessment of having no crown end rot issues associated with his fruit. • As a result of the ongoing supply chain reporting program implemented by the project, feedback was provided back to marketing groups based on visual identification of disease from photographs. • When the initial incidences of disease where reported to the project team representatives from the marketing group were informed of the reports and reminded about the current postharvest management strategies. • Based on the findings from the different research trials, supply chain survey and supply chain assessment and discussion with key personnel in these partner supply chains a management practice framework for crown rot of bananas was produced. • Assessment of the management options from site selection to irrigation practices through to packaging and dispatch revealed a broad range of farm management practices may have some level of incremental influence on disease management. • However, the only practice that provided management control commensurate with the expectations of the market place was the application of postharvest fungicides. • The studies undertaken have shown the presence of crown rot fungi to be pervasive in the banana growing system. However, there are incremental and additive benefits in reducing inoculum load, as opposed to promoting the fungal organisms by providing inoculum conducive conditions. • The results from the fungicide sensitivity testing concluded that there has been some shift in sensitivity in the crown rot fungal populations in relation to the use of thiabendazole. • This was more evident in isolates of *M. theobromae* collected from the wet tropical coast and was attributed to the historical use of the benzimidazole group of fungicides. • This work also highlighted that the fungicides with the active ingredient prochloraz generally have better activity against the broad spectrum of fungi associated with both crown rot and crown mould symptoms on banana. • The project also found that the longer fruit were held prior to ripening (on farm, in transport or at the distribution centre), the greater the likelihood of crown rot development on clusters. • There was no difference in the rate of symptom development or incidence between cultivars (Lady Finger or Cavendish) and the bunch position (top, middle or lower) did not appear to have an effect on the presence of crown rot. • Laboratory screening of different fungicide products identified some potential candidates for further testing. • The product 'Graduate A+' gave consistently low ratings for both crown mould and crown rot. This product had equal if not superior effects particularly on the presence of crown mould compared to the current registered products. • From pathogenicity tests, *Colletotrichum musae* was very aggressive but was very rarely found on crown tissue samples received from the markets. • There was some educational awareness of the symptoms that resulted in retailers being less concerned about surface type moulds on the fruit. • There was insufficient evidence to support that infection by crown rot fungi resulted from endophytic colonization or colonization of wound tissue. • In most cases, the evidence pointed toward contamination of crowns with air-borne inoculum of the various fungi from the point of removing hands from the peduncle and clustering at the packing shed. • The project used a range of existing and project specific extension and communication activities and channels to disseminate project outputs. • Key to the project was the regular discussion and feedback with the partner supply chain businesses that allowed the consideration of research results and identification of improved practices.

