Hort Innovation

Final Report

Improved plant protection in the banana industry

Project leader:

Mr Stewart Lindsay

Delivery partner:

Department of Agriculture and Fisheries, Queensland

Project code:

BA16001

Project:

Improved plant protection in the banana industry (BA16001)

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using the banana research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978-0-7341-4803-2

Published and distributed by: Hort Innovation

Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

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Public summary

The tropical and subtropical banana growing regions in Australia provide environmental conditions favourable for the development of a wide range of pest and disease problems. As a result, cost effective and sustainable pest and disease control practices producing fruit meeting the commercial market specifications remains a significant challenge and cost for the Australian banana industry. Research and development activities can help address these pest and disease issues through development of new integrated management practices and accessing and screening new disease resistant varieties. This project combined diverse research and development work into a program approach to undertake activities addressing these high priority issues.

A major priority was identification of banana varieties with adequate Fusarium wilt TR4 and Race 1 resistance. The project did this with varietal screening trials in north Queensland, the Northern Territory and NSW. Relationships between project staff and international banana breeding agencies in Taiwan, Brazil and France facilitated access to new banana germplasm. New banana selections were also available from a previous industry project using a novel breeding approach to improve agronomic characteristics or consumer acceptability in resistant varieties. Banana varieties identified in field trials with disease resistance and promising agronomic performance were advanced to assessment under commercial production practices in a network of on-farm field trials across the main Australian production regions.

Safe importation of new banana varieties was conducted through post-entry quarantine tissue culture and glasshouse facilities established to specifically facilitate importation of banana germplasm. These facilities allow for detailed screening against viral and phytoplasma diseases by experienced project staff.

Integrated pest and disease management activities were focused on key priorities confirmed through industry consultation. Softer chemical and biological control options were major research priorities for bunch pests, pest mites, leaf disease and nematodes. Field and glasshouse trials were undertaken to investigate these aspects to improve management practices and options for industry.

To manage a large, diverse and geographically spread work program across multiple agencies, the project leadership team had a special focus on maintaining regular and open communication and networking activities to build a more cohesive and collaborative banana research and development network. To achieve this the project undertook specific networking and team building activities to improve networking and collaboration between Australian banana research and development providers.

The project has been responsible for safely importing 23 new banana varieties into Australia, screening 44 varieties for TR4 resistance, 7 varieties for Race 1 resistance and 32 varieties for their agronomic performance. The project identified 14 varieties with adequate TR4 resistance and 1 Lady Finger hybrid with resistance to Race 1. The 3 Cavendish lines and the resistant Lady Finger hybrid have been progressed to field trials on commercial farms to assess their potential. New IPDM practices for management of pest nematodes, pest mites, leaf spot, bunch pests and bacterial corm rot have been developed, with demonstration of some practices now under way with commercial banana producers.

Updates and results from project activities has been regularly provided to the banana industry through written articles in the *Australian Bananas* magazine, at industry extension activities and on-line at the Better Bananas website - www.betterbananas.com.au .

Technical summary

The tropical and subtropical banana growing regions in Australia provide environmental conditions favourable for the development of a wide range of pest and disease problems. As a result, cost effective and sustainable pest and disease control practices producing fruit meeting the commercial market specifications remains a significant challenge and cost for the Australian banana industry.

Research and development activities can help address these pest and disease issues through development of new integrated management practices and accessing and screening new disease resistant varieties. This project combined diverse research and development work into a program approach to undertake activities addressing these high priority issues.

A major priority was identification of banana varieties with adequate Fusarium wilt TR4 and Race 1 resistance to assist the industry to manage the incursion of Fusarium wilt TR4 in NQ in 2015, and the on-going spread of Fusarium wilt R1 in the tropics and subtropics. To do this the project incorporated and refined approaches used by the previous banana plant

protection program (BA10020). Fusarium wilt varietal field screening trials were again conducted with inoculated sites in NT (TR4) and NSW (R1), while agronomic assessments and leaf disease resistance screening were conducted in coastal NQ. Identification of suitable banana germplasm was refined in BA16001 based on the BA14013 strategic review of global banana breeding efforts and consultation with the Banana Variety Subcommittee of the Project Reference Group, leading to a focus on commercially acceptable varieties known to the Australian market. Existing professional and institutional relationships between key DAF project staff and international banana breeding agencies in Taiwan, Brazil and France facilitated access to new banana germplasm. Additionally, new banana selections were also available from the outputs of the BA14014 mutagenesis program to improve agronomic characteristics or consumer acceptability in TR4 resistant Cavendish and Goldfinger. Banana varieties identified in field trials with disease resistance and promising agronomic performance were advanced to assessment under commercial production practices in a network of on-farm field trials across the main production regions.

Safe importation of new banana varieties was conducted through special post-entry quarantine tissue culture and glasshouse facilities that allowed for detailed screening against viral and phytoplasma diseases by experienced project staff.

Integrated pest and disease management activities were focused on key industry priorities confirmed through industry workshops and from the industry Strategic Agrichemical Review Process. Softer chemical and biological control options were major research priorities for bunch pests, pest mites, leaf disease and nematodes. Field and glasshouse trials were undertaken to investigate these aspects to improve management practices and options for industry.

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Updates and results from project activities has been regularly provided to the banana industry through written articles in the *Australian Bananas* magazine, at industry extension activities and on-line at the Better Bananas website - www.betterbananas.com.au . A summary of the information and communication outputs from the project is:

Growers/industry audience

- 53 Roadshow presentations (218 participants)
- 9 Seminar/meeting presentations (115 participants)
- 8 Industry workshops (127 participants)
- 11 Field walks (231 participants)
- 36 *Australian Bananas* magazine articles (1200 recipients)
- 24 Conference presentations/posters (843 participants)
- 3 Radio interviews (unknown)

Scientific community audience

- 3 peer reviewed papers (unknown)
- 3 Conference papers (unknown)
- 16 Conference presentations/posters (2110 participants)
- 14 Workshop/seminar presentations (217 participants)

Keywords

Banana; IPDM; disease resistance screening; agronomic assessment; germplasm; yellow Sigatoka; bunch pests; nematodes; viruses; scientific networking

Introduction

Cost effective and sustainable pest and disease control producing fruit that meets strict market specifications remains a significant challenge and cost for the Australian banana industry. The tropical and subtropical banana growing regions in Australia provide environmental conditions favourable for the development of a wide range of pest and disease problems. Foliar diseases such as yellow Sigatoka, foliar pests such as spider mites, systemic viral diseases like Banana Bunchy Top Disease, the pest complex of caterpillars and thrips that constitute bunch pests and root and corm pests and diseases such as plant parasitic nematodes, banana weevil borer and Fusarium wilt disease of bananas are all examples of current pest and disease issues confronting the Australian banana industry.

These issues are significant for the Australian banana industry because a lack of effective control for these pests and diseases can have serious and significant implications for producers, from significant production and financial losses for uncontrolled nematode, leaf disease and bunch pests to the existential threat to banana production posed by banana Fusarium wilt Tropical Race 4 (TR4) for which there are no current control practices. The lack of effective management options can stem from a lack of genetic resistance (Fusarium wilt, BBTD), loss of effective chemical treatments due to resistance development and deregistration, or knowledge gaps in cultural and biological control options.

Research and development activities can help address these pest and disease issues by improving management practice options and cost effectiveness through development of new integrated management practices and accessing, screening and identifying new disease resistant varieties. This project combined significant but diverse research and development focus areas into a program approach to undertake activities to address these high priority issues. A major priority was the identification of commercially suitable varieties with adequate genetic resistance to Fusarium wilt TR4 and Race 1 to assist the industry to manage the incursion of Fusarium wilt TR4 in NQ in 2015, and the on-going spread of Fusarium wilt R1 in the tropics and subtropics.

To do this the project incorporated and refined approaches used by the previous banana plant protection program (BA10020). Fusarium wilt varietal field screening trials were again conducted using methodologies developed in BA10020 with inoculated sites in NT (TR4) and NSW (R1), while agronomic assessments and leaf disease resistance screening were conducted in coastal NQ. Identification of suitable banana germplasm was refined in BA16001, based on a strategic review of global banana breeding efforts produced by the project BA14013 and consultation with the Banana Variety Subcommittee of the Project Reference Group leading to a focus on key commercially acceptable varieties known to the Australian market. Existing professional and institutional relationships between key DAF project staff and international banana breeding agencies in Taiwan and France facilitated access to new banana germplasm. Additionally, new banana germplasm was also available when the project assumed the on-going assessment of new variants of TR4 resistant Cavendish and Goldfinger developed within the project BA14014 using a novel mutagenesis approach to improve agronomic characteristics or consumer acceptability. Banana varieties identified in field trials with disease resistance and promising agronomic performance were advanced to assessment under commercial production practices in a network of on-farm field trials across the main production regions.

Safe importation of new banana varieties was conducted through accredited post-entry quarantine tissue culture and glasshouse facilities managed by experienced DAF personnel that allowed for detailed screening against viral and phytoplasma diseases.

Integrated pest and disease management activities were focused on key industry priorities confirmed through industry workshops and from the industry Strategic Agrichemical Review Process. Softer chemical and biological control options were major research priorities for bunch pests, pest mites, leaf disease and nematodes. Field and glasshouse trials were undertaken to investigate these aspects to improve management practices and options for industry.

In managing such a large and diverse work program geographically spread across Australia in multiple agencies the project leadership team had a special focus on maintaining regular and open communication and networking activities to build a more cohesive and collaborative banana RD&E network. To achieve this the project undertook specific networking and team building activities, including quarterly project team videoconferences and biennial symposia to improve networking and collaboration between Australian banana RD&E providers.

This project directly addressed Outcome 1 of the banana Strategic Investment Plan: Industry supply, productivity and sustainability: Australian banana industry has increased profitability, efficiency and sustainability through innovative R&D, sustainable BMP's and varieties

- Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining

or enhancing consumer and product quality attributes

- Strategy 4 – Develop and optimize fit-for-purpose pest and disease management strategies.

Methodology

Project structure and governance

Similar to the previous banana plant protection program (BA10020) this project combined significant but diverse research and development work areas into a program approach to undertake activities addressing high priority pest and disease management issues. There were 4 major research areas structured as project theme activities, each led by a theme leader with responsibility to manage and coordinate research work programs and reporting for that theme. Theme leaders in BA16001 were all senior DAF project staff with significant experience in their respective theme areas. The project theme structure and leadership was:

- Theme 1 – Sourcing and screening banana varieties for disease resistance and agronomic performance (Theme leader – Mr Jeff Daniells)
- Theme 2 – Ensuring safe, disease-free importation of new banana varieties and management and maintenance of the Australian banana germplasm collection (Theme leader – Mrs Sharon Hamill)
- Theme 4 – Investigating cost-effective and sustainable pest and disease management options (Theme leader – Mr Lynton Vawdrey/Ms Kathy Grice)
- Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry (Theme leader – Mr Stewart Lindsay)

With such a large and varied program of work there was a significant commitment to regular communication and consultation by the project leadership group with industry and Horticulture Innovation representatives via the project reference group and banana variety subcommittee meetings. The project leader also attended Horticulture Innovation banana SIAP meetings by invitation to provide project progress reports and updates.

Project Reference Group (PRG) and Banana Variety Subcommittee (BVS)

The PRG was established by Horticulture Innovation in September 2017 with agreement of the proposed nominees and development of the Terms of Reference for membership. The PRG was established with 8 members, structured around representation of the specific themes, including the project BA16005 that came under this PRG due to the complementary nature of the research effort. The Banana Variety Subcommittee (BVS) was established in September 2017 through nominations for membership with representation reflecting a range of stakeholders actively interested in varietal development, such as banana producers and supply chain representatives.

Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance

The work in Theme 1 on varieties is considered under 3 categories

- Sourcing
- Field testing
- Field germplasm maintenance

Sourcing Varieties

At the commencement of BA16001 the BVS was formed to strategically overview the process of importation and evaluation. It has been composed of representatives from industry, supply chain, ABGC, Queensland DAF and Horticulture Innovation. The subcommittee was guided by the banana variety development options paper delivered by project BA14013. Key breeding program partners identified from the options paper were the Taiwan Banana Research Institute (TBRI), as well as the French and Brazilian research organizations, CIRAD and EMBRAPA respectively which was endorsed by BVS. TBRI have developed Cavendish somaclones resistant to Fusarium wilt Tropical Race 4 (TR4) whilst CIRAD and EMBRAPA have been more focused on resistance to Sigatoka leaf disease and Fusarium wilt Race 1 (Race 1) in Lady Finger and Silk-style hybrids.

The negotiations to import varieties and to traverse Australian quarantine is a lengthy process which takes at least a few years. Eleven varieties were successfully imported during the previous plant protection project BA10020. These were released from quarantine following commencement of BA16001 and were essentially the core of what was available for evaluation. During BA16001 a further 23 varieties were imported. Four of these from CIRAD were released from quarantine in early 2020 and commenced field evaluations in that year. The others are expected to be released after BA16001 is completed. In addition, the Israeli Biotech company, Rahan Meristem had privately imported 4 improved Cavendish selections. FNQ producers that had seen the selections growing overseas were keen for these to be evaluated by DAF. With the support of industry these selections were included in South Johnstone evaluations and Rahan Meristem agreed that results of our evaluations could be made publicly available.

In 2020 the TR4 research project BA14014 finished, but the evaluation of the products of its mutagenesis component was unfinished. The responsibility for on-going assessment of the mutated selections of TR4 resistant Cavendish and Goldfinger was assumed in Theme 1 activities at the recommendation of the project leadership team and the BVS. As a result, the Phase 2 and 3 assessments of 20 improved Goldfinger selections at SJRF was assumed by this project in June 2020. In addition, the project has also facilitated the re-introduction to Queensland from Northern Territory of 17 mutated Cavendish selections developed by mutagenesis with TR4 resistance.

Field Evaluations

Experience has shown that it is essential to evaluate imported varieties in the field under Australian conditions to understand their performance in local environments and with Australian crop management practices. We chose to do our separate field evaluations for TR4 resistance, R1 resistance and agronomic characteristics/yellow Sigatoka concurrently rather than as some stepwise process. Whilst TR4 was an important focus of our work it is not the only priority for identifying suitable alternative varieties. The BVS emphasised the importance of not delaying the assessment of varietal performance under NQ conditions until we had confirmed their TR4 resistance, to save time in delivering the best varieties for on-farm evaluations. For Lady Finger growers the major problem facing growers in the subtropics is Race 1. It may be a very long time before TR4 finds its way to all the farms in that region, so finding suitable new varieties for the subtropics did not depend upon them also being resistant to TR4. The field evaluations are divided into:

- TR4 screening at DITT's Coastal Plains Research Farm (CPRF) in the Northern Territory (NT).
- Agronomic and yellow Sigatoka screening at DAF's South Johnstone Research Facility in Far North Queensland (FNQ).
- R1 and agronomic screening in subtropics at Duranbah, northern NSW and consumer testing at Ourimbah (NSW DPI).
- Pre-commercialisation trials on farms in FNQ and NT.

TR4 screening (NT)

For biosecurity reasons the NT is the only state/territory in Australia where such trials with TR4 can currently be conducted. It is a good site too because only one 'strain' (VCG 0123/16) of Fusarium wilt is present, so trial results are not confounded by multiple 'strains'. Field screening trials are used rather than greenhouse studies because issues can arise through higher inoculum pressures within pots, use of younger plants as well as the lack of a representative soil microbiome and growing conditions not representative of field conditions (Dita et al. 2021). A TR4 screening trial was established in June 2016 as part of BA10020, 12 months before BA16001 commenced. This trial was completed in 2018 as part of BA16001. An additional 2 screening trials were undertaken in BA16001. In each of the trials we included 3 reference varieties with known reactions to TR4 – very susceptible, intermediate and resistant. These are essential for interpreting the disease reaction of new varieties being assessed. It is not so much the absolute severity of disease exhibited by a new variety that is important, but rather how its reaction compares to that of the reference varieties.

Most of these trials were randomized complete block design with 6 plant plots replicated 4 times and grown for a plant crop and one ratoon. The screening site was artificially inoculated with TR4 by applying 200 ml of millet grain pre-colonised by the TR4 pathogen which was added to the planting hole in the field. These artificial inoculations are a key component to obtaining accurate trial results with all plants in the trial exposed to a measured amount of disease inoculum. Once external disease symptoms were evident, ratings of severity were taken monthly. The date of first disease symptoms, type of symptom and date of death were recorded. Upon death of the plant, the pseudostem was examined for the presence of internal symptoms and infected vascular tissue of each variety was collected for laboratory

confirmation of TR4. All remaining plants which reached bunch harvest stage, with or without any external symptoms, were then examined internally and any infected vascular tissue collected as required.

Agronomic/yellow Sigatoka screening (FNQ)

The main agronomic evaluations were conducted at South Johnstone in the centre of the FNQ banana industry, where the varieties are also screened for resistance to yellow Sigatoka. The first evaluation was established in 2018 and evaluated over 3 crop cycles plus a yellow Sigatoka screening (still to come) in the fourth cycle. This was a first look at many of the varieties and the necessary stage from which to make shortlist recommendations for on-farm testing. The varieties in the trial included 5 recent introductions from TBRI as well as the full suite of Taiwanese selections already in Australia. A second evaluation was established in 2020 following release of further imported varieties from quarantine.

These trials were randomized complete block design with 7-plant plots replicated 3 times. The standard data collected were crop cycle durations, components of bunch yield and fruit quality and plant height and girth. In the fourth crop cycle we will screen for yellow Sigatoka resistance. This is scheduled to coincide with the wet season in the first half of 2022 so that there is plenty of inoculum present which facilitates the rating and ranking of varieties. Leading into this we will nurse sucker the block to make the timing of the next crop uniform and rate each of the plants at monthly intervals on 3 occasions prior to bunch emergence (Daniells et al. 1996).

NSW R1 screening, agronomic and consumer testing

As with BA10020 the Race 1 screening site in the subtropics was located at Duranbah. In early 2018 there were 2 large trials established.

- 19 varieties were screened for resistance to Race 1 and cold tolerance.
- A semi-commercial planting of varieties identified from BA10020 to develop production and post-harvest recommendations and conduct consumer acceptance testing. The varieties nominated were FLF-1, PKZ, FHIA-17 and FHIA-25. Subsequently, FLF-1 was removed from the field evaluations because intellectual property had been claimed on it, which was granted by IP Australia.

The disease resistance screening trial approach was like that used in the TR4 studies, with artificial inoculation of individual planting sites to ensure a consistent level of inoculum across the trial. The trial design was a randomised complete block with 5-plant plots replicated 3 times.

The “best bets” agronomic trial was non-replicated and established as a commercial style planting using cultivation practices aligned with commercial subtropical industry practices. The agronomic performance of the varieties PKZ and FHIA-17 were assessed from 2 different planting densities and arrangements. The detailed methodology is described in Appendix 6.

In addition to the agronomic data collected for these varieties the NSW DPI horticulture team conducted a sensory evaluation and post-harvest assessment to determine whether commercialisation of these varieties should be pursued. Four banana samples were included in the sensory evaluation and post-harvest assessment. Two market samples of Cavendish bananas from northern NSW and NQ were included in the evaluation as commercial standards with the varieties PKZ and FHIA-17 as the remaining two samples. A consumer preference questionnaire was developed and administered to collect basic demographic data, banana consumption and preference information from the participants. The banana sensory evaluation trial was conducted at NSW DPI Ourimbah site with 46 volunteers made up from NSW DPI and University of Newcastle staff. For post-harvest assessment the bananas underwent ripening by a commercial operator prior to the sensory evaluation and assessment was conducted on the same day as the sensory evaluation. A sample of 10 fruit from each of the 4 banana varieties was selected and submitted for various post-harvest measures. The detailed methodology is described in Appendix 7.

Pre-commercialisation trials

In late 2017 the BVS asked for inclusion of pre-commercialisation trials in the project as they were very concerned about TR4 which was spreading in the Tully Valley. They wanted to see the best of the TR4 resistant Cavendish selections that had been identified that year at the Coastal Plains trial site planted on grower properties for further assessment of their prospects. Five farm trial sites were eventually identified – 2 in the Tully Valley, 1 in Innisfail, 1 on the Atherton Tablelands and 1 at Lake Bennett in the NT. The varieties chosen for the Queensland trial sites were GCTCV 215 and GCTCV 247. CJ19 was additionally included in the NT trial site. The varieties and numbers planted were negotiated with the cooperating

growers with 50-300 plants offered of the identified varieties under a MTA where required to protect the intellectual property of the originating breeding programs. The varieties were supplied by the project as tissue cultured plantlets and the cooperating producers were responsible for arranging the nursery phase to grow the plants on for planting. The NQ farms all opted to do this via commercial tissue culture nursery businesses with the NT opting to do this in their own nursery facilities. An equivalent number of Williams Cavendish were planned to be planted with the TR4 resistant varieties to provide a allow comparison of performance with the industry standard variety.

The plantings were not replicated as the objective was not to collect detailed agronomic performance data but rather to gather qualitative data (opinions/insights) from the cooperating growers regarding commercially important attributes and relative performance compared to Williams. The trials also served to provide a source of larger volumes of fruit for post-harvest and supply chain assessments.

A small amount of DAF innovation project funding was sourced to undertake a preliminary study of the post-harvest characteristics of GCTCV 247 and 215 in simulated commercial storage, transportation and ripening of fruit from these pre-commercialisation trials. Quantitative fruit quality assessments and consumer taste testing surveys were conducted to evaluate their post-harvest performance. The aim of the research was to see how the new varieties compare to the standard Williams Cavendish cultivar. Detailed methodology is presented in Appendix 9.

Assessment of lines developed by mutation breeding

The assessment of 20 improved Goldfinger selections developed by mutation breeding continued at SJRF under the auspices of BA16001 from June 2020. From an original 630 gamma irradiated plants evaluated in 2017/18, 20 variants with eating characteristics more favourable than the standard Goldfinger were selected. These lines were then multiplied as vegetative material for the phase 2 evaluation with a field trial planted in September 2019. Data on agronomic performance and eating characteristics were collected again to substantiate the findings from the phase 1 assessment which were based on just a single plant crop bunch. Agronomic performance was assessed for 2 crop cycles (plant crop + ratoon 1) and assessment of eating characteristics was conducted with personnel at the SJRF office complex. Fruit ripening was standardised with a process developed from ripening guidelines for Goldfinger (Seberry & Harris 1998; Gutirrez-Martinez et al 2010). Participants tasted 5-6 anonymised whole fruit per session, including Goldfinger and Lady Finger as standard controls. A standardised questionnaire with hedonic scales for responses asked questions around important aspects of eating quality.

Additionally, the project also facilitated re-introduction of 17 mutated Cavendish selections developed by mutagenesis with TR4 resistance to Queensland from Northern Territory. Plants identified in the field for phase 2 assessment were progressively established in tissue culture by the NT DITT and dispatched to be maintained at DAF's banana tissue culture facility at Maroochy Research Facility (MRF) from May to December 2021 under protocol to allow the transfer to occur by managing biosecurity risks associated with interstate movement of *in vitro* banana germplasm from NT to Queensland.

Field germplasm maintenance program

The Australian field collection of banana varieties is held at SJRF and supplies suckers on a regular basis to the *in vitro* germplasm collection at MRF for re-initiation into culture. This is to ensure that somatic variants, which develop over time *in vitro*, are kept to a minimum thus ensuring fidelity of the *in vitro* plants supplied to researchers and other users.

Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties

Post-entry quarantine management and screening

Access to banana quarantine facilities were reviewed following the closure of the existing facility at Eagle Farm in Brisbane, with new processes and facilities established by the previous banana plant protection program (BA10020) and maintained by BA16001 to safely import new banana varieties into Australia.

- The approved Australian banana quarantine tissue culture laboratory (DAF Maroochy Research Facility, MRF) and banana quarantine glasshouse (DAF EcoSciences Precinct, Brisbane) are accredited via an Approved Arrangement (AA) (previously known as a Compliance Agreement) defined by the Department of Agriculture, Water and Environment (DAWE).
- Project staff developed the AA and were registered as facility managers, with responsibility to ensure the quarantine facilities met the outlined conditions.

- Imported banana varieties enter Australia as tissue cultured plantlets into the tissue culture post-entry quarantine (PEQ) facility. Initial screening of imported tissue culture plantlets is undertaken very early in the import process to eliminate lines in which pathogens are detected.
- Imported lines then undergo very limited clonal multiplication to allow a subset of plants per line to be further screened in the banana PEQ glasshouse for the presence of pests and diseases.
- All plants in the PEQ glasshouse are destructively sampled for diagnostic evaluation and are not released. Lines are assayed for viruses and the Banana Wilt Associated Phytoplasma (BWAP) using molecular and electron microscopy methods (Appendix 11). Plants are sampled for virus indexing at 3 and 6 months after deflasking, and destructive sampling for BWAP indexing is undertaken at approximately 7-8 months.
- The paired plantlets in the PEQ tissue culture laboratory are released when the compulsory quarantine processes have been completed and the full suite of diagnostic assays have determined there are no pathogens detected in the plants. Once released from quarantine, varieties imported through the project enter the QBAN Tissue Culture Laboratory and are added to the Australian Banana Tissue Culture Collection which provides for their legal movement across Australia.
- To ensure the plants are high-quality, representative plants of imported varieties are planted in the SJRF variety block or other approved block for evaluation. Once determined as true-to-type, suckers are taken for re-initiation into the tissue culture collection following best practice and the conditions of NIASA and the QBAN scheme.
- The duration of this process from receiving the initial tissue cultured plantlets to release ranges from 18-24 months.

Maintenance and provision of banana germplasm

The Australian banana germplasm collection currently contains approximately 520 lines and is maintained to support all Australian research, biosecurity strategies and banana producers. The varieties required for the Theme 1 variety evaluation and screening activities are supplied by Theme 2 either by facilitating safe importation of new lines or by initiating, maintaining and distributing lines held within the Australian germplasm collection.

- The germplasm collection is managed as a dual system with the full complement of varieties and selections maintained *in vitro* at the QBAN research laboratory at the MRF and a field planting of around 200-300 varieties (approximately 50% of the collection) at SJRF.
- Those lines identified as most valuable for current and future needs for industry and projects are maintained under reduced growth conditions to reduce labour costs.
- Since many of the lines are stored in tissue culture for a long time, somaclonal variation can occur over time and produce off-types. To help maintain the quality of the collection the varieties are periodically replaced by initiating suckers collected from observed 'true-to-type' plants sourced from the field collection.
- For growers and researchers sourcing specific varieties (other than the project needs of BA16001) a user pays system is in place. This is a 'not for profit' fee for service system that is listed as a fee with Queensland Government and is indexed annually to ensure the costs of providing germplasm are being met. The system is designed to provide small numbers of plants from the germplasm collection for evaluation by researchers and growers, often under formal Material Transfer Agreements (MTAs) to maintain the intellectual property of the originating provider.

Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management options

The project developed an IPDM strategy focused on the highest priority issues for the national banana industry. The IPDM R&D approach developed by the project considered a range of information sources and meeting outputs that identified industry IPDM priorities, including outputs from the Strategic Agrichemical Review Process (SARP) for bananas and IPDM priority setting workshops conducted with banana producers and industry service providers in Far North Queensland. As a

result, the pests and diseases identified as the highest priority issues for R&D activity were bunch pests, pest mites, yellow Sigatoka leaf disease and plant parasitic nematodes. A small virus research effort focused on identifying and improving detection of new/emerging viruses identified during the PEQ process.

Entomology research

Bunch pests

Banana rust thrips, flower thrips, banana scab moth and sugarcane bud moth (BRT, FT, BSM, SCBM respectively) are the main insect pest complex that cause damage to the developing banana fruit. While seasonal conditions may slightly reduce population pressures for some pests (BSM, FT) the economic threshold population for BRT is practically zero, with the result that current control measures rely heavily on insecticide applications targeted directly at the bunch. The key issues for bunch pest management included the potential loss of effective insecticides through de-registration, a high risk of resistance development due to reliance on organophosphates and a lack of alternative insecticide groups for rotation and the labour intensive, costly and WHS risks associated with the current control measures. As a result, the research activities focused on:

- Field trials investigating non-chemical/cultural control practices on BRT infestation and damage
- Investigation of the genetic diversity of BSM to investigate for host/race interactions
- Identifying and screening of IPM compatible insecticide products in field trials, including novel botanical products, to support registration of a broader range of chemical groups.
- Identify and investigate suitable biological control agents (predators/parasites) for pest thrips in glasshouse trials

Foliar pests

Pest mites can cause significant damage to banana leaves during favourable weather conditions in both the tropics and subtropics. A new commercially available predatory mite (*Neoseiulus californicus*) with better adaptation to tropical conditions is being used by a small number of growers to control pest mites. A lack of information about the efficacy of this predatory mite, appropriate application rates and timings and the most efficient methods of application in bananas have limited their commercial adoption. Research activities undertaken to investigate some of issues were:

- Analysis of available monitoring data sets from commercial banana growers applying the predatory mites to investigate their efficacy against pest mite populations
- Conduct glasshouse trials to investigate efficacy of the predatory mite against pest mites and the predator/prey relationship

Plant pathology research

Leaf disease

Integrated management of yellow Sigatoka relies on the use of cultural practices to reduce inoculum levels and manipulate the canopy micro-climate (deleafing, drainage management) and timely applications of systemic and protectant fungicides. To address issues of the potential loss of currently registered fungicides and development of resistance, the research activities focused on:

- Investigating post-infection activity of systemic fungicides and oils to improve control during the wet season when periods of high infection pressure coincide with reduced spray opportunities. The detailed methodology is described in Appendix 13.
- Identifying and screening a range of products in field trials at SJRF, including fungicides, plant defence activators and biological products, to identify IPDM compatible products with efficacy against yellow Sigatoka. The detailed methodology is described in Appendix 13.
- Supporting varietal leaf spot screening conducted at the SJRF

Bacterial corm rot

Banana corm rot (BCR) is destructive and among the least recognised bacterial diseases. While it did not rank highly in the

initial IPDM prioritization process, the issue of management was raised during the project by industry and Biosecurity Queensland due to the similarity of external symptoms to those of Fusarium wilt disease. The ubiquitous nature of low level BCR infections on most farms in FNQ during the January to April period each year was a major risk to the Panama disease TR4 surveillance program through the potential masking of low level TR4 infection. To try to understand more about the cause and management of BCR the project:

- Investigated if *Pectobacterium* and *Dickeya* species are still the primary organisms implicated with BCR symptoms by subjecting recovered bacterial isolates from BCR samples collected from the field to molecular analysis to accurately identify species associated with BCR symptoms. The detailed methodology is described in Appendix 14.
- Investigated the potential to reduce sucker number on tissue cultured plants by varying the *in vitro* plantlet cutting technique to reduce the significantly greater BCR infection rate in plantings established with TC plants. The detailed methodology is described in Appendix 14.

Nematology research

Research activities underpinning an integrated management approach to plant-parasitic nematodes in bananas investigated the distribution, pathogenicity, and suitable management options for the major pest nematode (*Radopholus similis*) as well the emerging pest nematodes *Pratylenchus goodeyi*, *P. coffeae*, *Helicotylenchus multicinctus* and *Meloidogyne* spp. This was achieved through the following research activities:

- Conduct field surveys in production regions of NSW, south-east and Far North Qld, and Carnarvon, WA to determine which plant-parasitic nematode pests were causing major economic losses. Root and soil samples were taken from as many growers as possible to get a better understanding of the species that are impacting the various production areas.
- Pathogenicity testing of the plant parasitic nematodes identified from the survey against Williams Cavendish bananas in pot trials to determine if selected species of nematodes negatively impacted the growth of banana plants. The detailed methodology is described in Appendix 17.
- Identifying and screening of potential rotation crops in pot trials for their host status to the main species of nematodes identified in the survey, for use as rotation fallow crops in banana production systems. The detailed methodology is described in Appendix 17.
- Identifying and screening a range of non-chemical control and biological control products in pot trials under controlled conditions to determine their potential for nematode control. The detailed methodology is described in Appendix 17.
- Conducting resistance screening pot trials with the banana varieties PKZ and FHIA-17, identified in the previous banana plant protection program (BA10020) for consideration for commercialisation, to determine their susceptibility to high priority plant-parasitic nematodes. The detailed methodology is described in Appendix 17.
- Conduct training in nematode extraction, identification and reporting for plant pathologists from WA.

Virology research

The Australian banana industry is largely free of important virus diseases but is threatened by a number of economically significant banana viruses and strains of viruses from overseas and sub-tropical Australia eg. Banana bunchy top virus (BBTV). Maintaining disease-freedom in Australia relies on ongoing stringent PEQ processes and clean planting material schemes, and these measures are underpinned by the use of world-class diagnostic assays by skilled staff. Compared to other crops, viruses in banana have been relatively poorly studied and thus new viruses are still being discovered, especially through germplasm indexing and these need to be targeted for industry biosecurity. As such, research activities focusing on new/emerging viruses identified from the PEQ system were undertaken:

- Sequencing the genome of a novel picorna-like virus detected during PEQ screening and investigating the impacts of infection on plant growth. The detailed methodology is described in Appendix 16.
- Developing a simple and robust diagnostic assay for a new banana Ampelovirus detected in banana germplasm from SE Asia by electron microscopy. The detailed methodology is described in Appendix 16.

- Investigating and characterising an isolate of BBTV infecting non-banana hosts in French Polynesia. The detailed methodology is described in Appendix 16.

Diagnostic services for endemic banana diseases and pests

The project provided a small budget for provision of local pest and disease diagnostic services to banana producers and service providers at the DAF Mareeba and South Johnstone offices, with access to other diagnosticians if needed. The ability to receive samples for testing from banana producing regions provides information and data on the status of endemic pests and diseases, and potentially early detection of incursions of exotic threats.

Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry

Quarterly videoconferencing

Regular communication with project team members and other researchers working in banana plant protection underpinned the objective to foster a more cohesive RD&E program. An activity designed for this purpose was the instigation of a regular videoconferencing update on project activities to share research results, lessons learned and raise awareness of activities being undertaken in banana plant protection projects. The quarterly videoconferences (QVC's) were held 3-4 times per year in a 1 hour webinar format that invited project team members from BA16001 and other projects to report on their activities and findings and answer questions from participants. Agenda items and presentations were canvassed amongst the banana RD&E network before each QVC, with a rotation of researchers reporting to try and ensure an equal opportunity for all participants to report.

The option to record the webinars and upload the file to the project SharePoint site meant that the content of all the QVCs was available for members of the banana R&D network to watch at their convenience if they could not participate on the day. Evaluation of the QVCs was undertaken at regular intervals to track progress against its objective of improving cohesion and communication within the network of R&D providers and improving knowledge of plant protection R&D activities. (Appendix 19)

Banana Scientific Symposia (BSS)

The other key activity designed to achieve a more cohesive RD&E program was a biennial workshop for Australian banana researchers. These symposia were planned to provide a scientific forum for the exchange of ideas between R&D providers and other key stakeholders such as biosecurity agencies, funding agencies and industry organisation representatives. The symposia were also designed to encourage interaction and networking through facilitated problem solving and networking activities integrated into the program. Banana producers were not included in the workshops to avoid the need to pitch presentations and activities to both scientific and producer audiences.

The project plan proposed 2 workshops between the Australian Banana Industry Congress and the Banana Industry Roadshows organised by the National Banana Development and Extension projects (BA16007/BA19004). Two BSS were held during the project in November 2018 and April 2021. The second symposium was originally planned for November 2020 but was delayed due to COVID-19 restrictions on travel and group gatherings. The 2021 symposium included on-line participation and presentation to help overcome the travel restrictions and assist remote participation, as well as facilitating the remote involvement of a keynote international speaker. The detailed methodology is described in Appendix 19.

Project SharePoint site

To facilitate access to key project documents, resources and materials the project developed an electronic repository that could be accessed by project team members and other key stakeholders (by invitation). A SharePoint site was established to help manage project content across all project team members in all themes (including project members of BA16005) and the site was accessible from anywhere at any time irrespective of organisational affiliation.

The site was structured with a folder for each theme where team members (irrespective of which theme they are working on) could easily locate, share and collectively work on documents. The site contained a newsfeed section so that attention could be drawn to newly added documents or relevant industry information highlighted. A team contact list was established in the site so that everyone could access contact details, including the respective themes for each team member. A collective communications and extension activities spreadsheet was also uploaded to the site so that team members could progressively add details about their communication activities.

Each theme leader received one-on-one advice on using the site with the opportunity to provide feedback before being rolled out to the whole project team. Team members were given an overview of the site during the November 2017 video conference as well as receiving instructions via email on how to login and use the site.

Results and discussion

Project structure and governance

The PRG planned to meet twice per year during the period of the project, including at least 1 meeting in-person annually, with minutes recorded for each meeting. The advent of the COVID-19 pandemic in early 2020 and the associated health regulations restricting movement and group gatherings resulted in the PRG meeting less regularly and using on-line meetings instead. The on-line meeting was recorded and uploaded to the project SharePoint site for members to access at their convenience. The dates and attendance for the PRG meetings are presented in Appendix 1.

The BVS planned to meet in-person at least annually during the period of the project with minutes recorded for each meeting. Additional meetings were held as required to deal with emerging issues, such as the development of a Memorandum of Agreement with the Taiwan Banana Research Institute to access new TR4 resistant Cavendish lines. As a result, the BVS met more frequently until 2020 when health regulations restricted travel due to the COVID-19 pandemic, with no meeting during 2020 and 1 on-line meeting in 2021. The on-line meeting was recorded and uploaded to the project SharePoint site for members to access at their convenience. The dates and attendance for the BVS meetings are presented in Appendix 1.

Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance

Sourcing Varieties

An agreed variety importation plan was developed by the project based on the banana variety development options paper delivered by project BA14013, with a priority focus on Cavendish varieties with TR4 resistance and selections and hybrids of Lady Finger and Silk with resistance to Race 1. Key partners identified to achieve this were the Taiwan Banana Research Institute (TBRI), as well as the French and Brazilian research organizations, CIRAD and EMBRAPA. The variety importation plan was endorsed by the BVS which was established by the project in 2017 to provide strategic input on identifying and screening of new banana varieties.