	• A key project output was also the development of an effective network with representatives from the major banana supply chain businesses that facilitated improved feedback and communication with the project team.
Outcomes	• The project was successful in achieving the objective of providing new information to growers, wholesalers and retailers to limit losses from crown end rot through the banana supply chain. • A draft management strategy was presented to industry and resulted in practice change that, in turn, delivered improved fruit quality at the market place. • Further, the use of postharvest fungicides increased by approximately 25% as a result of the project. The cost of fungicide averages $18/L with an application rate of 55mL/100L water (Kathy Grice, pers. comm., 2020). • The survey of banana producers and supply chain businesses improved understanding of the nature and extent of the crown rot problem. • The survey resulted in an improved appreciation of the perception of crown rot and other rots and moulds of banana fruit in the supply chain. • The improved understanding allowed the project to accommodate a redefinition of the problem and then design monitoring and assessment, research and communication activities to reflect the situation better. • As a result of communication and extension activities and materials there has been an improved understanding reported at the retail level of the low level of risk associated with certain rots and moulds. This has resulted in fewer outright rejections for consignments without actual rotting of the crown tissue. • One of the major outcomes of the project was the two-way relationships that have been built and maintained with key supply chain personnel in most of the major banana marketing groups. • These relationships have developed as a result of the regular reporting and interaction with the partner supply chain businesses and provided crucial insights into the commercial perception of the problem of crown rot. • This has subsequently provided the most appropriate context for planning future crown rot research and extension activities. • These relationships also have established lines of communication between businesses in the supply chain and retail sector and R&D staff that did not previously exist. • This has provided the opportunity for researchers to provide information and extension materials that incorporated R&D findings that had positive impacts on crown rot management. • For example, communication of project results and discussions via e-mail and in person at the Australian Banana Industry Congress with a technical representative from a major retail outlet resulted in an improved understanding of the different organisms that cause crown rot and the typical symptoms associated with each respective organism. • This has resulted in a major part of the retail sector having a greater confidence that surface mould symptoms which are noticeable on the crown surface only (e.g. caused by *Fusarium* spp.) are unlikely to develop into more severe symptoms that are typically caused by *T. musarum* or *Colletotrichum musae.* • The banana industry has gained a better understanding of the symptoms and causal organisms associated with crown rot and crown mould. • The pathogenicity tests confirmed that there was variability in symptom expression between the different fungal genera, as well as within the same species. • All levels of industry (growers, supply chain and supermarkets) now have an awareness that allows them to make a more considered judgement in relation to rejections of fruit, based on symptoms observed. • The potential loss of fungicides from the development of resistance was identified as a key research area impacting on management of crown rot and crown mould by

	industry. Growers using postharvest chemicals have mostly shifted toward the use of products containing prochloraz. • The project identified alternative fungicide products that warrant further investigation to confirm their effectiveness and progress registration. • Wholesalers and retailers are now more aware of the potential of crown rot or crown mould development and can take the necessary steps to reduce fruit losses through the supply chain. There is now greater recognition that improved management of fruit residence time within the supply chain leads to a reduction in rejections.
Impacts	• Increased productivity and/or profitability for some Australian banana growers (and associated supply chain businesses) from improved fruit quality (increased average value) driven by: (a) improved management practices that reduce the incidence and/or severity of crown rot (both on farm and in transport and storage), (b) reduced rejection of banana consignments through improved understanding and identification of crown rot symptoms and issues throughout the supply chain, (c) reduced fungicide resistance for postharvest treatments through improved data on existing resistance and effectiveness of available actives, and (d) enhanced relationships and communication between growers, supply chain businesses, retailers and researchers. • Potentially, increased costs of production for some growers (and associated supply chain businesses) from implementation of new and improved crown rot management practices (e.g. increased use of postharvest fungicide treatments). • Increased efficiency of resource allocation for crown rot of banana RD&E investments through identification of key information gaps and priority areas for further research. • Potentially, some negative environmental outcomes from increased fungicide use that increases agricultural chemical export off-farm. • Increased scientific knowledge and research capacity. • Potentially, improved regional community wellbeing through spillover benefits from a more productive and profitable Australian banana industry.

Project Investment

Nominal Investment

Table 3 shows the annual investment (cash and in-kind) in project BA13011 by Hort Innovation and DAF.

Table 3: Annual Investment in the Project BA13011 (nominal $)

Year ended 30 June	Hort Innovation ($)	DAF ($)	Total ($)
2015	36,663	130,165	166,828
2016	46,238	164,160	210,398
2017	15,309	54,352	69,661
2018	27,760	98,557	126,317
Totals	125,970	447,234	573,204

Source: derived from BA13011 Project Agreement and Variation documents supplied by Hort Innovation 2020

Program Management Costs

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

For the DAF investment, it was assumed that management and administration costs were already included in the cost data shown in Table 3.

Real Investment and Extension Costs

For the purposes of the investment analysis, investment costs of all parties were expressed in 2019/20 dollar terms using the Gross Domestic Product deflator index (ABS, 2020). No additional costs associated with project extension were incorporated as the project dedicated significant resources to communication and extension activities and included a high level engagement with producers and other banana supply chain businesses.