Based on this approach the project identified and subsequently safely imported 23 new varieties consisting of:

- 6 TR4 resistant Cavendish varieties from TBRI in July 2020 – Tai Chiao No. 3, Tai Chiao No. 7, True-to-type GCTCV 218 (TTT Formosana), GCTCV 218-2 and GCTCV 219
- 1 Cavendish selection (MA13) and 5 novel hybrids (925; 918; L9; X-17 and PRAM01) from CIRAD
- 2 Lady Finger selections (Pacoua and Pacovan), 3 Lady Finger hybrids (Pacovan Ken, Platina and Japira), 2 Silk hybrids (Princesa and Tropical) and 3 parental lines (017041, 028003 and 042079) from EMBRAPA.
- 1 Race 1 tolerant Lady Finger selection, SCS451 Catarina, from another Brazilian organization, EPAGRI.
- 1 Ducasse selection (Dwarf Namwa) from Taiwan.

Five Material Transfer Agreements (MTAs) and 1 Memorandum of Agreement (MoA) have been issued and finalised for their upcoming field evaluations.

Access to the TBRI material required the development of a MoA between DAF and TBRI containing a collaborative R&D proposal with associated funding for accessing and researching their improved Cavendish germplasm with TR4 resistance. Although TBRI and DAF signed this MoA in May 2019, the development of a subcontractor agreement with TBRI was delayed by revisions required by the Taiwanese Council of Agriculture Intellectual Property committee. Consequently, the delay meant the MoA was only finalised on 15 April 2020 after multiple revisions to address their concerns.

A component of the collaborative R&D agreement was study tours and information sharing between Australian and Taiwanese researchers on TR4 resistant Cavendish variety development. Visiting trial sites and research facilities in both countries became impossible because of international travel restrictions due to the global COVID-19 pandemic. In lieu of these activities a webinar was held on 3 March 2021 with 28 participants, consisting of BA16001 project staff, industry

reference group members and Taiwan Banana Research Institute staff. The webinar shared the results of research activities assessing TBRI Cavendish selections with resistance to Fusarium wilt TR4 in Australia and Taiwan. The meeting agenda is presented in Appendix 2.

The responsibility for screening the TR4 resistant Cavendish and Goldfinger mutagenesis selections developed and identified in the project BA14014 was assumed in Theme 1 activities at the recommendation of the project leadership team and the BVS. As a result, the phase 3 assessment of 20 Goldfinger selections with improved eating characteristics at SJRF was assumed by this project in June 2020. In addition, the project has also facilitated the re-introduction to Queensland from Northern Territory of 17 Cavendish selections developed by mutagenesis with TR4 resistance, so that the selections can be maintained for further evaluation. This process required the development of the protocol "Collection of Banana Suckers or Bells for Tissue Culture Initiation and Corresponding Diagnostic Samples from the NT for Virus Indexing in Queensland" to meet the interstate biosecurity requirements for safely managing the risks associated with bringing banana plant material into Queensland from Northern Territory.

Field Evaluations

Fusarium wilt TR4 screening (Northern Territory)

Three varietal screening field trials were conducted during the period of BA16001. A TR4 screening trial of 27 varieties was established at Coastal Plains Research Farm (CPRF) in June 2016 as part of BA10020. This was inherited by BA16001, and the plant and ratoon crop assessments were completed by January 2018. In December 2018, 32 varieties (totaling 616 plants) were established in the field at CPRF for TR4 disease screening. This trial was completed by August 2020. A third TR4 screening trial of 24 varieties (totaling 576 plants) was established at CPRF in December 2020 with only assessment of the plant crop achieved before the completion of the project. Results for the completed trials are presented in Appendix 3.

From the trials completed during BA16001 (June 2016 and Dec 2020) 14 varieties with sufficient levels of resistance to TR4 have been identified consisting of:

- 6 Cavendish selections – GCTCV 215, GCTCV 247, CJ 19, GCTCV 217, GCTCV 105, Asia Pacific #3
- 6 hybrids from conventional breeding programs – CIRAD 03, CIRAD 04, CIRAD 05, FHIA-02, FHIA-18 and SH-3641
- 2 cooking bananas – Dwarf French Plantain, Pisang Gajih Merah

For Australian banana producers these results mean we have both Cavendish and non-Cavendish varieties that may offer options in managing TR4 infections, although the varieties must also demonstrate suitable agronomic and post-harvest characteristics. The results of the disease resistance screening as well as the results of agronomic assessments are fundamental to identifying varieties suitable for advancing to on-farm pre-commercialisation trials. GCTCV 247, GCTCV 215 and CJ19 have all been deployed in pre-commercialisation trials during BA16001. From the 2018 trial the TR4 resistant Cavendish variety Asia Pacific #3 is identified for inclusion in future pre-commercialisation trial plantings, with the true-to-type Asia Pacific #1 selection also being considered pending plant crop trial results.

Additionally, we have identified 9 highly resistant parental lines as suitable parents for breeding purposes – SH-3362, SH-3142, Inarnibal, M53, Manang, Tjau Lagada, Pisang Bangkahulu, Sinwobogi and Pisang Sapon. These results are very important for the conventional breeding programs that have participated with DAF and BA16001 to supply banana germplasm (CIRAD, EMBRAPA and FHIA), as they can focus more confidently on crosses using material with identified TR4 resistance. The results have been shared with these partner agencies.

Agronomic/yellow Sigatoka screening (FNQ)

Two field trials were conducted at SJRF during the period of BA16001. The first trial was planted in September 2018 and consisted of 32 varieties (totaling 672 plants), including 23 Cavendish varieties, 4 novel triploid hybrids and 2 Lady Finger varieties. Assessment of agronomic performance was conducted over a plant crop and 2 ratoon crop cycles and was completed in early Spring 2021.Yellow Sigatoka resistance screening will commence in January 2022 with completion in June 2022. Detailed results for the agronomic screening are presented in Appendix 4.

The results in summary are:

- The 9 TR4 resistant Cavendish selections from TBRI were considerably slower to reach ratoon 1 harvest than Williams (19.6 – 23.7 months compared to 17 months).

- The TR4 resistant Cavendish varieties GCTCV 119, 215, 217, 247 and Asia Pacific #3 were all significantly taller than Williams. A considerable number of bunches on Asia Pacific #3, GCTCV 119 and GCTCV 217 did not make it through to harvest in the first ratoon crop. However, rather than breaking over from wind damage, losses were typified by snapping at the point of connection of the wooden prop to the pseudostem (in the single row trial bunch support is in the form of propping).
- The lower bunch weights for some varieties and slower cycle times resulted in cumulative yields over 2 crop cycles (plant + ratoon 1) representing only 63 – 92% of the industry standard Williams. Asia Pacific #3 was the only variety with cumulative yield not significantly less than Williams over 2 crop cycles (plant + ratoon 1). This productivity, combined with TR4 resistance significantly better than Formosana (intermediate resistance standard) advances its candidacy for inclusion in the on-farm pre-commercialisation trials.
- The 4 Cavendish selections from Rahan Meristem (Gal, Jaffa, Adi 9001, Adi 9168) have performed at a high level in the agronomic trial at South Johnstone compared to the industry standard Williams. It is noteworthy that Adi 9001 (2.7 m) and Adi 9168 (2.3 m) were both significantly shorter than Williams (3.1 m) in the ratoon cycle without displaying any issues with choking often associated with dwarf varieties. Approximately 300 suckers of these selections have been provided from the trial to the commercial tissue culture laboratory managing the commercialisation of these varieties in Australia as the sole supplier. A few commercial farms have begun growing these varieties on a small-scale due to their promising agronomic qualities.
- The cumulative yields of the CIRAD hybrids (03, 04, 05, 06) were slightly better in the ratoon than for the plant crop but were still only 57 – 66% of that of Williams. Plants remained significantly taller (11 – 31%) than Williams. Their brittle pseudostems were prone to snapping, and their long, narrow leaf stalks readily bent over leading to much reduced leaf area. Like some of the Taiwanese selections, these too were prone to snapping at the propping point.
- The two dwarf selections of Cavendish, Brier and Dwarf Cavendish, had comparable cycle times and bunch weights to Williams, although Dwarf Cavendish had shorter fruit than both Brier and Williams (indicated by the percentage of fruit in the 22 – 26 cm size category).

The second trial of 16 varieties (totaling 394 plants), including TR4 resistant Cavendish, 6 Lady Finger varieties and 5 hybrids was established at South Johnstone in October 2020. These plants have so far been assessed for agronomic performance only in a plant crop.

Fusarium wilt Race 1 screening, agronomic and consumer testing (NSW)

Established in February 2018, 1 variety trial screening comprising 19 varieties (~270 plants) for Race 1 resistance screening was completed at Duranbah. Disease assessments could not be completed for most of the varieties because of a serious infestation of banana weevil borer, originating from a neighbouring commercial plantation, which undermined the trial (Figure 1). Additionally, external symptom rating was confounded in the subtropics due to leaf yellowing and leaf drop caused by low minimum temperatures during winter and prolonged dry conditions and as such was not well correlated with internal symptom expression. It was possible to obtain sufficient internal symptom disease severity and agronomic trait data at harvest of the plant crop for only 7 of the 19 varieties. Of the 7 varieties which had sufficient data, 2 varieties have been advanced to pre-commercialisation trials – the Lady Finger hybrid JV42.41 and the dwarf Cavendish selection Plantanera Brier. Detailed results are presented in Appendix 5.

Figure 1. Severe banana weevil borer (*Cosmopolites sordidus*) damage causing rhizome destruction and plant death at the Duranbah site

The second field trial conducted at Duranbah comprised 4 varieties identified from BA10020 and were established as a semi-commercial planting to develop production and post-harvest recommendations and conduct consumer acceptance testing. Despite the unreplicated nature of the trial, a statistical model was able to be fitted and mean responses estimated. A summary of results from the trial were:

- FHIA-17 – the results show that FHIA-17 planted in double rows had a shorter mean pseudostem height than single rows, a shorter plant crop cycle and slightly heavier bunch weight. When planted in single rows it had an average fruit weight that was heavier than when planted in double rows and slightly longer and thicker fruit
- PKZ – planted in double rows PKZ had heavier bunch weights, slightly longer fruit and 1 more hand per bunch when compared to averages of these traits in single row plantings. Planted in single rows PKZ possessed a shorter pseudostem than plants in double rows, a shorter plant crop cycle, higher number of functional leaves and slightly heavier fruit weight.

The mean and standard errors for the agronomic traits evaluated can be seen in Appendix 6.

The consumer acceptance assessments in NSW compared FHIA-17 and PKZ with Cavendish sourced from NQ and NNSW. The consumer tasting revealed:

- The NQ Cavendish banana samples had the highest mean liking scores for several sensory attributes, namely aroma, sweetness, acidity, overall flavour and aftertaste, and came very close to NNSW for texture and starchiness liking.
- The NQ Cavendish samples were considered the most preferred banana variety among the four samples tasted and participants had positive comments about it.
- Although PKZ and FHIA-17 possess some desirable agronomic attributes and disease resistance, they did not appeal to consumers when compared to Cavendish bananas sourced from NQ and NNSW.

Based on these findings it was recommended that PKZ and FHIA-17 not be pursued for commercialization. Results for each trial are presented in Appendix 7.

Pre-commercialisation trials

Four on-farm trials sites were established in north Queensland (2 Tully, 1 Innisfail, 1 Walkamin) with the 2 TR4 resistant Cavendish selections GCTCV 215 and GCTCV 247 between October 2019 and June 2020. An additional site with TR4 was eventually established in NT after more than 12 months of negotiation with various parties, and the variety CJ19 was planted in addition to the GCTCV lines. CJ19 was not recommended in the NQ trial sites as it performs better in a consistently warm and dry climate like the Darwin region. Each trial planting was managed through a MTA specifying the conditions of use and requirements.

Williams Cavendish plants were supposed to be planted with the test lines for comparison, but this did not occur at 2 of the NQ trials sites and plants were not co-located at a third site, making meaningful performance comparisons difficult or impossible from these sites. A report on the trial sites is presented in Appendix 8.

The objective of the trials was not to collect detailed agronomic performance data but rather to gather qualitative data (opinions/insights) from the cooperating growers regarding commercially important attributes and relative performance compared to Williams. The trials also served to provide a source of larger volumes of fruit for post-harvest and supply chain assessments.

Overall, the GCTCV lines performed similarly to the research trial results with longer crop cycles and taller plant stature compared to Williams, except for CJ19 which is a semi-dwarf Cavendish variety. Typical feedback from the cooperating growers has been:

- fruit quality (fruit length and appearance) and bunch conformation of the GCTCV lines was comparable to Williams. Assessments of fruit shipped to the Sydney markets were positive and comparable to the industry standard Williams
- longer crop cycles for the GCTCV lines meant that productivity was noticeably lower than Williams
- observations that there are fewer, less vigorous suckers than with Williams
- the tall plant stature and relatively thin pseudostem circumference of the GCTCV lines made them more

prone to snapping and much more susceptible to loss due to strong winds, requiring extensive bunch support practices to minimise losses. Significant losses (44-47%) were experienced at Tully north from a thunderstorm, and complete crop losses were experienced at the Innisfail (winds associated with a developing tropical cyclone) and Lake Bennett sites (strong winds)

- the GCTCV lines appear to be less tolerant of extreme heat and more susceptible to pseudostem breakage in hot conditions
- the GCTCV lines reportedly had higher levels of yellow Sigatoka infection on 1 NQ site
- GCTCV 247, GCTCV 215 and CJ19 all showed much lower TR4 infection rates at the NT site than Williams. In September 2021, 10 months after planting, around 50% of the Williams plants had died with an additional 36% displaying external symptoms, compared to 4-8% plant death and up to 14% of plants displaying mild external symptoms for the resistant lines.

The preliminary post-harvest assessment for GCTCV 247 and 215 found:

- there was no significant difference between the new varieties and Williams for residual shelf life, percentage weight loss, fruit firmness, fruit colour and defect ratings
- there was no significant difference between the new varieties and Williams for the destructive parameter assessments – dry matter, fruit angularity (a measure of maturity), starch index, total soluble sugars or total acidity
- the results of the consumer acceptance survey indicated 77% of participants liked the flavour of new varieties compared to 88% that like the flavour of Williams; 68-74% of respondents indicated that they would be willing to purchase the new varieties and gives some confidence that these TR4 resistant varieties would be acceptable to consumers

In summary, the findings from the pre-commercialisation trials have shown that despite having significantly improved TR4 resistance, the poor agronomic features of these Cavendish varieties are a barrier to commercial adoption. However, the value of the pre-commercialisation trials in providing feedback on performance and attributes of identified lines has been demonstrated. A further 3 promising varieties – Asia Pacific #3, JV 42.41 and Plantanera Brier – have been identified from the agronomic and TR4 field trials for the next round of pre-commercialisation trial plantings.

Assessment of lines developed by mutagenesis

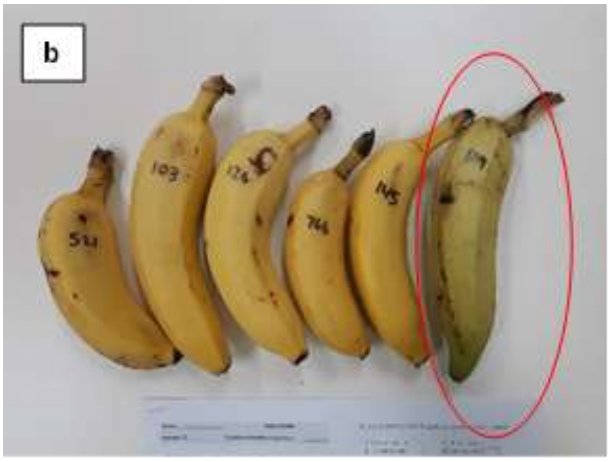
The top 20 plants which demonstrated eating characteristics more favourable than the standard Goldfinger fruit were selected from the original mutagenesis trial and carried forward into the phase 2 assessment. Sucker and bit material from the original plants was field planted on 11 September 2019. Bunches began emerging from the more established plants in March 2020 and continued throughout the year. The final harvest was performed in January 2021. Data was again collected on both agronomic performance and eating characteristics to substantiate the findings from the first investigation which were undertaken from a single plant in the plant crop only. Detailed results for the assessments are presented in Appendix 10 and a summary of results is:

- Half of the selections were not significantly different to the height of Goldfinger. Six had an improved ratio (shorter height and greater girth), and only 4 of the selections had a height-to-girth ratio less desirable than the control.
- 14 of the selections had significantly lighter bunch weights, selection 366 had heavier bunches while the remaining 5 were comparable in size to standard Goldfinger. Encouragingly, 3 of the selections in the latter category also performed well in the taste-testing.
- Lady Finger cv. Rossi, standard comparison, scored the highest overall rating (6.8) of all the varieties included in the taste panelling, closely followed by the variant 521 (6.5), which was the best performer out of all the Goldfinger selections. Several comments were made that this selection had similar eating characteristics to a Lady Finger. The Goldfinger control was rated 4.7 on average, with 255 the only selection below it at 3.7.
- Selections 211, 544, 144 and 903 joined 521 in making up the 5 selections which were given the highest overall eating experience rating and had the greatest number of people answer ‘yes’ to the purchasing

question.

- There were 2 selections with undesirable characteristics which had gone undetected in the phase 1 trial. Selection 843 had severely fused fingers, to the point in which several hands in a bunch were unusable (Figure 2a), and selection 119 had fruit which retained a green tinge upon ripening (Figure 2b). Such features make them unsuitable for pursuing further as they would hinder successful commercialisation.

Figure 2. a) Fused fingers on many of the 843 plants make them a poor contender for commercialisation; b) The fruit from plant 119 (circled) remained relatively green upon ripening.



From the phase 2 assessments we have selected the top 5 performers based largely on eating characteristics – 211, 544, 144, 903 and 521. The phase 3 assessment encompasses sending fruit of these 5 selections to DAF's Coopers Plains food science laboratory in Brisbane between December 2021 and March 2022 for formal evaluation of consumer acceptability. In this process DAF consumer sensory scientists will engage much larger groups of taste testers to assess the bananas and assist with pinpointing the one or two with the greatest commercial potential. Once narrowed down to 1-2 selections, it will be a more manageable proposition to have the necessary postharvest research done to determine how to get the best out of those being taken further forward. From there larger scale on-farm pre-commercialisation trials are planned which will form a part of the evaluation stage.

The project has also facilitated the re-introduction to Queensland from Northern Territory of 17 Cavendish selections developed by mutation breeding with TR4 resistance (Table 1).

Table 1. 17 Cavendish selections developed by mutation breeding reimported to Queensland from NT under protocol

Identified selection	
23/23	3/42
19/18	4/15
18/18	5/27
1/38	5/30
2/06	5/40
2/28	6/04
2/34	6/18
3/15	6/39
3/17	

This process required the development of the protocol "Collection of Banana Suckers or Bells for Tissue Culture Initiation and Corresponding Diagnostic Samples from the NT for Virus Indexing in Queensland" to meet the interstate biosecurity

requirements for safely managing the risks associated with bringing banana plant material into Queensland from Northern Territory. All these selections are established as *in vitro* cultures at the MRF TC laboratory and will be available for phase 2 assessment of agronomic performance in future projects undertaking variety screening work

Field germplasm maintenance program

The field germplasm collection at SJRF supplied suckers of 178 varieties to the MRF tissue culture laboratory to maintain true-to-type cultures in the *in vitro* collection.

Replanting of the field collection at South Johnstone, which had been previously renewed in 2015, commenced in 2020. Prepared sucker planting material from half of the varieties was successfully reestablished in the field. Wet weather in 2021 hindered planting suckers of the remaining varieties directly in the field, so they were established in potting bags containing soil instead. This allows more flexibility and a larger window of opportunity for field planting. The potted suckers are progressing well and were field planted in early December 2021.

Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties

Post-entry quarantine management and screening

Banana Post-Entry Quarantine (PEQ) facilities were maintained and operated in accordance with requirements of the Federal Department of Agriculture, Water and Environment (DAWE) and facilitated entry of new banana varieties into Australia using best-practice methods to safeguard industry. This included implementing significant new PEQ requirements introduced by DAWE in 2020. PEQ Tissue Culture laboratories Q2264/Q2860 and Glasshouse Q2325 and the banana germplasm import process Q2762 remained compliant with Federal Biosecurity procedures throughout the project. All audits were passed, and no corrective actions were received. Additionally, the diagnostic assay suite for PEQ virus indexing was strengthened by incorporation of the test developed for the recently detected banana picorna-like virus.

As a result of this:

- 29 imported varieties (38 accession lines) were released from PEQ during the project.
- 15 varieties (47 accession lines) are currently held in the project PEQ Tissue Culture Laboratory Q2264
- 13 varieties (16 accession lines) are currently growing in the PEQ glasshouse for pest and disease screening.

Banana wilt associated phytoplasma (BWAP) – PEQ diagnostics

To improve detection of phytoplasmas during post entry quarantine indexing of imported germplasm conducted in Theme 2, and in conjunction with Dr Lilia Costa-Carvalhais (QAAFI, UQ – BA16005), Dr Crew (as the lead Plant Pathologist for the banana pest and disease screening) has secured additional operating funds from the Network for Plant Biosecurity Diagnosticians/SPHD Laboratory Residential program to visit Papua New Guinea to view BWAP symptoms first hand and to investigate phytoplasma detection in BWAP-infected plants prior to the development of symptoms.

Additional funds have also been awarded by the Crawford Fund (activity led by Dr Costa-Carvalhais) to extend the visit to Papua New Guinea to include a training workshop for NARI and NAQIA staff on detection of banana pathogens. Dr Crew will present a component of this workshop on BBTV detection and diagnosis.

These activities were planned for June 2020, however COVID-19 restrictions have required postponement of these training, development and research activities until such time as travel to and within Papua New Guinea is allowed and safe.

Maintenance and provision of banana germplasm

The Australian banana germplasm collection was heavily relied upon to provide plants to all BA16001 variety evaluation and pre-commercialisation trials and supported a wide range of other Australian banana research projects and commercial growers. During the project 30,403 banana tissue culture plantlets from the germplasm collection were supplied from a wide range of cultivars:

- 8,523 plants for BA16001 variety evaluation and pre-commercialisation trials

- 10,187 plants for other Australian banana research projects
- 11,693 plants to meet commercial banana grower requests (fee for service charged for cost recovery)

The high-health status of the collection was maintained, to facilitate safe distribution of banana tissue culture plantlets across Australia. This included transition to the industry NIASA QBAN with Biosecure HACCP banana module at the end of 2020. Virus indexing of 213 germplasm samples entering the *in vitro* collection was conducted and banana suckers initiated into tissue culture under the industry clean planting (QBAN) scheme were certified as free of banana bunchy top virus.

The *in vitro* germplasm collection was maintained in good condition with 178 cultivars replaced from true-to-type plants from the field germplasm collection at SJRF.

Twenty-four new banana cultivars were imported for use in this project and 38 cultivar accessions were released for use in this and future projects, including some where processing has carried forward from prior project.

Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options

IPDM priority setting workshops

Three separate priority setting workshops were held with producers and industry service providers on 10/5/2017, 26/5/2017 and 22/1/2018, and the detailed results are presented in Appendix 12.

From these sources the identified priority pests and diseases were bunch pests, mites, leaf diseases and nematodes, which were identified in the original project proposal.

- Entomology research activities - flower thrips, banana rust thrips, banana scab moth and pest mites were reported as the highest concerns to tropical banana growers, with emphasis on research activities investigating elements of an IPM approach employing chemical, biological and cultural control strategies to manage pests. Consequently, the research activities focused on screening biological and new mode of action chemical products against bunch pests (thrips and caterpillars), investigation of cultural controls and pheromones for thrips, checking the genetic diversity of banana scab moth to investigate the host/race interactions and surveying and measuring the efficacy of biological control agents for banana rust thrips, banana scab moth and spider mites.
- Leaf disease research activities – management of yellow Sigatoka is dependent on the use of cultural practices (removal of diseased leaves, leaf trash and drainage management) and timely applications of systemic and protectant fungicides. Issues identified as priorities included potential loss of current fungicides through de-registration and resistance development, as well as a better understanding of the role of pre- and post-infection activity of existing products to improve efficacy during the wet season when spray intervals are regularly disrupted. Consequently, the research activities focused on screening an identified suite of fungicides, plant defence activators and biological products with varying levels of efficacy against yellow Sigatoka, to evaluate new 'softer chemical' options. The post-infection activity of systemic fungicides and oils was also investigated to identify when and which type of systemic fungicide would provide the best level of control during the wet season. The project will also support varietal leaf spot screening work conducted at South Johnstone to identify resistance levels in newly imported banana germplasm.
- Nematode research activities – the most damaging nematode pest of bananas worldwide is the burrowing nematode (Radopholus similis), however there are other major nematodes increasing on farms in all of the Australian banana growing regions, as identified by recent surveys of banana farms in Qld, WA and NSW. The pathogenicity and impact of these species is not well understood in bananas and more investigation is needed. The banana industry has been successful in reducing the amount of nematicides used to manage burrowing nematode through crop rotations and soil health management, however little is known about the host-status for these emerging nematode pests, and nematicide options have reduced significantly due to de-registration and loss of manufacturing capacity. Consequently, the research activities focused on assessing the pathogenicity of identified nematode species and developing new tools and information required to provide integrated management options for all nematode pest species, particularly investigating the host status of popular fallow crop species and identifying possible biological control products.

Entomology research

Bunch pests

Investigation of non-chemical/cultural control practices on banana rust thrips (Chaetanaphothrips signipennis) infestation and damage

Coloured traps and pheromone lures for flower and banana rust thrips

Different coloured traps were found to collect different numbers of both FT and BRT with significant differences between the colours. The greatest number of adult BRT were attracted to blue traps compared to all other traps. The predicted mean number of adult BRT was significantly higher for blue traps than all other traps.

Significantly greater numbers of FT were attracted to sticky traps with Lurem® T sachets compared to the control traps without lure sachets. Insufficient rust thrips were caught in the trial to warrant statistical analysis. The analysis of variance found a significant interaction of trap type and time (p=0.021). Pairwise comparisons found the lure trap mean FT catch 15 days after set-up was significantly higher than all other means. The lure was found to be most effective for about two weeks at which time numbers reached a peak. There was no significant difference in the mean trap catches over time for the control traps. Detailed results are presented in Appendix 15.

Influence of bunch cover colour

High thrips pressure in the trial block led to a preliminary trial to observe damage when bagged bunches were assessed with and without bell-injection. The results indicated the importance of bell-injection prior to embarking on the large-scale bunch cover trial due to the high thrips pressure. It was expected that the treatment would reduce thrips damage to a level where any differences would be assessable due to the bunch cover colours. Two field trials were conducted in 2018 and 2019 and their results in summary are:

- In 2018 orange plastic bunch covers produced significantly more rust thrips damage than all other treatments. This was confirmed in the 2019 trial, except where a spun-bonded liner was added to the orange polyethylene bunch cover, which resulted a significantly lower mean fruit damage rating. This was the only treatment with a significant difference in rust thrips damage between the same colour covers, with and without a spun bonded polypropylene liner
- In the 2018 trial craft paper bunch covers had the lowest mean fruit damage rating but were not significantly better than green, light blue, silver and white. In the 2019 trial craft paper, with and without a liner, were not significantly different from worst performing cover colour (orange) regardless of the presence of a liner
- In 2019 the white plastic bunch covers without a liner produced the lowest mean rust thrips damage, although it was not significantly different from blue (+/- liner), red (+ liner), paper (- liner) and orange (+ liner). This was consistent with the 2018 bunch cover trial in which white plastic covers also produced the lowest mean rust thrips damage of all the coloured plastic tested.
- The fruit damage ratings were higher across the treatments in 2019 compared to 2018, with none of the 2019 treatments providing a commercially acceptable damage of <1. The increased damage is likely due to increased thrips populations compared to 2018.

Overall, the results indicate different levels of banana rust thrips damage were associated with different bunch cover colours in the absence of insecticide applications. These findings have important implications as they provide an insight into how different coloured bags can be incorporated into an IPM program. These results have been communicated with bunch cover suppliers and producers at Roadshows and other extension activities.

Investigation of the genetic diversity of banana scab moth (Nacoleia octasema) to understand host/race interactions

During the last few years there have been increasing problems associated with banana scab moth (BSM) in both Lady Finger and Ducasse plantings on the Atherton Tableland and coastal areas. Growers have experienced difficulties controlling these moths as they are feeding on both the foliage of these varieties, as well as the bunches. In summary, the research results are:

- Fifty-eight scab moth samples were collected from Ducasse, Ladyfinger and Williams Cavendish grown at Mareeba,

East Palmerston and South Johnstone. DNA extractions and sequencing of the samples was conducted by DAF Biotechnologists. The partial COI gene sequenced compared DNA of forty collected specimens and six Genbank reference sequences for *N. octasema*. Three of the reference sequences originated from Australia and three were from Papua New Guinea.

- Within the forty *N. octasema* samples sequenced, only three unique sequences were identified and these were from larvae feeding on a bunch of Williams Cavendish at SJRF. These samples are more closely aligned with the Claudie River and PNG references, sitting between GenBank reference sample Claudie River (grouping by itself) and GenBank reference sample Mareeba (grouping with the bulk of the *N. octasema* samples).
- The majority of *N. octasema* samples aligned with the GenBank reference sample Mareeba. These samples included both leaf and bunch feeders from the three locations.

The results of this sequence analysis did not provide evidence for a host-race interaction. Samples feeding on leaves had the same DNA sequence as those feeding on bunches. This information does not prove the presence of a separate leaf feeding subspecies, however it does indicate the presence of separate mutation episodes occurring over a long time. Detailed results are presented in Appendix 15.

Identifying and screening IPM compatible insecticide products in field trials to support a broader range of chemical groups

As a high priority identified in the IPDM priority setting workshops the project investigated suitable IPM compatible insecticides from alternative insecticide groups for bunch pest control. Currently there are only 3 registered or permitted products for bell injection (Group 1B, 3A and 5) with concerns about resistance development for 2 of these due to other registered uses that target the same pest species. Three field trials were conducted in 2018, 2019 and 2021 examining 13 treatments each, including industry standard products and water as control treatments. The summarised results are:

2018 trial

- There was insufficient banana scab moth (BSM) damage to allow an analysis of control
- Banana rust thrips (BRT) damage assessments at bract fall were consistently low with insufficient damage to allow statistical analysis
- Flower thrips (FT) damage assessments showed that only 2 treatments had a damage rating significantly higher than the standard industry treatment T1 (omethoate (Group 1B) – the water control and T7 (combination Groups 22A & 15)
- 5 products, including the 2 industry standard treatments omethoate (Group 1B) and bifenthrin (Group 3A) recorded FT mean damage ratings less than 1 (0-4 scale, with 1 representing 1-10 “pimples” per fruit surface).

2019 trial

- There was insufficient BSM damage to allow an analysis of control
- BRT damage assessments at bract fall were consistently low with insufficient damage to allow statistical analysis
- Flower thrips (FT) damage assessments showed 2 treatments with significantly lower mean damage ratings than the industry standard treatment T5 (acephate – Group 1B) – T3 (combination Groups 4A & 6) and T12 (Group 5A)
- 6 treatments (T6 – industry standard spinetoram, Group 5; T7 – Group 4C; T9 – group unknown; T10 – Group 6&28; T11 – Group 6; T13 – Group 4A&23) provided mean FT damage ratings not significantly different from the industry standard treatment T5 (acephate – Group 1B)
- 3 treatments provided FT mean damage ratings not significantly different from the water control – T2, T4, T8.

2021 trial

- There was insufficient banana scab moth (BSM) damage to allow an analysis of control
- BRT damage assessments were delayed in this trial to provide more time for early damage to develop. Trial bunches were left unbagged on the parent plant after the initial assessments performed at bract fall and assessed

again when they reached harvest size. This additional assessment of BRT damage was performed to determine whether there was any residual insecticidal activity against this pest from the bell injection treatment.

- No treatments provided significantly lower FT mean damage ratings than the industry standard control T7 (spinetoram – Group 5), but T3 (treated as Group D) and T8 (Group 6) recorded equivalent mean damage ratings to T7.
- 7 treatments recorded FT mean damage ratings not significantly different from the water control – T4, T6, T9, T10, T11, T12, T13.
- For the BRT mean damage ratings at harvest no treatment produced a significantly lower rating than the industry control T7 (spinetoram – Group 5), but T3 (treated as Group D) and T13 (Group 4A) produced ratings that were not significantly different.
- 9 treatments recorded BRT mean damage ratings not significantly different from the water control – T1, T2, T4, T6, T8, T9, T10, T11, T12. These results should be interpreted cautiously as the assessment of unbagged bunches at harvest allowed for significant weathering of any residual product from bell injection treatment. In commercial practice the application of the bunch cover would likely preserve the activity of some of these treatments.

Overall, the trials have shown the potential for a number of insecticides from alternative chemistry groups to provide commercially acceptable control of FT, with indications of acceptable control of BRT. These data can assist with future decisions around advancing products for consideration and possible registration with a diversity of chemistries that are more IPM compatible and offer opportunity for meaningful rotations to manage the risk of insect resistance developing. Detailed results are presented in Appendix 15.

Identify and investigate suitable biological control agents for pest thrips in glasshouse trials

Four commercially available thrips predators were tested in a glasshouse pot trial at the SJRF to determine their efficacy in controlling banana rust thrips (BRT). BRT feed both on the plant tissues of the leaf bases/pseudostem and the fruit of banana, therefore it was decided to test the thrips predators in a controlled environment using potted plants. Four different biological control agents (treatments) were applied to the infested plants. There were three unique mite predators – Cucumeris (*Neoseiulus cucumeris*), Hypoaspis (*Stratiolaelaps scimitus* formerly *Hypoaspis miles*), Montdorensis (*Typhlodromips montdorensis*) – and one predatory bug, Orius (*Orius tantillus*) tested.

Assessments were made of the youngest leaf with BRT damage (YLD), the youngest leaf with characteristic V-shaped markings commonly, herein called youngest leaf with sergeant striping (YLSS) and the presence of aphids. Two assessments of YLD and one of YLSS and aphid presence/absence were made prior to the release of the predators, and three assessments made post application. Assessments were also conducted to identify the youngest unfurled leaf (YL) with thrips damage or active thrips. Once, the YL had been assessed, observations for symptoms of sergeant stripes (distinct V-ing) were conducted on the remaining leaves, and the leaf position recorded. Summarised trial results showed:

- Significant treatment differences for the youngest leaf with damage (YLD) assessments were found on the last 2 of the 3 post treatment assessment dates.
- On the second post treatment release assessment made 17 days after treatment (10/9/2021), the control plants had a significantly lower mean YLD (the youngest leaf with rust thrips damage) than both Hypoaspis and Orius treatments. This suggests that some level of control has been provided by these two biological control agents.
- At the third post release assessment (17/9/2021) the YLD for the control was only significantly lower than the YLD for Cucumeris, suggesting Cucumeris was providing some control of BRT on the plant.
- There was a significant difference between the YLSS for plants allocated to treatments at the pre-treatment assessment on 21/8/21. Fitting these pre-assessment YLSS values as a covariate in the post-release analysis of YLSS did not alter the overall conclusions.
- Only the final post-treatment assessment (17/9/2021) produced any significant treatment effects.
- At the final post-release assessment, the control plants recorded a significantly lower mean YLSS than Cucumeris. The mean for Cucumeris was also significantly higher than Hypoaspis and Montdorensis but not different from the Orius treatment.

Overall, the results indicated that some control of BRT was occurring on the potted plants. More detailed glasshouse and

field research is required to determine the potential for commercial application of these predators for control of BRT. Detailed results are presented in Appendix 15.

Foliar pests

Investigation of commercial use of the predatory mite Neoseiulus californicus (McGregor) for control of pest mites in banana plantations

Research into the efficacy of predatory mite species in coastal and inland areas was initiated in 2017. A very large data set was generously made available by a banana grower who provided several years of monitoring data. Spider mite adult and egg numbers were monitored routinely across the entire farm for 1.5 years before the predatory mite *N. californicus* was introduced into the growing system. Both spider mite and predator populations were routinely monitored after the introductions.

The monitoring data was analysed and converted to show average numbers of adults and eggs per row and was then graphed across time (Appendix 15). The data was assessed using cumulative frequency analysis to aid in understanding the effect of introducing the predatory mites from 29 May 2015. The cumulative frequency analysis or 'frequency of non-exceedance' calculates how often an observed value exceeds a reference value. The plots in the graph shown in Appendix 15 illustrate the percentage of values that exceed a given value. In summary:

- The analysis of this data set suggests that the predatory mite *N. californicus* does impact on spider mite populations in bananas.
- The extent of this influence is difficult to statistically evaluate, however the frequency of exceedance plots suggest that the predatory mite did lower spider mite populations on this farm.
- It's important to note that the data analysis and assumptions made from the analysis are dependent on the integrity and consistency of data collected through monitoring. Monitoring methods and data may vary between individual crop monitors and in this instance, monitoring was not undertaken by DAF staff.
- Another consideration is the management practices used concurrently with predatory mites. Reduced and or absence of miticide applications significantly determine predator populations and efficacy.

The analysis of data from this farm provided good evidence to continue further studies into the efficacy of the *Neoseiulus californicus* predatory mite species on spider mite in bananas.

Investigate efficacy of the Neoseiulus californicus for control of the pest mite Tetranychus lambi

In 2021, a trial was undertaken to investigate the efficacy of the commercially available predatory mite, *Neoseiulus californicus,* in controlling the strawberry spider mite *Tetranychus lambi* on Williams Cavendish banana plants at 2 different rates in a glasshouse environment. The predatory mite is known commercially as "Californicus". This trial compared the efficacy of two different stocking rates for the application of the predator.