Impacts

Table 4 provides a summary of the principal types of impacts delivered by the project. Impacts have been categorised into economic, environmental and social impacts.

Table 4: Triple Bottom Line Categories of Principal Impacts from Project BA13011

Economic	• Increased productivity and/or profitability for some Australian banana growers (and associated supply chain businesses) from improved fruit quality (increased average value) driven by: (a) improved management practices that reduce the incidence and/or severity of crown rot (both on farm and in transport and storage), (b) reduced rejection of banana consignments through improved understanding and identification of crown rot symptoms and issues throughout the supply chain, (c) reduced fungicide resistance for postharvest treatments through improved data on existing resistance and effectiveness of available actives, and (d) enhanced relationships and communication between growers, supply chain businesses, retailers and researchers. • Potentially, increased costs of production for some growers (and associated supply chain businesses) from implementation of new and improved crown rot management practices (e.g. increased use of postharvest fungicide treatments). • Increased efficiency of resource allocation of banana RD&E investments through identification of key information gaps and priority areas for further research for crown rot.
Environmental	• Potentially, some negative environmental outcomes from increased fungicide use that increases agricultural chemical export off-farm.
Social	• Increased scientific knowledge and research capacity. • Potentially, improved regional community wellbeing through spillover benefits from a more productive and profitable Australian banana industry.

Public versus Private Impacts

The impacts identified in this evaluation are largely private. Private benefits are likely to be realised by banana growers and associated supply chain businesses through reduced consignment rejection rates and increased average fruit quality.

Some public benefits also may occur and include increased efficiency of public resource allocation for crown rot RD&E, increased scientific knowledge and capacity, and, potentially, enhanced regional community wellbeing. However, there is also potential for some negative public impacts through the increased application of postharvest fungicides.

Distribution of Private Impacts

The impacts on the Australian banana industry from investment in project BA13011 will initially be captured by banana growers/exporters. However, benefits will be shared along banana supply chains according to relevant short- and long-term supply and demand elasticities.

Impacts on Other Australian Industries

No direct or significant impacts to other Australian industries were identified.

Impacts Overseas

No direct impacts to overseas parties were identified. However, knowledge sharing may result in positive impacts for overseas banana industries, for example, through improved identification of the pathogens that cause crown rot in wet tropical conditions.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 5. The project findings and related impacts will contribute to Rural RD&E Priorities 4, and to Science and Research Priority 1.

Table 5: Australian Government Research Priorities

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

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

Alignment with the Banana Strategic Investment Plan 2017-2021

The strategic outcomes and strategies of the banana industry are outlined in the Banana Strategic Investment Plan 2017-2021[2] (2017). Project BA13011 primarily addressed Outcome 1 (Strategy 1.3 and, to some extent, 1.5) and contributed to Outcome 4 (Strategy 4.1).

Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Two economic impacts were valued. First was increased profitability for some Australian banana growers attributable to the investment in BA13011. Second was increased efficiency of resource allocation for banana crown rot RD&E.

Impacts Not Valued

Not all of the impacts identified in Table 4 could be valued in the assessment. In particular, environmental and social impacts were hard to value due to a lack of evidence/data on which to base credible assumptions, difficulty in quantifying the causal relationship and the pathway between BA13011 and the impact and/or the complexity of

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

assigning magnitudes and monetary values to the impact.

The economic impact identified but not valued was:

- Potentially, increased costs of production for some growers (and associated supply chain businesses) from implementation of new and improved crown rot management practices (e.g. increased use of postharvest fungicide treatments).

Though not valued as a specific, separate impact, the potential additional costs associated with the implementation of new crown rot management strategies in Australian banana plantations (e.g. fungicide use) were considered as an adoption cost in the valuation of the first economic impact noted above.

The environmental impact identified but not valued were:

- Potentially, some negative environmental outcomes from increased fungicide use that increases agricultural chemical export off-farm.