Assessments consisted of:

- Counts of pest mite adults, nymphs and eggs
- Leaf damage index to determine any differences in leaf damage relating to pest mite feeding damage.
- Leaf development index to investigate if pest mites feeding on banana leaves had an impact on leaf development, especially new leaf emergence rates.
- Final plant biometric data to investigate if pest mite feeding damage influenced various plant growth parameters such as fresh weight and plant height.

A summary of the trial results is:

- Pest mite numbers declined in all treatments with increasing time
- Significant differences between the treatments were observed at day 42, 55, 63 and 70, all occurring after the predatory mites were introduced.
- At the first assessment after the introduction of the predators (day 42), the control treatment had a significantly higher mean *Tetranychus lambi* nymph count per plant than the lower rate predatory mite treatment. At day 55,

63 and 70, the control had a significantly higher mean nymph count than the higher rate predatory mite treatment but was not significantly different from the lower rate treatment until day 63. These results may suggest the control of the pest mites has occurred more quickly with the higher rate treatment compared to the low treatment.

- The results of the weekly average plant growth rate found no significant difference between the treatments ($p = 0.958$).
- For the leaf damage index, no significant treatment effect was detected at count 1 ($p = 0.218$), count 2 ($p = 0.932$) or count 3 ($p = 0.498$).
- For the final plant measurements, no significant differences between the treatments were found for any of the attributes measured ($p > 0.05$).

While the results were not as definitive as expected the analysis of the grower data, and some of the glasshouse trial data, indicate that the use Californicus to manage pest mites is worthy of further investigation.

Plant pathology research

Yellow Sigatoka leaf disease

Investigating post-infection activity of systemic fungicides and oils to improve control during the wet season when periods of high infection pressure coincide with reduced spray opportunities

Initial experiments compared the 'fitness' of collected *P. musae* for production of conidia, selecting the most fecund isolate for the experiment. Using a purpose-built 'dew' chamber, TC plants inoculated with conidia developed typical Sigatoka lesions 34-43 days post inoculation, confirming that artificial inoculation was successful.

However, subsequent experiments investigating post-infection activity of fungicides and spray oils were inconclusive due to inconsistent symptom expression – either failure of inoculation in treatments or delayed symptom expression (64-69 days) confounding results due to natural leaf senescence masking treatment effects. Attempts to address inoculation failures through increased inoculum treatment concentrations were restricted by the inherent difficulty of producing sufficient single spore inoculum *in vitro*. Limitations of the 'dew' chamber meant that we were also unable to create optimal conditions for the development of the disease. Due to these difficulties the investigation was concluded.

Any future work in the development of this technique needs to focus on reducing the incubation period of yellow Sigatoka by maximizing spore production from isolates used to inoculate the test plants and creating optimum environmental conditions for the development of the disease. Correspondence with Dr. David Jones and Dr. Bob Fullerton, both of whom have used a similar technique to evaluate banana germplasm for susceptibility to Sigatoka, was unable to shed any light on why we have been unable to consistently develop Sigatoka lesions in controlled studies.

Identifying and screening a range of products in field trials at SJRF, including fungicides, plant defence activators and biological products, to identify IPDM compatible products with efficacy against yellow Sigatoka

The 2019 and 2020 trials compared 10 and 9 new products/spray programs with 2 and 3 industry standard treatments respectively. Disease pressure was moderate-severe for the duration of both trials due to consistently warm, wet conditions. There was no significant difference between the total number of leaves produced per plant at any of the three assessment points for either trial, indicating that no treatment had adverse effects on the rate of leaf emergence of the treated plants. Significant results from these trials were:

- Most organic-style treatments provided significantly less disease control than the industry standard treatments mancozeb plus paraffinic oil or chlorothalonil
- One product (Group 7 and 12 combination) demonstrated significantly better control than industry standard treatments, with the alternative systemic product (Group 5) plus paraffinic oil providing control equivalent to the industry standard treatments
- Incorporating the plant defence elicitor into the commercial spray program (substituted for every second fungicide application) provided equivalent control to the commercial spray program while reducing the total number of fungicide applications
- 3 new products performed sufficiently well to warrant further investigation in commercial style spray

programs – a Group 5 fungicide with systemic action, a combination of active ingredients from Groups 7 and 12 with systemic and protectant activity respectively and a plant defence elicitor.

The 2021 trial comprised 7 spray program treatments based around the 3 products identified in the 2019 and 2020 trials. Each product was tested in programs based around mancozeb plus paraffinic oil, or Serenade® Prime plus paraffinic oil, as these were the dominant protectant fungicides used by the industry whilst still allowing application of trial chemicals with paraffinic oil. The main results from the trial were:

- No new treatment program provided significantly better control than the industry standard mancozeb plus paraffinic oil or chlorothalonil programs, although 3 programs containing the 3 identified products combined with mancozeb plus paraffinic oil provided equivalent disease control
- Overall, the programs that contained mancozeb as their protectant fungicide provided a significantly better level of disease control compared to those based around Serenade® Prime or paraffinic oil only, although these other treatments stilled provided adequate control
- The best performing new program treatment was the Group 7 and 12 product with the mancozeb program which showed no significant difference to the two most widely used and best performing industry controls (mancozeb plus paraffinic oil program, and chlorothalonil program).
- Disease control achieved applying the Group 5 fungicide plus mancozeb program, and the plant defence elicitor plus mancozeb program was as effective as the industry control, mancozeb plus paraffinic oil program.
- The plant defence elicitor plus mancozeb program resulted in reduced volume of products applied – 13.2kg less Mancozeb 750 WP and 30L less paraffinic oil per hectare – over the trial period when compared to the industry standard program consisting of mancozeb plus paraffinic oil program
- There were no significant differences between the control treatment 5L/ha paraffinic oil only or the plant defence elicitor plus 3L/ha paraffinic oil treatment. Based on the results, it is possible to achieve comparable disease management to the paraffinic oil control (5L/ha) with 2L/ha less oil per application and the addition of the plant defence elicitor applied as every second spray.
- Bunch assessments were conducted on the 15 November 2021 to measure datum bunch sizes. There was no significant difference between treatments for the total number of hands per bunch ($p = 0.740$), or for the total number of fingers per bunch ($p = 0.290$), indicating no adverse effects on bunch size resulted from the trial treatment applications.

Detailed results of all trials are presented in Appendix 13.

Supporting varietal leaf spot screening conducted at the SJRF

Project plant pathology staff have supported the planning for the yellow Sigatoka varietal screening activity with discussions on assessment methodology to be used, particularly the timing and number of assessments and consideration of seasonality impacts on results.

Bacterial corm rot research

Investigate if Pectobacterium and Dickeya species are still the primary organisms implicated with BCR symptoms.

Recovered bacterial isolates from BCR samples collected from the field were subjected to molecular analysis to accurately identify species associated with BCR symptoms. This resulted in the identification of *Dickeya fangzongdai* as a newly associated causal organism and this information was provided to Biosecurity Queensland. The *D. fangzongdai* isolate was genetically different to other strains previously described and associated with BCR. Additional studies of historical *Dickeya* spp. and *Dickeya chrysanthemi* isolates from a range of hosts were compared to those recently recovered from banana to determine if BCR isolates or strains are endemic to Australia or have been previously mis-identified. The bacterial isolates recovered from banana finger rot symptoms and banana corm rot were identified as *Dickeya zeae* (E20_570_1) and *D. fangzongdai* (E20_571_1) respectively, using molecular gapA and dnaX sequences.

Koch's postulate was conducted and confirmed the pathogenic nature of *Dickeya fangzhongdai* (E20_570_1) by inoculating 4 tissue culture plants of Williams Cavendish (6 month old plants). Isolations and identification were made from inoculated and uninoculated plants to prove pathogenicity. The inoculated plants showed initial marginal yellowing

of lower leaves after 10 days and these then turned brown in colour and marginal yellowing progressed to young leaves after five weeks. After 7 weeks, plants were dissected and exhibited black discoloration (no putrid smell), like those observed in naturally infected plants. No symptoms were observed in the control treatment.

Isolations and recovery of *D. fangzhongdai* from symptomatic corm tissue confirmed its pathogenic nature. This proved the presence of other *Dickeya* spp./strains, in addition to those earlier reported *Dickeya* species that could cause major losses to banana production under certain environmental conditions. This was the first report of *D. fangzhondai* causing banana corm rot in Australia. Detailed trial results are presented in Appendix 14.

Investigate the potential to significantly reduce the greater BCR infection rate in plantings established with TC plants by varying the in vitro plantlet cutting technique to reduce the sucker number on tissue cultured plants

Working with a local tissue culture laboratory and nursery, 75 plants each of the standard technique and the modified technique were supplied to DAF and potted up and assessed at 3-month intervals in the glasshouse at SJRF with growth parameters assessed for all plants e.g. stem diameter and plant height. After the second glasshouse assessment, six plants of each cutting type were planted in the field at SJRF for further assessment on sucker development. These plants were uprooted after four months, and assessments made recording the number and origin of suckers, peepers and buds.

A statistically significant reduction in sucker number was observed in the modified cutting technique, with a reduction from 1 to 0.2 per plant at the first assessment in the glasshouse pot trial for the standard and modified cutting techniques respectively. Additionally, a 50% reduction in early sucker development was recorded between the standard and modified cutting techniques from the in-field plants. Detailed trial results are presented in Appendix 14.

The study has indicated that sucker production can be reduced by removing excess tissue below the growing point during micropropagation. This may potentially decrease the incidence of BCR while providing other significant economic benefits, through labour and cost savings due to reduced desuckering. The technique is being adopted by Mission Beach Tissue Culture Nursery and will be assessed further at commercial scale for sucker development and BCR management. The above information was presented in a poster format at the Australian Banana Industry Congress in Cairns, May 2021 and to growers at a SJRF field walk in June 2021.

Nematology research

Field surveys

A national survey of 126 sites (38 farms NQ – Lakeland Downs, Atherton Tablelands, Innisfail, Tully; 10 farms SEQ; 12 farms NSW; 41 farms WA – Carnarvon) identified seven main plant-parasitic nematode pests in banana crops: *Meloidogyne* spp. (root-knot nematode, 3 species), *Helicotylenchus multicinctus* (banana spiral nematode), *Radopholus similis* (burrowing nematode), *Rotylenchulus reniformis* (reniform nematode) and *Pratylenchus goodeyi* (banana lesion nematode). Some species were widespread (root-knot and banana spiral nematode were prevalent nationwide), but others such as reniform nematode (north Queensland) and banana lesion nematode (SEQ/NNSW) were more restricted in their distribution. *R. similis* is confined to the east coast of Australia, *P. goodeyi* is confined to the subtropics, while molecular identification confirmed that the three *Meloidogyne* species (*M. arenaria, M. javanica* and *M. incognita*) are all prevalent in Australian banana production areas. Detailed survey results are presented in Appendix 17.

Pathogenicity testing of plant-parasitic nematodes

The most damaging nematode pest of bananas worldwide is the burrowing nematode (*R. similis*). However, other plant-parasitic nematodes are becoming more prevalent in Australian banana growing regions. The pathogenicity of these species on banana was studied in glasshouse pot experiments by inoculating Williams Cavendish banana plants with different species of plant-parasitic nematodes.

Pathogenicity was determined by comparing banana growth parameters (top fresh weight, root fresh weight, height to highest leaf axil, pseudostem diameter at 4cm above soil) of inoculated plants with uninoculated plants, and by calculating nematode multiplication.

Radopholus similis, M. javanica, M. incognita and *M. arenaria* (root-knot nematodes) multiplied well on banana, demonstrating the host potential of bananas. Furthermore, these four species all reduced growth of bananas,

demonstrating pathogenicity in glasshouse pot trials.

While *R. reniformis* (reniform nematode) reproduced well on banana in this study there were no reductions in any measured plant parameters. This shows banana is a good host of *R. reniformis*, but that this nematode may not impact the growth of banana. Further data from field trials may be desirable for this species. Detailed trial results are presented in Appendix 17.

The reduced growth of banana plants found in these experiments demonstrates the pathogenicity of burrowing and root-knot nematodes and will translate to lost productivity if not managed in banana plantations.

Identifying and screening non-host fallow crops

Host range studies in the glasshouse screened 40 cultivars from 24 plant species for resistance to burrowing nematode. For a rotation crop to be deemed as having good resistance to burrowing nematode and banana lesion nematode it must reduce the population by more than 95% compared with banana controls in glasshouse experiments. A total of 30 cultivars from this screening work have been identified with 95-100% resistance to *R. similis,* and would be good options to plant as non-host crop rotations to reduce *R. similis* numbers in the soil (Appendix 17). Four low-growing interrow grass species were screened for resistance to two species of root-knot nematode (*M. incognita, M. javanica*), while six plant species were screened for resistance to *P. goodeyi*. Sweet smother grass was identified as highly resistant to both *M. incognita* and *M. javanica* while narrowleaf carpet grass was identified as resistant to *M. javanica*. Sunn hemp, Jumbo sorghum, Wilson pinto peanut, narrowleaf carpet grass, sweet smother grass and green couch were all 95-100% resistant to *P. goodeyi* (Appendix 17) and would be good options to plant as non-host crop rotations to reduce *P. goodeyi* numbers in the soil. Detailed trial results are presented in Appendix 17.

Information on the host status of these and other plant species that have been tested against plant-parasitic nematodes of concern for banana growers can be found on the Lucid key developed during this project.
https://keys.lucidcentral.org/keys/v3/crop_rotation_plant_parasitic_nematodes/

Identifying and screening a range of non-chemical and biological control products

An integrated nematode management strategy using biological formulations has many potential advantages, providing efficacy of nematode suppression or increased plant tolerance can be demonstrated.

Banana plants inoculated with *R. similis* (burrowing nematode), a migratory endoparasitic nematode or *M. javanica* (root-knot nematode) a sedentary endoparasitic nematode or left uninoculated, were treated with formulations or combinations of plant extracts, bio-stimulants, microbial soil conditioners, Humic acid, Fulvic acid and a hydrophilic concentrate product. These are purported to potentially stimulate plant growth, plant defence responses and/or directly or indirectly reduce the abundance of nematodes.

Results from the experiments using products S1, S2, A1, A2, H1, B and G (some at multiple rates) showed they were not effective biological products to reduce numbers of *R. similis* in infested banana plants, however, product G did increase the root weight of banana plants.

Furthermore, the products S1, S2, A1, A2 and H1 were not effective biological products to reduce numbers *of M. javanica* in infested tomato plants, however, the S2 product enabled the tomato plants to tolerate the presence of *M. javanica* as it increased plant height and top weight in the presence of *M. javanica*. Detailed trial results are presented in Appendix 17.

As a result, we found no evidence that any of the biological products tested would actively help to control plant-parasitic nematodes if added into an integrated management system for bananas.

Screening for resistance in the banana varieties PKZ and FHIA-17

With TR4 threatening our banana industry, new cultivars are being developed and introduced into Australia to slow the spread of that disease. It is important to know the susceptibility of new banana cultivars to other pests and diseases in Australia. Plant-parasitic nematodes can be destructive to banana production should these new cultivars be particularly susceptible.

FHIA-17 and PKZ are all less susceptible to *R. similis* than Cavendish cv Williams, with both varieties having significantly lower reproduction factors and number of nematodes/100 gram of roots at harvest. FHIA-17 hosted the least reproduction of *M. incognita* in terms of numbers of nematode/100 gm of roots compared with Cavendish cv Williams

and PKZ, which were not significantly different. Detailed trial results are presented in Appendix 17.

Conduct nematology training for WA DPIRD staff

During the first years of the project, two plant pathologists/agronomists from WA were trained in nematode extraction and identification in laboratories in SEQ. They also had the opportunity to spend several days in the heart of banana production in FNQ, gaining knowledge of the local production systems.

Virology research

Taxonomic and biological characterization of the banana picorna-like virus and test results for a wide range of Australian banana germplasm

In May 2020, the new banana picorna-like virus was detected in germplasm lines grown in the PEQ glasshouse. Three RT-PCR amplicons from the diagnostic assay (representing three germplasm lines) were sequenced and were 100% identical to each other and 99.9% identical to the original isolate (across 545 nt). A summary of the research results is:

- Visual symptoms observed in infected plants were twisted leaves, patchy thickening of secondary veins, reduced rates of unfurling of the new leaf and necrosis of secondary veins. Infected plants were only grown in pots in the PEQ glasshouse for approximately 6 months, so the yield effect of these symptoms could not be assessed.
- A small screening activity of 37 varieties from the Australian banana germplasm collection returned negative results for the virus, hence it is likely that the banana picorna-like virus is exotic to Australia.
- Mechanical transmission was demonstrated via an abrasive sap solution and secateurs, and standard sanitising practices prevented transmission.

The banana picorna-like virus is readily transmissible from banana to banana and this research has been communicated with the DAF tissue culture laboratory, the importer of the material and the supplier. The results of the transmission test and Australian germplasm testing have been provided to DAWE for evaluation. It is likely that the banana picorna-like virus will be added to the list of exotic species imported germplasm must be tested for, to preclude unknowing importation of this potentially economically important virus. A scientific manuscript detailing the virus detection, genome sequence and detection assay is being prepared for peer-reviewed publication. Detailed trial results are presented in Appendix 16.

Documentation of the symptoms of BBTV in Alpinia sp., knowledge of BBTV symptoms of infected Fe'i banana cultivars, genome sequences for BBTV-Alp from Alpinia purpurata and a Fe'i banana and bioinformatic analysis of these sequences in comparison with typical BBTV

In 2017, an isolate of BBTV was detected in *Alpinia* sp. (Family Zingerberales) on Tahiti, in French Polynesia. Until this detection, BBTV was not known in French Polynesia. The island of Tahiti, French Polynesia hosts the South Pacific banana field germplasm collection, which is curated by Dr Maurice Wong (Direction de l'Agriculture). With supplementary travel funding from the Crawford Fund, Dr Crew visited Dr Wong and his staff at the Direction de l'Agriculture, French Polynesia in August 2018 and hosted a visit of Dr Wong and Ms Melanie Vairaa in April 2019.

The visit to Tahiti determined the symptoms of BBTV in *Alpinia* sp, collected reference material for this isolate (which was returned to Australia for sequence analysis), discussed further research to characterize this isolate (transmission to Cavendish banana, confirmation of other alternative hosts), and trained local colleagues in the suite of current banana virus indexing assays used in PEQ in Australia. A summary of the research results is:

- High throughput sequencing of the BBTV-Alp viral genome shows the BBTV-Alp appears to lack one of the 6 components present in typical BBTV and shows significant recombination events in the 6 identified components.
- Additional to the detection of BBTV in *Alpinia* sp., field infection of *Heliconia* sp. has also been reported from Hawaii, USA (Hamim et al. 2017). Our Hawaiian colleagues hope to be able to send preserved tissue from their collection or identify other field infected Heliconia plants to allow comparison with BBTV-Alp and typical BBTV isolates.
- The symptoms displayed by infected *Alpinia* sp. plants were stunted, chlorotic, bushy growth with dark green dot-dash lines on the laminar and hooks into the midrib typical of BBTV in banana. Flower size was also dramatically reduced. Similar symptoms were observed in *Alpinia vittata* plants.