The social impacts identified but not valued were:

- Increased scientific knowledge and research capacity.
- Potentially, improved regional community wellbeing through spillover benefits from a more productive and profitable Australian banana industry.

Valuation of Impact 1: Increased profitability for some Australian banana growers

The investment in BA13011 is likely to have resulted in improved profitability for some Australian banana growers driven by:

a) Improved management practices that reduce the incidence and/or severity of crown rot (both on farm and in transport and storage) thereby improving average fruit quality,
b) Reduced rejection of banana consignments through improved understanding and identification of crown rot symptoms and issues throughout the supply chain,
c) Reduced fungicide resistance for postharvest treatments through improved data on existing resistance and effectiveness of available actives, and
d) Enhanced relationships and communication between growers, supply chain businesses, retailers and researchers.

Data on changes in consignment rejection rates and discounted prices associated with crown rot incidence were not specifically collected during the project (Kathy Grice, pers. comm., 2020). Much of the evidence was anecdotal and noted in communications between researchers, growers and supply chain partners. It was therefore necessary to make several uncertain assumptions for the valuation of Impact 1.

The valuation of Impact 1 centred on the assumption that the investment in BA13011 has contributed to increased average net returns for a proportion of the Australian banana industry. Specific assumptions for the valuation of Impact 1 are described in Table 6.

Counterfactual

Crown rot is a postharvest disease that affects bananas in all banana-producing countries and major losses generally occur during shipping because of early ripening, appearance defects, and storage decay. This negatively impacts the market value of bananas, especially when they are assessed at the port of arrival or in ripening facilities (Lassois, Jijakli, Chillet, & de Bellaire, 2010). Given the significance of potential economic losses to the Australian banana industry, it was assumed that, without investment in BA13011, some investment associated with management of crow rot would have taken place (e.g. through state department and industry RD&E investments such as DAF QLD and ABGC). However, it is likely that the level of investment would have been significantly less, and the resulting RD&E may have been less efficient and/or effective. Thus, it was assumed that 80% of Impact 1 was driven specifically by the BA13011 investment.

Attribution

Pest and disease management has been, and continues to be, a complex and multifaceted area for banana RD&E. It was considered likely that BA13011 was not the only investment contributing RD&E outputs to disease management issues such as in-field crop hygiene, shed sanitation, and the use of fungicide. Thus, an attribution factor of 25% was applied to the net benefits to estimate the impact of the investment in BA13011; this recognises the contribution of other investments.

Valuation of Impact 2: Increased efficiency of resource allocation for banana RD&E investments

The investment in BA13011 is likely to have contributed to the identification of key gaps in crown rot and banana disease management RD&E and prioritisation for areas of future investment. Consequently, it was assumed that BA13011 was likely to have marginally improved Hort Innovation's investment prioritisation, selection and management for R&D investments associated with banana disease management, and therefore contributed to increased efficiency of RD&E resource allocation.

Hort Innovation's total, average annual investment in banana RD&E was estimated to be $3.65 million (3-year average) (Hort Innovation, Annual Report, 2018 to 2020). It was assumed that 20% of the average annual RD&E investment was associated with disease management and that the investment in BA13011 contributed to a 2.0% efficiency dividend for the period 2018/19 to 2022/23.

Specific assumptions for the valuation of Impact 2 are described in Table 6.

Attribution

Based on conservative assumptions made, it was assumed that 100% of the estimated benefits were attributable to the investment in BA13011.

Counterfactual

It was assumed that, without the BA13011 investment, the benefits estimated would not have occurred.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	Assumption	Source/Comment
Key Baseline Data		
Total average Australian banana production area (bearing age)	12,487 ha	10-year average derived from ABS Series 7121.0 *Agricultural Commodities, Australia* (2009/10 to 2018/19) (see Table 1)
Total average Australian banana production	349,371 t	10-year average, derived from ABGC production statistics based on the compulsory industry levy (see Table 1)
Average yield (derived)	28.0 t/ha	349,371 t / 12,487 bearing ha
Estimated average net return to growers	$22.00 / 15kg carton	Analyst estimated based on the average net return to grower after marketing and ripening costs reported in the Banana Enterprise Comparison Report 2016/17 (Appendix 1) (Pinnacle Agribusiness, 2018)
Impacts 1: Increase profitability for some Australian banana growers		
Valuation Assumptions		
First year of impact	2018/19	Year after last year of investment in BA13011
Year of maximum impact	2022/23	Five years after first year of impact
Proportion of total Australian banana production area achieving increased net returns through improved crow rot management	25%	Analyst assumption – based on approximately one third of growers in FNQ (which represents approximately 80% of Australian production)
Increase in net return to	2.5%	Analyst estimate – conservative

applicable growers		estimated based on maximum average net returns of approximately $25/15kg carton for the top 10 industry performers in the 2016/17 Banana Enterprise Comparison Report (Pinnacle Agribusiness, 2018)
Risk Factors and Other Variables		
Probability of output	100%	Analyst assumption, based on successful completion of BA13011
Probability of outcome	60%	Analyst assumption – refers to the probability that the adoption rate assumed above is realised
Probability of impact	80%	Analyst assumption, allows for exogenous factors that may affect realisation of impact
Attribution of benefits to investment in BA13011	25%	See 'valuation of impact 1' above.
Counterfactual	80%	See 'valuation of impact 1' above
Impact 4: Increased efficiency of resource allocation for banana RD&E		
Valuation Assumptions		
Total average annual investment in banana RD&E by Hort Innovation	$3.65 million	Three-year average, Hort Innovation Annual Report 2018 to 2020
Proportion of average annual investment directed to disease management RD&E	25%	Analyst assumption
Efficiency dividend due to improved prioritisation, selection and management for R&D investments	2.0%	Analyst assumption
First year of impact	2018/19	Year after last year of investment in BA13011
Period of efficiency dividend	5 years (to 2022/23)	Analyst assumption
Risk Factors and Other Variables		
Probability of output	100%	Analyst assumption, based on successful completion of BA14012
Probability of outcome	80%	Analyst assumption – refers to the probability that the outputs of project BA14012 will be adopted to improve RD&E resource allocation
Probability of impact	80%	Analyst assumption, allows for exogenous factors that may affect realisation of impact
Attribution of benefits to investment in BA13011	100%	See 'valuation of impact 2' above.

Results

All costs and benefits were discounted to 2019/20 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the modified internal rate of return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the project investment period plus 30 years from the last year of investment (2017/18) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

Table 7 shows the investment criteria estimated for different periods of benefit for the total investment. Table 8 shows the investment criteria estimated for different periods for the Hort Innovation investment only. The present value of benefits (PVB) for Hort Innovation was estimated by multiplying the total PVB by the proportion of Hort Innovation investment in project BA13011 (24.7%).