- Disease incidence in *Alpinia* sp. was very high, approaching 100% in many localities, and infected plants were widespread on the two islands visited with detections on 2 additional islands (from 6 islands surveyed). Movement of planting material and cut flowers carrying *Pentalonia* sp. aphids is assisting with distribution of BBTV-Alp.
- No banana plants growing in close proximity to infected *Alpinia* sp. displayed typical BBTV symptoms.
- Indexing of the South Pacific germplasm collection detected BBTV in a single Fe'i banana plant, however this plant did not display typical symptoms. No literature is available that documents symptoms of BBTV-infected Fe'i bananas, so it is unknown whether the lack of typical symptoms in the plant with BBTV-Alp is because of the host genotype or characteristics of this isolate of BBTV.
- In bananas inoculated with standard BBTV at ESP, the cv. 'SAR-219' plants died, but inoculations were successful for Fe'i banana cv. 'Utufun', 'Wain', 'Menai' and 'Riminia' plants, and the Cavendish control plants. 'Utufun', 'Wain' and 'Menai' plants had symptoms of typical BBTV infection, however no symptoms were observed in the BBTV-infected cv. 'Riminia' plants.
- French Polynesian colleagues will conduct transmission experiments to infect Cavendish bananas with BBTV-Alp to observe its symptomatology, and to other related plant species to investigate their status as alternative hosts.
- Current BBTV indexing assays (ELISA, IC-PCR) detect BBTV-Alp, however they do not differentiate between BBTV-Alp and typical BBTV.

Dr Crew has notified DAWE, Biosecurity Queensland and NSW DPI of the identification of a non-banana host of BBTV, so that consideration can be given to the policy/regulation implications for border and local biosecurity. DAWE has currently imposed a temporary ban on the import of plants from the family *Zingiberales* from the south Pacific region, however additional information including knowledge of the distribution of BBTV-Alp in the Pacific as well as its host range are required for implementing long-term policy changes. Should BBTV-Alp and typical BBTV co-infect a single plant, recombination or reassortment events could occur that allow development of a severe strain of BBTV which readily transmits between bananas and alternative hosts. Detailed trial results are presented in Appendix 16.

Complete genomes of three novel banana ampeloviruses detected in south-east Asian germplasm and design of diagnostic primers for molecular assay detection of these viruses

Ampelovirus particles (family *Closteroviridae*; with very flexuous rod-shaped particles) were detected by electron microscopy in five international germplasm accessions from two south-east Asian countries. South-east Asia is an area from which new banana germplasm is currently being imported for TR4 disease management in Australia. While ampeloviruses are new viral detections for banana, they are known to cause economically important diseases in pineapple (pineapple mealybug wilt disease) and grapevine (grapevine leafroll disease). The related Citrus tristeza closterovirus also causes an important economic disease in citrus. Additionally, freedom from viruses with rod-shaped particles is a critical requirement of the testing prescribed on DAWR import permits. Hence, a robust, sensitive and rapid molecular detection assay(s) needs to be developed for the banana ampeloviruses. A summary of the research results is:

- Ampelovirus isolates from the DAF Plant Virus Isolate Collection originated from Vietnam and Indonesia. RNA was extracted and bioinformatics analysis was conducted using Geneious (Biomatters, New Zealand), with additional high throughput sequencing undertaken through AGRF (Melbourne, Australia).
- Two distinct full genomes (13,239 and 13,224 nt respectively) were assembled, and phylogenetic analysis placed them with other subgroup II ampeloviruses.
- Comparison of sequences from other accessions indicated that further ampelovirus diversity exists. Additional sequencing of the other four isolates in which ampelovirus particles were detected revealed a third species of group II ampelovirus with a genome of 12,783 nt.
- Accessions were either singly infected or had a mixed infection of two of the three viruses. Multiple related virus species in a single host species is not uncommon for ampeloviruses (e.g. five species of pineapple mealybug wilt-associated virus, four species of grapevine leafroll ampelovirus).
- Limited regions of conserved nucleotides exist between the genomes, making design of a set of diagnostic primers for use in PEQ indexing a challenging task.
- Several sets of primers were designed and have been received, however COVID-related disruptions

means that they are yet to be tested and incorporated into PEQ indexing.

Detailed trial results are presented in Appendix 16.

Diagnostic services for endemic plant diseases and pests

Unseasonal weather conditions, the TR4 outbreak and the COVID-19 pandemic impacted on the number of diagnostic samples received during the project. However, 414 samples were received for pathology (290), entomology (17) and virology (107). No exotic pathogens or pests were reported throughout the project, but there were new findings including two *Dickeya* species associated with bacterial corm rot and a caterpillar (*Pyroderces* sp.) commonly referred to as 'pink scavenger'. The latter was only identified in the Lakeland Downs region causing damage to the fruit peel on a number of farms. Detailed trial results are presented in Appendix 18.

Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry

Quarterly videoconferencing

The quarterly videoconferences (QVC's) were held 3-4 times per year in a 1 hour webinar format that invited project team members from BA16001 and other projects to report on their activities and findings and answer questions from participants. Agenda items and presentations were canvassed amongst the banana RD&E network before each QVC, with a rotation of researchers reporting to try and ensure an equal opportunity for all participants to report on their work.

Table 2. Record of QVCs conducted during BA16001

Date	Participation	Evaluation conducted
30/8/17	24	Yes
22/11/17	27	Yes
28/2/18	27	
24/5/18	29	Yes
27/9/18	21	
5/2/19	31	Yes
2/5/19	27	
29/8/19	17	
7/11/19	25	
12/2/20	21	
20/5/20	33	Yes
12/11/20	24	
3/2/21	29	
20/5/21	5 – Theme leaders	

The option to record the webinars and upload the file to the project SharePoint site meant that the content of all the QVCs was available for members of the banana R&D network to watch at their convenience if they could not participate on the day. Evaluation of the QVCs was undertaken at regular intervals to track progress against its objective of improving cohesion and communication within the network of R&D providers and improving knowledge of plant protection R&D activities.

Banana Scientific Symposia

The project plan proposed 2 workshops between the Australian Banana Industry Congress and the Banana Industry Roadshows organised by the National Banana Development and Extension project (BA16007/BA19004). Two Banana

Scientific Symposia were held during the project in November 2018 and April 2021. The second symposium was originally planned for November 2020 but was delayed due to COVID-19 restrictions on travel and group gatherings. The 2021 symposium included on-line participation and presentation to help overcome the travel restrictions and assist remote participation, as well as facilitating the remote involvement of a keynote international speaker, Dr Phillipe Tixier from CIRAD. Participation in both symposia was excellent with 55 attendees from 8 agencies/institutions in 2018, increasing to 82 participants (60 in person and 22 on-line) from 11 agencies/institutions in 2021.

Evaluation was undertaken for both events to measure progress in achieving the objectives of improved networking, communication, knowledge of R&D activities and collaboration, with results showing significant achievement of these. A detailed report for each symposium is presented in Appendix 19, including evaluation results.

Project SharePoint site

The project communications and extension activities spreadsheet was successful in recording the details of team members' communication and extension activities. A summary of the extension and communication outputs is summarised below, with a detailed report in Appendix 20.

Table 3. Summary of communication/extension outputs from the project

Communication/extension activity	Number	Attendees/participants
Producer/industry service provider audience		
Roadshow presentations	53	218
Seminar/meeting presentations	9	115
Industry workshops	8	127
Field walks	11	231
Australian Banana articles	36	1200*
Conference presentations/posters	24	843
Radio interviews	3	N/A
Scientific community audience		
Peer reviewed papers	3	N/A
Conference papers	3	N/A
Conference presentations/posters	16	2110
Workshop/seminar presentations	14	217

* Distribution mailing list

Usage of the project SharePoint site by all team members was not as high as intended, although the ability to progressively capture the communication/extension outputs and to host recordings of QVC's was very valuable. Evaluation of the overall usage of the SharePoint site remained roughly static during the period assessed, with 42 and 46% of respondents reporting that they had accessed the sites during the project (Table 4).

Table 4. Evaluation of usage of the project SharePoint site

Have you accessed the project SharePoint site? (% of respondents)		
	Feb 2019 (n=20)	**May 2020 (n=30)**
Yes	42	46
No	58	54

Outputs

Table 1. Output summary

Output	Description	Detail
Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance		
5 Material Transfer Agreements and 1 Memorandum of Agreement established with international agencies for germplasm supply	5 MTAs and 1 MoA signed with international agencies to access banana germplasm for importation and screening	The project established 1 MoA with the TBRI and 5 MTAs with TBRI, CIRAD, EMBRAPA and EPAGRI to access identified banana germplasm for disease resistance and agronomic screening; these agreements have allowed access to a range of varieties that are not readily available to other banana producing nations, especially TR4 resistant Cavendish selections from TBRI.
23 new banana varieties imported into post-entry quarantine	23 new banana varieties introduced into Australia for disease resistance screening and agronomic research	23 new banana varieties have been identified and imported into the post-entry quarantine process in Australia; the strategy behind the identification and importation of new varieties was agreed with representatives of the banana industry and banana supply chain.
37 varieties and 17 parental lines screened for resistance to TR4	A total of 37 varieties and 17 parental breeding lines have been fully screened across 2 field trials for resistance to TR4	Field trials assessing banana varieties for TR4 resistance have screened 37 varieties and 17 breeding lines used by key banana breeding programs; associated trial data on disease reaction collected for 41 banana varieties and 17 parental breeding lines; from these trials 14 lines with sufficient resistance to TR4 have been identified, including 6 Cavendish selections, 6 hybrids from conventional breeding programs and 2 cooking banana types; these results have contributed to the identification of varieties for deployment in on-farm pre-commercialisation trials; 9 parental lines with high resistance have also been identified and these results have been shared with the key breeding programs in Honduras, France and Brazil.
32 varieties assessed for their agronomic performance	32 varieties have been assessed over 3 crop cycles for their agronomic characteristics	23 Cavendish lines, 4 novel hybrids and 2 Lady Finger selections have been compared to industry standard varieties for their agronomic performance at SJRF; agronomic performance data collected for 28 varieties over 2 crop cycles in FNQ; 1 Cavendish variety with yields slightly less than Williams (and TR4 resistance better than Formosana) has been identified for progression to on-farm commercialisation trials; 4 privately imported and 1 other Cavendish variety have demonstrated equivalent production to Williams while demonstrating more desirable plant stature.
Fusarium wilt Race 1 disease resistance data collected for 7 varieties	7 varieties have been assessed for Race 1 resistance in the subtropics	Field trial data on disease resistance has been collected for 7 varieties under subtropical conditions, including 3 Lady Finger hybrids and 4 Cavendish selections; from this trial 2 varieties – JV 42.41 (Lady Finger hybrid) and Plantanera Brier (Cavendish selection) have been included in subtropical pre-commercialisation trial plantings in 2022.
2 disease resistant varieties identified in BA10020 subtropical trials	Consumer acceptability and productivity assessed for 2 varieties	Field trial data on productivity, post-harvest attributes and consumer acceptance was generated for the disease resistant varieties PKZ and FHIA-17; poor consumer acceptability of both varieties compared to Cavendish from NNSW and FNQ resulted in the recommendation to not proceed with commercialisation of

assessed for possible commercialisation	identified in BA10020 subtropical trials for possible commercialisation	these varieties.
5 improved selections of Goldfinger identified	5 variants of Goldfinger with improved eating characteristics have been identified to progress to the next assessment phase	The Goldfinger variety has desirable disease resistance and agronomic performance but has poor consumer acceptability; the project BA14104 developed variants using mutagenesis with the objective of improving the consumer acceptability; the phase 2 assessment was assumed by BA16001 after the completion of BA14014; 5 selections were identified from an original 20 selections in phase 2 assessments for formal consumer acceptability research; selections highly favoured in these assessments will be progressed to on-farm pre-commercialisation trials.
17 TR4 resistant Cavendish selections developed by mutagenesis re-introduced to Qld	17 TR4 resistant Cavendish selections developed by mutagenesis have been re-introduced into Qld from NT as *in vitro* cultures	These new TR4 resistant Cavendish selections were developed by mutagenesis in BA14014 and initial screening of the individual plants was conducted in NT in the presence of TR4; the importation and subsequent establishment of *in vitro* cultures of the 17 selections at the DAF tissue culture laboratory means that these plants can now be maintained and move to phase 2 screening in the major production region in FNQ.
5 pre-commercialisation trials established on commercial farms	5 pre-commercialisation trials are established on farms across NQ and NT to observe agronomic performance	5 trials sites on commercial farms have been established to gather qualitative data on the performance under commercial growing practices of identified with potential for commercialisation; 75-300 plants of up to 3 TR4 resistant Cavendish varieties have been planted at each site.
Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties		
Release of 29 new varieties from post-entry quarantine	29 new banana varieties screened and released from post-entry quarantine	29 new banana varieties have been safely released from post-entry quarantine and are now available for research and grower based assessments; those varieties released from 2017-20 have been included in field trial assessments within the project.
15 new varieties currently in the PEQ system	15 new banana varieties are currently held in PEQ TC laboratory prior to finalisation of PEQ screening	As well as varieties already released from PEQ for disease resistance screening, 15 additional varieties have been imported and are held in the PEQ TC laboratory; 13 varieties are currently undergoing pest and disease screening in the PEQ glasshouse; these new varieties will constitute a key part of the future trials assessing disease resistance and agronomic performance.
Protocol developed for the movement of *in vitro* cultures from NT to Qld	The protocol addressed biosecurity risk associated with movement of plant material	The protocol was developed by BA16001 project staff to allow the importation of *in vitro* cultures and leaf material for virus indexing from NT into Qld; the protocol was required to address biosecurity risks associated with the movement of banana plant material; as a result, 17 mutated Cavendish selections were able to be re-introduced to Qld to be maintained and supplied for future research activities.

	from NT to Qld	
30,403 high health tissue cultured plantlets supplied for research and commercial purposes	30,403 TC plantlets of varieties held in the Australian germplasm collection have been supplied to researchers and commercial producers	BA16001 research activities, other research projects and commercial producers request small volumes of specific varieties held in the Australian banana germplasm collection; of the 30,403 high health TC plantlets supplied, 18,710 were supplied for research activities and 11,693 for commercial producers; a fee-for-service cost recovery system charges for plants used outside of BA16001.
Renewal of *in vitro* cultures of the Australian Germplasm collection	178 varieties held in the Australian banana germplasm collection have been renewed	178 varieties held in the Australian banana germplasm collection have been renewed with fresh *in vitro* cultures as part of the maintenance of the germplasm collection; long term storage of *in vitro* cultures leads to the development of off-types and possible loss of the true-to-type variety; a major part of maintaining true-to-type (TTT) material in the germplasm collection is regular renewal of the *in vitro* cultures; this ensures that research projects and commercial producers can access TTT material.
Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options		
IPDM work priorities outputs from industry workshops and SARP	IPDM work plan based on priorities developed with grower stakeholder input	3 workshops conducted with growers and key stakeholders in FNQ identified the high priority issues for the project to address – bunch pests, mites, leaf spot and nematodes; work plans for IPDM research were developed from this input.
Field trial data set for non-chemical management options for banana rust thrips	Cultural/non-chemical management options for BRT investigated in field trials in FNQ	1 field trial investigating the use of pheromones and colours to attract pest thrips was conducted, leading to 2 additional trials investigating the attractiveness of bunch cover colours to BRT and associated fruit damage; attractive and unattractive colours were identified and this information has been conveyed to industry and key input suppliers.
Genetic diversity data set on banana scab moth	Genetic diversity in BSM was screened to understand observed host/race relationships	Genetic diversity data has been analysed to investigate unusual foliar feeding behaviour of BSM in the Atherton Tablelands region; analysis of 58 collected BSM samples did not indicate a genetic basis for the observed behaviour; these results have been communicated to growers and industry stakeholders.
Efficacy data set for alternative insecticides for IPM compatible bunch pest management	3 field trials assessed insecticides in alternative chemistry groups to assist potential future access to IPM compatible products	3 field trials collected efficacy data for a range of alternative insecticides for bunch pest control to address identified industry concerns about IPM compatibility, resistance management and deregistration for the limited existing registered and permitted products; effective products from alternative chemistry groups have been identified.
Efficacy data set for management of BRT with	4 potential biological control agents of BRT	3 predatory mites and 1 predatory bug were investigated for control of BRT in a glasshouse pot trial; data collected indicated that 2 predatory mite treatments reduced BRT damage; this preliminary data now requires further investigation in

predators	were investigated in a glasshouse pot trial	glasshouse and field trials to better determine their potential application.
Efficacy data set for biological control of pest mites with predatory mites	Analysis of commercial monitoring data and results from a glasshouse pot trial are promising for expanded use	Results from 1 preliminary investigation in a glasshouse pot trial and analysis of monitoring data from a commercial producer indicate potential for greater use of *Neoseiulus californicus* for IPM of pest mites in bananas.
Efficacy data set for alternative fungicides for IPM compatible Yellow Sigatoka leaf spot management	3 field trials assessed fungicides, biological products and plant defence elicitors to assist potential future access to IPM compatible products	3 field trials collected efficacy data for a range of products for control of Yellow Sigatoka leaf spot to address identified industry concerns about IPM compatibility, resistance management and deregistration for the existing registered products; effective products from alternative chemistry groups have been identified, including options that can reduce the total volume of synthetic fungicide applied.
First report of *Dickeya fangzongdai* causing bacterial corm rot of banana in Australia	Molecular analysis of bacterial isolates recovered from BCR infected plants identified a new causal organism	Molecular analysis of bacterial isolates recovered from BCR samples collected in the field identified *D. fangzongdai* and *D. zeae* species. A glasshouse experiment investigating their pathogenicity confirmed that these species can cause BCR symptoms; this is the first report of *D. fangzongdai* causing BCR in Australia; the information has been reported to Biosecurity Queensland and publication of these results is in progress.
Pathogenicity data set generated for bacteria species associated with bacterial corm rot	Recovered bacterial isolates were tested for their pathogenicity in glasshouse trials	This research has confirmed the presence of other *Dickeya* spp./strains (*D. fangzongdai, D zeae*), in addition to other species identified previously (*D. chrysanthemi*) can cause BCR losses.
Trial data set generated for modified micropropagation technique to reduce sucker numbers	A modified cutting technique in the tissue culturing process has reduced the subsequent number of suckers produced	Removal of unwanted suckers in banana plants produces wounds that can be an infection site for bacteria that cause BCR; plants derived from tissue culture produce more suckers and report greater incidences of BCR; a comparison of conventional and modified micropropagation cutting techniques shows the modified technique significantly reduces sucker numbers in the first crop cycle; these results have been shared and demonstrated with growers and TC plant producers.
New micropropagation cutting technique developed to reduce sucker number in TC bananas	A modified micropropagation technique has been developed and demonstrated to growers and TC producers	The modified cutting technique reduces the number of suckers produced by tissue culture derived plants in the plant crop cycle; this has the potential to reduce the risk of BCR infection by reducing wounding associated with sucker removal; it can also reduce the labour inputs associated with removal of the greater number of excess suckers produced and improve productivity in the crop by reducing the number of competing sinks on the plant; this technique has been demonstrated to banana growers and TC producers.