Table 7: Investment Criteria for Total Investment in Project BA13011

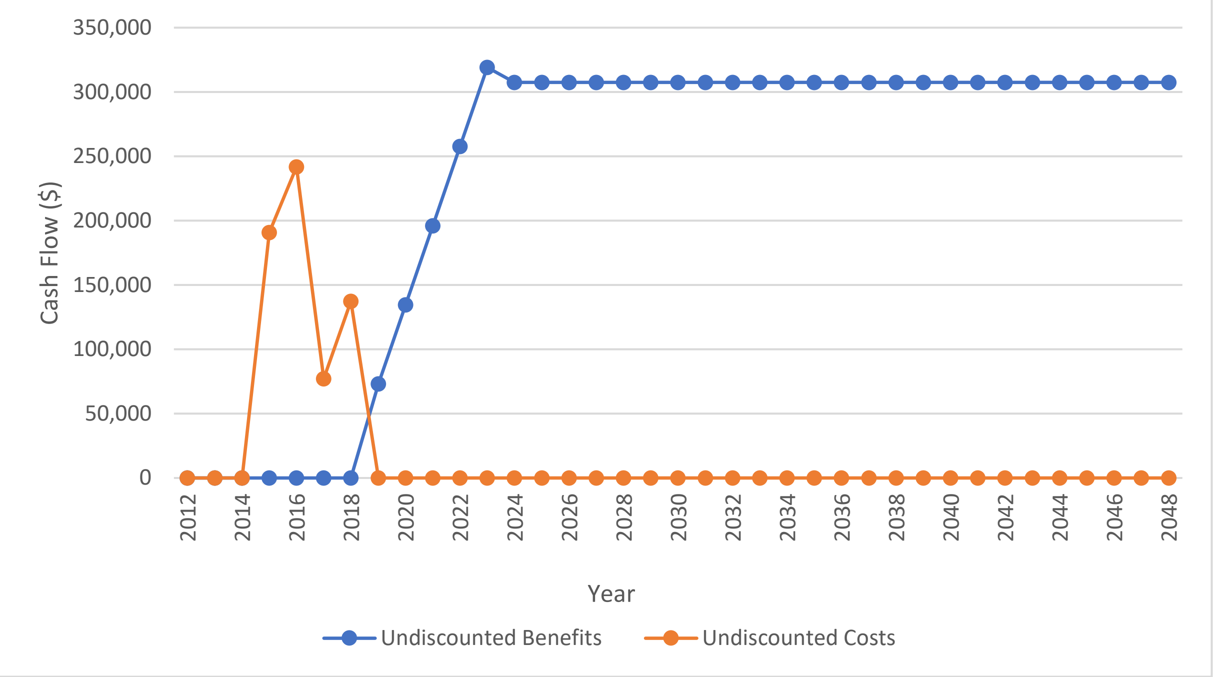
Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	0.00	0.91	2.06	2.96	3.66	4.22	4.65
Present Value of Costs ($m)	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Net Present Value ($m)	-0.78	0.13	1.28	2.18	2.89	3.44	3.87
Benefit-Cost Ratio	0.00	1.17	2.64	3.80	4.71	5.42	5.98
Internal Rate of Return (%)	negative	8.09	19.66	22.01	22.69	22.91	22.98
MIRR (%)	negative	9.79	16.52	13.97	11.54	10.34	9.18

Table 8: Investment Criteria for Hort Innovation Investment in Project BA13011

Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	0.00	0.22	0.51	0.73	0.90	1.04	1.15
Present Value of Costs ($m)	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Net Present Value ($m)	-0.19	0.03	0.32	0.54	0.71	0.85	0.95
Benefit-Cost Ratio	0.00	1.17	2.64	3.80	4.71	5.42	5.98
Internal Rate of Return (%)	negative	8.09	19.63	22.01	22.65	22.91	22.98
MIRR (%)	negative	9.79	16.52	13.97	11.54	10.34	9.18

The annual undiscounted benefit and cost cash flows for the total investment for the duration of BA13011 investment plus 30 years from the last year of investment are shown in Figure 2.

Figure 2: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Contribution of Benefits

Table 9 shows the contribution of each impact to the total Present Value of Benefits (PVB).

Table 9: Contribution to Benefits by Source

Impact	**PVB ($m)**	**% of Total PVB**
Impact 1: Increased profitability	4.60	98.8
Impact 2: Increased efficiency of RD&E	0.06	1.2
Total	4.65	100.0

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 10 present the results. The results were moderately to highly sensitive to the discount rate. This was largely because the benefits occur into the long-term future and future cash flows are subjected to more significant relative discounting.

Table 10: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present Value of Benefits ($m)	8.67	4.65	2.94
Present Value of Costs ($m)	0.65	0.78	0.93
Net Present Value ($m)	8.02	3.87	2.01
Benefit-cost ratio	13.39	5.98	3.16

A sensitivity analysis was then undertaken for the assumed increase in net grower returns for Impact 1. The results are presented in Table 11 and show a moderate sensitivity to the assumed increase. This was expected as the assumed increase in net grower returns was a key driver of the valuation of Impact 1.

Table 11: Sensitivity to Increase in Net Grower Returns
(Total investment, 30 years)

Investment Criteria	**Increase in Net Grower Returns**		
	0.5%	**2.5% (base)**	**5.0%**
Present Value of Benefits ($m)	0.97	4.65	9.25
Present Value of Costs ($m)	0.78	0.78	0.78
Net Present Value ($m)	0.20	3.87	8.47
Benefit-cost ratio	1.25	5.98	11.88

Finally, a sensitivity analysis was undertaken for assumed proportion of the banana production area that would implement practice change and therefore receive the benefits of increased net returns. The results are presented in Table 12 and show a moderate sensitivity to the assumed proportion of the banana area affected. A break-even analysis indicated that, with all other variables at their base values, investment criteria remain positive with a proportion of the banana production area affected of approximately 4%.

Table 12: Sensitivity to Proportion of Banana Production Area Affected
(Total investment, 30 years)

Investment Criteria	**Proportion of Banana Area**		
	5%	**25% (base)**	**40%**
Present Value of Benefits ($m)	0.97	4.65	7.41
Present Value of Costs ($m)	0.78	0.78	0.78
Net Present Value ($m)	0.20	3.87	6.63
Benefit-cost ratio	1.25	5.98	9.52

Confidence Rating

The results produced are highly dependent on the assumptions made, some of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 13). The rating categories used are High, Medium and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 13: Confidence in Analysis of Project

Coverage of Benefits	**Confidence in Assumptions**
Medium-High	Medium-Low

Coverage of benefits was assessed as Medium-High – two primary economic impacts were valued; however, several other economic, environmental, and social benefits identified were not able to be valued within the scope of the current assessment. Such benefits were considered secondary benefits and were likely small relative to the primary impacts valued.

Confidence in assumptions was rated as Medium-Low. Baseline data used in the analysis were drawn from published and/or credible sources such as Hort Innovation, published scientific journal articles and the ABGC. However, key impact data (such as data on changes in consignment rejection rates and discounted prices associated with crown rot incidence) were not specifically collected during project BA13011, it was therefore necessary to make several uncertain assumptions about the level of adoption over time, the counterfactual and the magnitude of the likely change.

Conclusion

The investment in BA13011 has produced valuable knowledge about the cause and management of crown rot in bananas that is likely to have led to reduced incidence and/or severity of crown rot and rejection of export consignments. This, in turn, will contribute to increased profitability for some Australian banana producers.

Total funding from all sources for the project was $0.78 million (present value terms). The investment produced estimated total expected benefits of $4.65 million (present value terms). This produced an estimated net present value of $3.87 million, a benefit-cost ratio of 5.98 to 1, an internal rate of return (IRR) of 22.98% and a modified IRR of 9.18% over 30-years at a discount rate of 5% and a reinvestment rate of 5%.

A number of economic, environmental, and social impacts were also identified but not valued as part of the current assessment. Thus, given the impacts not valued, combined with conservative assumptions made for the principal economic impacts valued, it is reasonable to conclude that the investment criteria reported may be an underestimate of the actual performance of the BA13011 investment.

Glossary of Economic Terms

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

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Abbreviations

AL	Almond
ABS	Australian Bureau of Statistics
BA	Banana
CCP	Critical Control Point
CT	Citrus
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (QLD)
FNQ	Far North Queensland
Hort Innovation	Horticulture Innovation Australia Ltd
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NSW	New South Wales
NT	Northern Territory
VN	Onion
PVB	Present Value of Benefits
QLD	Queensland
R&D	Research and Development
RDC	Research and Development Corporation
RD&E	Research, Development and Extension
SIP	Strategic Investment Plan
WA	Western Australia