Survey data set collected on pest nematode incidence in main Australian banana production regions	A national field survey was conducted in banana production regions to identify the main plant parasitic nematodes associated with bananas	A national survey of 126 sites identified 7 main plant parasitic nematode species in banana crops; some species were widespread but others were restricted in their distribution; while burrowing and root-knot nematodes are well researched the results identified the need to research the pathogenicity and host range of the other major species identified; this information has been shared with banana growers and other industry stakeholders at 2018 Roadshows and 2019 & 2021 banana industry congresses.
Nematode host status data set generated for potential fallow crops	Glasshouse trials screened potential fallow crops against the main pest nematodes identified in the national survey	More than 40 cultivars from 32 plant species were screened for resistance to 4 main pest nematode species, with potential fallow crop species with suitable resistance identified; these results have been provided to growers and industry stakeholders at Roadshows, banana congresses and published in the industry magazine; the data has been incorporated into a Lucid Key to assist in selection of appropriate fallow options.
Lucid Key developed for fallow crop host status information for plant parasitic nematodes	Information on the host status of plant species that have been tested against plant-parasitic nematodes of concern for banana growers have been recorded on the Lucid Key	Lucid Keys are computer-based identification tools that enable identification keys to be easily developed and accessible for use; plant species screened for resistance to burrowing nematode, root-knot nematodes and root lesion nematode in BA16001 were added to existing data on host status and entered into the Lucid Key; growers and industry service providers can access the key on-line to identify suitable fallow crops https://keys.lucidcentral.org/keys/v3/crop_rotation_plant_parasitic_nematodes/
Pathogenicity data set generated for identified pest nematodes of bananas	The pathogenicity of newly identified pest nematodes of bananas was investigated	The pathogenicity of pest nematodes (other than burrowing nematode) found in Australian banana growing regions was studied in glasshouse pot experiments; the pathogenicity of root-knot nematode on banana was demonstrated with significant implications for production in Carnarvon WA where this nematode rises to greatest prominence; these results have been shared with growers and industry stakeholders at Roadshows and banana congresses.
Nematode resistance data set generated for 2 banana varieties identified with potential in the subtropics	2 disease resistant banana varieties selected in the subtropics for further assessment were tested for their resistance to pest nematodes	FHIA-17 and PKZ varieties were screened for resistance to burrowing and root-knot nematodes in glasshouse pot trials; both varieties demonstrated improved resistance to burrowing nematode compared to Cavendish; both varieties demonstrated poor consumer acceptability and will not be progressed for commercialisation.
Efficacy data set for biological products for control of pest nematodes	An integrated management approach for nematodes that includes biological products offer	Non-chemical products that can suppress nematode populations or increase plant tolerance would be valuable additions for integrated nematode management; results from trials screening the efficacy of 7 products (some at multiple rates) showed they were not effective in reducing nematode numbers in infested plants.

	potential advantages in worker safety	
Characterisation and taxonomic classification of banana picorna-like virus	A picorna-like virus was identified from banana germplasm during PEQ screening	Characterisation of visual symptoms and molecular taxonomy was carried out for this relatively unknown virus; transmission studies showed ready mechanical transmission; 37 varieties in the germplasm collection were screened with no infection found, indicating the virus is likely exotic to Australia; DAWE and the importer and supplier of the varieties have been notified; a scientific manuscript detailing the virus detection, genome sequence and detection assay is being prepared.
Characterisation and taxonomic classification of Banana Bunchy Top Virus infecting non-banana hosts	BBTV identified infecting ornamental gingers in French Polynesia was investigated for genetic diversity and ability to infect bananas	*Alpinia* sp in Tahiti and surrounding islands was confirmed infected with a novel BBTV, with visual symptoms recorded; Fe'i bananas surrounding infected gingers showed no typical BBTV symptoms but indexing the South Pacific germplasm collection identified a symptomless Fe'i banana infected with the BBTV-Alp; genetic sequencing of the virus showed it has significant genetic differences from typical BBTV; DAWE and biosecurity agencies in Queensland and NSW have been notified of the identification of a non-banana host of BBTV.
Genomic characterisation of novel banana ampeloviruses	Complete genomes for 3 novel ampeloviruses were assembled and diagnostic primers designed for molecular assay detection	3 novel ampelovirus isolates recovered from SE Asian banana germplasm in the PEQ system were characterised and placed in subgroup II ampeloviruses; several sets of diagnostic primers were designed however COVID related disruptions means they have yet to be tested and incorporated into PEQ indexing.
Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry		
Project reference group established	The PRG was established in Sept 2017 with 9 members	The PRG met 5 times during the project to review project activities and progress and provide feedback; COVID disruptions to travel and meetings during 2020 and 2021 meant less meetings were held than intended.
Banana Variety Subcommittee established	The BVS was established in Sept 2017 with 12 members	The BVS membership reflected a range of industry stakeholders actively interested in varietal development, including banana producers and supply chain representatives; it met 7 times during the project with COVID disruptions to travel during 2020 resulting in less meetings held than intended.
14 quarterly videoconferences (QVC's) conducted during the project	QVCs were the regular communication activity used by the project to share project results and activities amongst team members and stakeholders	The QVCs were held on-line using the MS Teams software; participants consisted of project team members, other banana research project staff and key industry stakeholders; participation rates were very good and evaluation data showed participants valued the QVCs with associated increases in knowledge and understanding of project activities.
2 Biennial Banana Symposia conducted	The BSS were conducted for research	Held in November 2018 and April 2021, participation at these 2 day events was excellent with 55 participants (from 8 agencies/institutions) and 82 participants (from 11 agencies/institutions) respectively; the symposia consisted of short

	providers, agencies and institutions, and funding agencies working in bananas to improve networking and collaboration	presentations on research activities as well as facilitated networking and problem solving activities; evaluation undertaken for each symposia showed significant achievement of improved networking and knowledge of RD&E activities.
Extension & communication activities recorded for project	A purpose-built spreadsheet was developed to capture the extension and communication outputs from the project	The record captured these outputs from the project for: Growers/industry • 53 Roadshow presentations (218 participants) • 9 Seminar/meeting presentations (115 participants) • 8 Industry workshops (127 participants) • 11 Field walks (231 participants) • 36 *Australian Bananas* magazine articles (1200 recipients) • 24 Conference presentations/posters (843 participants) • 3 Radio interviews (unknown) Scientific community audience • 3 Peer reviewed papers (unknown) • 3 Conference papers (unknown) • 16 Conference presentations/posters (2110 participants) • 14 Workshop/seminar presentations (217 participants) Full details for each output are presented in Appendix 20.

Outcomes

Table 1. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance			
Improved linkages with international research agencies leading to increased access to identified banana germplasm	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – New knowledge available to growers on the performance and product quality attributes of new varieties resistant to Panama TR4	The project has established access to germplasm from breeding programs in Taiwan, Brazil and France, with 5 Material Transfer Agreements allowing access to a range of new disease resistant banana germplasm. With no banana breeding program in Australia access to banana germplasm from these institutions is fundamental to achieving Strategy 1 of Outcome 1 of the Banana SIP.	Feedback from personnel at the breeding programs Number of MTA's signed Number of banana varieties received for the post-entry quarantine process
Improved knowledge and awareness by growers of variety importation and testing strategy used in BA16001	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – New knowledge available to growers on the performance and product quality attributes of new varieties resistant to Panama TR4	Banana growers and other industry stakeholders have reported an increased knowledge and awareness of the strategy behind identifying, accessing and testing new banana varieties Understanding and awareness of the strategy by growers through consultation and communication builds trust and confidence and contributes to improved participation and potentially adoption	Evaluation activities conducted during extension activities e.g. variety trial field walks, banana industry Roadshows
Improved knowledge and awareness of banana varieties with sufficient Fusarium wilt TR4 and Race 1 resistance	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a	Banana growers and other industry stakeholders have an increased knowledge and awareness of the TR4 resistance, Race 1 resistance, agronomic characteristics and supply chain performance of new	Evaluation activities conducted during extension activities e.g. variety trial field walks, banana industry Roadshows

	focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – New knowledge available to growers on the performance and product quality attributes of new varieties resistant to Panama TR4	banana varieties. Participation by growers in trialling banana varieties identified with potential under commercial conditions (pre-commercialisation trials) has resulted from this increased knowledge and awareness. This outcome is an identified KPI for Strategy 1 of Outcome 1	
Plantings of new Cavendish banana varieties with improved agronomic characteristics	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – Improved knowledge and availability of commercialised varieties that are resistant to Panama TR4 for grower trials or adoption	Approximately 10 banana growers have planted trial commercial plantings (around 50,000 plants in total) of new Cavendish varieties, based in part on the agronomic performance reported and observed in trial assessments conducted by the project. The privately owned varieties were imported by the originating company and are licensed through an exclusive supplier in Australia. Some growers planting these varieties have indicated the importance of the project field trial in their decision to implement these plantings.	Personal interviews with the implementing banana producers
Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties			
New banana germplasm safely imported and available to support research and commercial activities	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – Improved knowledge	As a vegetatively propagated crop, bananas are considered a very high biosecurity risk for importation into Australia. The provision of PEQ facilities and experienced staff by the project has enabled new banana germplasm to be imported into Australia without introduction of exotic pests or diseases.	Number of new banana varieties exiting the PEQ screening process

	and availability of commercialised varieties that are resistant to Panama TR4 for grower trials or adoption	Availability of this material underpins research activities in disease resistance and agronomic screening that supports achievement Outcome 1 – Strategy 1 of the Banana SIP.	
High health Australian banana variety collection available to support research and commercial activities	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 1 – Develop and evaluate new disease-resistant varieties, with a focus on Panama TR4, while maintaining or enhancing consumer and product quality attributes KPI – Improved knowledge and availability of commercialised varieties that are resistant to Panama TR4 for grower adoption or trialling	30,403 high health tissue cultured plantlets of a wide range of varieties were supplied from the *in vitro* banana germplasm collection to support research projects (18,710) and commercial producers (11,693)	Number of banana plantlets supplied from the banana germplasm collection. Number of banana research projects supplied with plantlets from the banana germplasm collection.
Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options			
Improved knowledge and awareness of IPM practices for bunch and foliar pests	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Integrated management of bunch pests like banana rust thrips and flower thrips was topic covered in detail during extension and communication activities. Evaluation activities undertaken as part of these events showed changes in grower knowledge and intent to change practices as a result, particularly for banana rust thrips. Project trial results on the use of predatory mites have been successfully applied in 2 innovation trials conducted on farm with commercial growers by BA19004. Extension of these outcomes with banana growers are on-going.	Evaluation activities conducted during extension activities. e.g., banana industry Roadshows and grower seminars/meetings

Improved knowledge and awareness of IPM practices for leaf spot management	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Research trials demonstrating the efficacy of registered fungicides in commercial-style spray programs combining protectant and systemic products were communicated to growers, consultants and agricultural retailers. As a result, the participants indicated a change in knowledge on the use of fungicides in management of yellow Sigatoka	Evaluation activities conducted during extension activities. e.g., banana industry Roadshows and grower seminars/meetings
Improved knowledge and awareness of causal organisms for Bacterial corm rot	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Biosecurity Queensland and interstate biosecurity agencies are now aware of new *Dickeya* sp associated with Bacterial Corm Rot symptoms in bananas, particularly the first recorded instance of *D. fangzongdai* reported in Australia.	Personal interaction between project team members and biosecurity agency staff.
Adoption of modified micropropagation technique by major provider of tissue cultured plants	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	A modified technique in the current micropropagation process has been adopted by Mission Beach Tissue Culture, the main supplier of banana tissue cultured plantlets to the Australian banana industry. Research trials demonstrated the benefit of the new technique in reducing production of extra suckers on TC derived plants in the first crop. Growers will benefit by reduced desuckering costs, improved plant productivity and reduction in incidence of Bacterial Corm Rot in the 2nd crop	Personal interaction between project team members and the implementing business.

		cycle.	
Improved knowledge and awareness by growers of the main pest nematodes in bananas across Australia's production regions	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Banana growers and other industry stakeholders have an increased knowledge and awareness of the range of pest nematode species present in the tropical and subtropical production regions in Australia. This knowledge supports selection of appropriate management options for the species in question. Survey trial results have been instrumental in the identification and establishment of a BA19004 innovation trial investigating nematode IPM systems with a commercial grower in Carnarvon WA. Extension of these outcomes are on-going.	Evaluation activities conducted during extension activities. e.g., banana industry Roadshows and grower seminars/meetings
Improved knowledge and awareness by growers of suitable non-host fallow crop options for pest nematodes	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Banana growers and other industry stakeholders have an increased knowledge and awareness of the range of suitable non-host fallow crop options for managing pest nematodes. Trial results have underpinned a BA19004 innovation trial investigating nematode IPM systems with a commercial grower in Carnarvon WA. Agricultural retailers are now supplying banana growers blended seed mixes for fallow crops containing suitable non-host species. Development of a Lucid Key for fallow crop options by pest nematode species has simplified and improved access to trial	Evaluation activities conducted during extension activities. e.g., banana industry Roadshows and grower seminars/meetings Discussion between project team members and agricultural retailers

		results.	
Improved knowledge by biosecurity agencies of novel viruses of biosecurity concern in banana germplasm	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Federal and state biosecurity agencies have improved knowledge of novel viruses in imported banana germplasm.	Interaction between project team members and biosecurity agency staff.
Improved knowledge by biosecurity agencies of a Banana Bunchy Top Virus infecting non-banana hosts	Banana SIP 2022-26 Outcome 1 – Industry supply, productivity and sustainability Strategy 4 – Develop and optimise fit-for-purpose pest and disease management strategies KPI – Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Federal and state biosecurity agencies have improved knowledge of new Banana Bunchy Top Virus variants exotic to Australia that can also infect non-banana hosts. As a result, the Department of Agriculture, Water and Environment has implemented new border security regulations with a temporary ban on importation of plants from the family *Zingiberales* from the South Pacific region.	Interaction between project team members and biosecurity agency staff.
Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry			
Improved knowledge and awareness of plant protection research activities amongst Australian banana researchers	Banana SIP 2022-26 Outcome 3 – Extension and capability Strategy 1 – Provide opportunity for engagement between industry, and across industry and other stakeholders regionally, nationally and internationally to innovate	Establishment and regular updating of a list of RD&E staff working in banana project activities facilitated the implementation of Quarterly Videoconferences and Biennial Banana Symposia to share information on research activities and results. Evaluation activities conducted for these communication activities demonstrate an increase in knowledge and awareness of banana plant protection research amongst	Evaluation activities conducted during activities

		participating scientists. This outcome contributes to improved research quality.	
Improved networking and communication between RD&E staff engaged in banana projects	Banana SIP 2022-26 Outcome 3 – Extension and capability Strategy 1 – Provide opportunity for engagement between industry, and across industry and other stakeholders regionally, nationally and internationally to innovate	Establishment and regular updating of a list of RD&E staff working in banana project activities facilitated the implementation of Quarterly Videoconferences and Biennial Banana Symposia to share information on research activities and results. Evaluation activities conducted for these communication activities demonstrate increased networking and familiarity between participating scientists. This outcome contributes to improved research quality	Evaluation activities conducted during activities
Improved research collaboration and project outcomes for the banana industry through improved networking	Banana SIP 2022-26 Outcome 3 – Extension and capability Strategy 1 – Provide opportunity for engagement between industry, and across industry and other stakeholders regionally, nationally and internationally to innovate	Establishment and regular updating of a list of RD&E staff working in banana project activities facilitated the implementation of Quarterly Videoconferences and Biennial Banana Symposia to share information on research activities and results. Evaluation activities conducted for these communication activities demonstrate increased collaboration between participating scientists. This outcome contributes to improved research quality	Evaluation activities conducted during activities

Monitoring and evaluation

Table 1. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Overarching		
Has the overall program ensured the Australian banana industry effectively manages pests and diseases with systems and tools and varieties developed to underpin sustainable and improved plant protection practices? (*Effectiveness*)	Yes – importation and assessment of Fusarium wilt resistant banana varieties is fundamental to long term sustainable banana production in the absence of effective management practices. BA16001 has identified a range of banana germplasm with sufficient resistance to be commercially useful. The further assessment of the agronomic performance of these identified varieties on commercial properties is another key activity of the project. Accessing and importing new varieties safely into Australia for testing and potential commercialisation is entirely undertaken through BA16001. Key components of IPDM systems have been investigated and developed to improve management options for the high priority pests and diseases identified by the industry.	The project scope is very large making the overall project management very complicated and time consuming, and therefore not as responsive as the banana industry may desire. Separating future investment into separate projects for clearly associated works areas (ie varietal assessment and IPDM) can help address this issue. Significant progress has been made with identifying and sourcing new varieties that match the current Australian banana market. Overall, the opportunity to access additional banana germplasm is likely to decrease in the future as the originating programs look to protect their intellectual property even more closely and achieve a return on their investment. Industry levy payers' expectations appear to significantly exceed the capacity and boundaries for the project to always deliver. This is particularly evident around improving access to new/alternative insecticide and fungicide products.
Has this project achieved planned objectives while maintaining expenditure in line with budgeted allocations? (*Efficiency*)	Yes – the project has achieved the objectives set out in the project contract and undertaken additional activities, like the ongoing phase 2 & 3 assessments of the BA14014 mutagenesis selections, that were not originally contracted in BA16001. This has been achieved within the contracted project budget.	Budget management has been time consuming and complicated for such a large project with a broad scope of activities. Despite this the project has been delivered within the contracted project budget, and project staff members have leveraged additional funds outside Horticulture Innovation funding for small activities that have enhanced the project outputs.
Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance		
To what extent has the project assisted Australian banana growers to be aware of and have access to	The project has had a significant impact on increasing access and awareness of new banana varieties.	Extension activities showcasing project results and undertaking demonstration of new management

alternative practices developed to underpin sustainable and improved plant protection practices? (*Effectiveness*)	Evaluation results demonstrating this impact are: • July 2021 variety trial field walk – Percentage of attendees indicating they would consider trialling new varieties as a result of attending – yes=45%, no=23%, maybe=32% • March 2020 variety field walk –85% of attendees ranked improved knowledge of results from project activities as a result of attending of 3 or higher (ranking scale 1-lowest, 5-highest); 57% of attendees indicated they have planted/trialled new varieties as a result of project activities. • Sept 2019 NextGen grower group NT visit – 100% of attendees ranked their improved understanding of R&D investment in variety screening and development as 4 or greater (ranking scale 1-lowest, 5-highest); 100% of participants indicated their interest in contributing to the development and/or evaluation of new varieties The project has also maintained regular written updates and results from research activities to keep industry informed, with 36 articles in the *Australian Bananas* magazine and 24 presentations and posters at the 2019 and 2021 Australian Banana Industry Congresses. The project has also played a significant role in the commercial trialling and adoption of new Cavendish varieties with improved agronomic characteristics. Approximately 10 banana growers have planted trial commercial plantings (around 50,000 plants in total) of these varieties, based in part on the agronomic performance reported and observed in trial assessments conducted by the project. 3 growers planting these varieties indicated the importance of the project field trial in their decision to implement these plantings.	options will continue beyond the project period. Therefore, project impacts will continue to accrue outside the project period in a timeframe beyond the current project evaluation resources. Future investment in the 'pipeline' approach to varietal testing and development will support the prospects for identification of varieties suitable for commercialisation.

	The privately owned varieties were imported by the originating company and are licensed through an exclusive supplier in Australia. (Full detail in Appendices 20, 21, 22 & 23)	
To what extent has the project met the needs of industry levy payers for knowledge about alternative banana varieties? (*Relevance*)	The project has had a significant impact on increasing the level of knowledge and awareness of new banana varieties. Evaluation results demonstrating this impact are: • July 2021 variety trial field walk – 97% attendees ranked increase in knowledge of banana varieties from participation of 3 or higher (ranking scale 1-lowest, 5-highest) • 2020 Roadshows – Knowledge of banana variety R&D increased as a result of attending Roadshows with 99% of participants providing rankings of 3 or greater at the conclusion of the event compared to 49% at the beginning (ranking scale 1-lowest, 5-highest) • March 2020 variety field walk – 86% attendees ranked increased knowledge of project activities to evaluate banana varieties of 3 or higher 3 or higher (ranking scale 1-lowest, 5-highest); 85% ranked improved knowledge of results from project activities as a result of attending of 3 or higher (ranking scale 1-lowest, 5-highest) • Oct 2019 Banana Speed Dating Night – 91% attendees ranked increased knowledge of banana variety R&D of 3 or higher (ranking scale 1-lowest, 5-highest) • June 2019 field walk – 95% attendees ranked increased knowledge of trials to evaluate new banana varieties of 3 or higher 3 or higher (ranking scale 1-lowest, 5-highest) The project has also maintained regular written updates and results from research activities to keep industry informed, with 36 articles in the *Australian Bananas* magazine and 24 presentations and posters at the 2019 and 2021 Australian Banana	The project undertook the supervision of the pre-commercialisation trial network within the existing project staff resourcing, and this has resulted in delayed interaction with cooperators at times. No other improvements are suggested.

	Industry Congresses. (Full detail in Appendices 20, 21, 22 & 23)	
To what extent were target engagement levels of industry levy payers achieved? (*Process appropriateness*)	Engagement levels have been high for the project through participation in larger extension and communication activities (Roadshows etc) as well as project specific activities (variety trial field walks). No specific targets were set but total attendance has been: • 53 Roadshow presentations (218 participants) • 9 Seminar/meeting presentations (115 participants) • 8 Industry workshops (127 participants) • 11 Field walks (231 participants) • 36 *Australian Bananas* magazine articles (1200 recipients) • 24 Conference presentations/posters (843 participants) • 3 Radio interviews (unknown) (Full detail in Appendices 20, 21, 22 & 23)	No improvements are suggested as engagement has been at a high level.
Have regular project updates being provided through linkage with the industry communication and extension projects? (*Process appropriateness*)	Yes – the project has been a regular and consistent contributor throughout the project via written material contributed to the *Australian Bananas* magazine (1200 recipients), and extension and communication activities such as field walks, grower meetings & seminars and the 2018 & 2020 Roadshows (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as project extension and communication outputs have been significant
Did the project engage with industry levy payers through their preferred learning styles? (*Process appropriateness*)	Yes – extension and communication activities for the project participated in a range of approaches including workshops, Roadshow presentations, trial field walks, *Australian Bananas* magazine articles and on-line videos and updates on the *Better Bananas* website to maximise engagement and participation. Evidence of the success for this was collected during evaluation of events. • July 2021 variety trial field walk – asked to rate the event overall, 93% attendees scored it 7 or higher (ranking scale 1-no value, 9-	No improvements are suggested as engagement has been at a high level.

	extremely valuable) • 2020 Roadshows – asked to rate the event overall, 76% attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable) • March 2020 variety field walk – asked to rate the event overall, 93% attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable), and 100% indicated they wanted to continue to be informed about trial results. • Oct 2019 Banana Speed Dating Night – asked to rate the event overall, 96.7% attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable) • June 2019 field walk – asked to rate the event overall, 84% of attendees scored it 7 or greater (ranking scale 1-lowest, 10-highest) (Full detail in Appendices 20, 21, 22 & 23)	
How accessible were the extension events to industry levy payers? (*Process appropriateness*)	The extension events were openly advertised and accessible to all banana industry stakeholders. For activities such as Roadshows, events are held in the main Australian production regions to maximise the opportunity for industry members to participate. On-line material (videos and updates) is posted to the *Better Bananas* website and is accessible at the convenience of the user. (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as engagement has been at a high level.
Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties		
To what extent has this project contributed to providing the facilities and processes for new banana cultivars to be safely imported into Australia free from pests and pathogens? (*Effectiveness*)	All banana cultivars imported into Australia during the project (June 2017- Dec 2021) have done so under the auspices of BA16001. There is currently no other accredited facility in Australia for importation of banana germplasm. DAF has provided significant capital investment and upgrades for PEQ TC facilities independent of the project budget during this period. Operational costs of PEQ glasshouse and TC facilities, including	Safe importation of new banana germplasm into Australia takes time and money and underpins the project and industry objectives in identifying disease resistant varieties. Examining options for improving cost-effectiveness for varietal importation should be undertaken rationally and with the understanding that banana germplasm has high biosecurity risks

	auditing/accreditation, have been provided through BA16001.	associated with it.
To what extent has this project contributed to maintenance of a high plant health Australian banana tissue culture collection so plants can be safely moved across Australia? (*Effectiveness*)	The project provides for experienced staff and resources to undertake indexing of banana germplasm being added to the Australian germplasm collection. During the project: • The diagnostic assay suite for PEQ virus indexing was strengthened by incorporation of a test developed for the recently detected banana picorna-like virus. • 213 germplasm samples entering the Australian banana germplasm *in vitro* collection were virus indexed to ensure the highest health status of these accessions. • Banana suckers propagated by tissue culture under the industry clean planting (QBAN) scheme were certified as free of banana bunchy top virus.	Maintenance of disease-free banana germplasm in Australia takes time and money and underpins a range of significant industry research activities. Many of the existing varieties have been provided under research agreements that strictly control their use and access. Examining options for improving cost-effectiveness for banana germplasm management and maintenance should be undertaken rationally and in consultation with a broad range of stakeholders.
To what extent has the project met the needs of industry levy payers end R&D providers for importation and access to new varieties and availability of disease-free banana germplasm? (*Relevance*)	The project has succeeded in accessing and importing almost all the lines identified for assessment, with the impacts of COVID-19 being the biggest impediment during the project. The project safely imported 23 new banana varieties during the life of this project and has released 29 varieties from PEQ (includes varieties imported during BA10020 completing their PEQ screening in BA16001). The project has also supplied 30,403 high health tissue cultured plantlets in small batches for research and commercial purposes (18,710 for research activities, 11,693 for commercial producers). The plants supplied for research purposes have largely been for BA16001 research and pre-commercialisation trials but have also supported these other significant research projects: • BA14014 – Fusarium wilt Tropical Race 4 research program • ACIAR 2018/192 – An integrated management response to the spread of Fusarium wilt of banana in SE Asia • BA17006 – Development of	The future of support for the maintenance of the banana germplasm collection will have significant ramifications for some of the current R&D projects that rely on access to varieties in the collection.

	molecular markers for Fusarium wilt resistance in banana • BA19002 – Understanding the latency of Banana Bunchy Top Virus symptom expression • Queensland University of Technology (Prof J Dale) and University of Queensland (Dr J Anderson) research trials	
Have regular project updates being provided through linkage with the industry communication and extension projects? (*Process appropriateness*)	Yes – the project has been a regular and consistent contributor throughout the project via written material contributed to the *Australian Bananas* magazine (1200 recipients), and extension and communication activities such as field walks, grower meetings & seminars and the 2018 & 2020 Roadshows (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as project extension and communication outputs have been significant
Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options		
To what extent has this project developed new IPDM technologies and practices that are now available for industry adoption? (*Effectiveness*)	The project has developed new IPDM technologies that can and are being adopted now around: • Increased non-host fallow crop options for nematode management, particularly plant species suitable to the FNQ summer • The attractiveness of bunch cover colour to banana rust thrips • Modification of tissue culture micropropagation to reduce Bacterial corm rot infection through reduced desuckering wounds • The use of the predatory mite *Neoseiulus californicus* for managing pest mites • The importance of fungicide selection and the role of paraffinic oils in improving systemic fungicide performance for management of yellow Sigatoka leaf spot Other research activities have made significant progress but require more work before alternative management practices are suitable for implementation in a commercial setting. e.g. biological control of pest mites and banana rust thrips	Extension activities showcasing project results and undertaking demonstration of new management options will continue beyond the project period. Therefore, project impacts will continue to accrue outside the project period in a timeframe beyond the current project evaluation resources. Some priority issues, such as banana rust thrips, have no obvious alternative solution that is commercially acceptable. More time to explore options in an integrated system under controlled conditions is required.

To what extent has the project met the needs of industry levy payers for new IPDM technologies? (*Relevance*)	The project has engaged in research activities on the highest priority issues identified during the priority setting workshops, including cultural and biological options, as well as identification of more 'environmentally friendly', IPM compatible fungicides and pesticide products. The project has developed new IPDM technologies that can and are being adopted now while other research activities require more work before alternative management practices are suitable for commercial adoption. Project activities have significantly increased knowledge and awareness of IPDM research activities and outcomes. Evaluation results demonstrating this impact are: • Feb 2021 Banana Agribusiness Managers (BAGMan) discussion group meeting – the BAGMan group meeting provides a forum for discussion of topical issues amongst banana industry service personnel; 100% of participants responded with a rating of 4 or 5 (ranking scale 1-strongly disagree, 5-strongly agree) when asked if participation in the meetings made them better informed about banana R&D activities • 2020 Roadshows – 83% of participants rated the usefulness of the banana rust thrips management workshop as a 4 or 5 (1-not very useful, 5-very useful); asked if they would consider changing any practices as a result of participating in the workshop 27% responded yes, 20% responded maybe and 53% responded no. This outcome is significant given the majority of the same group indicated they were satisfied with their current level of control (81% rated 3 or greater; ranking scale 1-not satisfied, 5-extremely satisfied) • Oct 2019 Banana Speed Dating Night – 52% of attendees ranked their change in knowledge of bunch pest R&D a 4 or higher (ranking scale 1-	More time and additional research in some aspects is required to achieve alternative management practices that are ready for implementation on commercial farms. As a result, project impacts will continue to accrue outside the project period in a timeframe beyond the current project evaluation resources.

	not at all, 5-quite a lot); 46% of attendees ranked their change in knowledge of leaf spot R&D a 4 or higher (ranking scale 1-not at all, 5-quite a lot); 67% of attendees ranked their change in knowledge bacterial corm rot R&D a 4 or higher (ranking scale 1-not at all, 5-quite a lot) The project has also maintained regular written updates and results from research activities to keep industry informed, with 36 articles in the *Australian Bananas* magazine and 24 presentations and posters at the 2019 and 2021 Australian Banana Industry Congresses. (Full detail in Appendices 20, 21 & 23)	
To what extent were target engagement levels of industry levy payers achieved? (*Process appropriateness*)	Engagement levels have been high for the project through participation in larger extension and communication activities (Roadshows etc) as well as project specific activities (variety trial field walks). No specific targets were set but total attendance has been: • 53 Roadshow presentations (218 participants) • 9 Seminar/meeting presentations (115 participants) • 8 Industry workshops (127 participants) • 11 Field walks (231 participants) • 36 *Australian Bananas* magazine articles (1200 recipients) • 24 Conference presentations/posters (843 participants) • 3 Radio interviews (unknown) (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as engagement has been at a high level.
Have regular project updates being provided through linkage with the industry communication and extension projects? (*Process appropriateness*)	Yes – the project has been a regular and consistent contributor throughout the project via written material contributed to the *Australian Bananas* magazine (1200 recipients), and extension and communication activities such as field walks, grower meetings & seminars and the 2018 & 2020 Roadshows (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as project extension and communication outputs have been significant
Did the project engage with industry	Yes – extension and communication	No improvements are suggested as

levy payers through their preferred learning styles? (*Process appropriateness*)	activities for the project participated in a range of approaches including workshops, Roadshow presentations, trial field walks, *Australian Bananas* magazine articles and on-line videos and updates on the *Better Bananas* website to maximise engagement and participation. Evidence of the success for this was collected during evaluation of events. • 2020 Roadshows – asked to rate the event overall, 76% attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable) • 2018 Roadshows – asked to rate the event overall, 90% of attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable); 92% responded yes when asked if they would attend an event like this again; 99% responded yes when asked if they would recommend this event to others. • Oct 2019 Banana Speed Dating Night – asked to rate the event overall, 96.7% attendees scored it 7 or higher (ranking scale 1-no value, 9-extremely valuable) (Full detail in Appendices 20, 21 & 23)	engagement has been at a high level.
How accessible were the extension events to industry levy payers? (*Process appropriateness*)	The extension events were openly advertised and accessible to all banana industry stakeholders. For activities such as Roadshows, events are held in the main Australian production regions to maximise the opportunity for industry members to participate. On-line material (videos and updates) is posted to the *Better Bananas* website and is accessible at the convenience of the user. (Full detail in Appendices 20, 21 & 23)	No improvements are suggested as engagement has been at a high level.
Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry		
Has this theme contributed to keeping researchers well informed, working cooperatively and ultimately have a more interconnected R&D programme in the plant protection area? (*Effectiveness*)	Yes – the project has been very successful in encouraging greater networking and information sharing. Evaluation undertaken for the project quarterly videoconferences (QVCs) and banana scientific symposia (BSS) clearly demonstrate increased knowledge of plant protection R&D	There has been an effective network with improved information sharing and collaboration built as a result of this project, but there is no future project that has the imprimatur to maintain the momentum that has been developed. The opportunity exists to continue

	activities, improved achievement of project outcomes and improved networking for sharing information and knowledge (see Appendix 19 for detailed data)	some of this momentum, and feedback from the BSS events indicated a strong interest in continuing the activity.
To what extent has the project contributed to ensuring outcomes are more effectively delivered to the banana industry? (*Effectiveness*)	The project has had a significant positive impact on the effective delivery of plant protection outcomes for the banana industry. Evaluation results for the QVCs and BSS show that participation in these activities helped to achieve project outcomes (Full details in Appendix 19)	No improvements are suggested
To what extent has the project met the needs of RD&E providers for greater cooperation and networking? (*Relevance*)	The project has been extremely successful in improving cooperation and networking for RD&E providers in banana plant protection. Evaluation of the QVC's over 3 time points (May 2018, Feb 2019, May 2020) showed participant scores for: • The degree to which the activities brought the project team together – range of 93-100% scored 4 or 5 (ranking scale 1-poor, 5-excellent) • The degree to which QVCs improved knowledge of R&D activities – range of 97-100% scored 4 or 5 (ranking scale 1-poor, 5-excellent) • The degree to which QVCs helped achieve project outcomes – range of 43-83% scored 4 or 5 (ranking scale 1-poor, 5-excellent) Detailed evaluation results presented in Appendix 19 also demonstrate the significant impact of the BSS and their role in improving networking, knowledge sharing and collaboration.	The success of the activities, particularly the BSS, demonstrated an unmet need for a scientific forum for banana scientists to meet and share knowledge and information. This is obviously not being provided by the current Australian Banana Industry Congress format. Participants reported that the absence of growers from the events is beneficial to focus more on the science. There has been quite a bit of interest from international banana R&D agencies to attend or participate in the BSS events to be held in the future.
To what extent were target engagement levels of industry levy payers and RD&E providers achieved? (*Process appropriateness*)	The project collated an initial contact and distribution list of banana RD&E staff in Australia for invitation to both the QVCs and BSS, and this list increased during the project period as more connections were made. The best example of the improved engagement is the increase in participation for the 2021 BSS from the 2018 BSS despite the limitations to travel and group events posed by COIVD-19 – 82 participants from 11 agencies/institutions participated in	No improvements are suggested as engagement has been at a high level.

	2021 compared to 55 participants from 8 agencies/institutions in 2018.	
Have regular project updates being provided through linkage with internal project networking, the industry communication and extension projects? (*Process appropriateness*)	Yes – the project has been a regular and consistent contributor throughout the project via written material contributed to the *Australian Bananas* magazine (1200 recipients), and extension and communication activities such as field walks, grower meetings & seminars and the 2018 & 2020 Roadshows. The project has also undertaken significant internal networking and communication activities with 14 QVCs and the 2 BSS. (Full detail in Appendices 19, 20, 21 & 23)	No improvements are suggested as engagement has been at a high level.
Has this theme assisted with increased collaborations between RD&E providers? (*Efficiency*)	Yes – detailed evaluation results (Appendix 19) for the QVCs and BSS show that the activities conducted in this theme have significantly improved collaborations between banana RD&E providers.	Opportunity to evaluate the influence of these project activities on the formulation and interaction of RD&E providers in new projects.

Recommendations

Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance

- **Biosecurity and specifically the Panama TR4 program needs to remain a high priority for industry to maximise its capacity to support and realise its investment in variety importation and development.** Despite the identification of many varieties with resistance to TR4, now is not the time for anyone to let down their guard on biosecurity. Firstly, we have not yet reached the tipping point with respect to being allowed to replant bananas in infested ground in Queensland. Secondly, if you got the disease after the tipping point was reached and you were allowed to plant TR4 resistant bananas, the resistant Cavendish selections so far identified come with a yield penalty (typically 20% or more) compared to the industry standard, Williams. This would result in a distinct economic disadvantage for any grower growing the TR4 resistant varieties while plenty of Williams is able to be grown in disease-free locations elsewhere.
- **It's important that industry maintains good working relationships with international breeding programs. This will require regular communication and upholding conditions of current and future Material Transfer Agreements (MTAs).** In general, the negotiation for access to banana germplasm from any of the identified international programs has taken much longer than anticipated, partly as a result of increased requirements for protection of intellectual property. The protection of the breeding programs' IP has now assumed even greater levels of priority than previously experienced, and the reputation of Australian R&D agencies for respecting their IP ownership has allowed us access not granted to other banana producing countries. Therefore, it is crucial that the Australian banana industry and the project agency partners recognise the importance of protecting the IP associated with imported varieties.
- **Market development of new products will be best pursued by private enterprise.** In the final report for BA10020 the following recommendation was made. - *"New varieties have been identified through the project that present opportunities for diversification in the Australian market. Industry needs to work on a commercialization plan with the license holder, and grower champions need to be identified, to take new*

varieties to the market. This will involve further work within the supply chain to ensure fruit can be brought to market with consumer appeal and to satisfy continued demand for the variety". Notably the only development which has occurred in this banana space since then was the marketing company Perfection Fresh adding specialty bananas (Ecoganic, Little Gem and Havana) to their portfolio. This approach was suggested by BA09041 to foster the development of niche/specialty products and largely requires IP to make it work well. Market end experience and ongoing support is vital for such development. Industry as-a-whole has not demonstrated any real commitment to diversification for several reasons described in the BA09041 final report. Consideration of the best approach for commercialisation of non-Cavendish varieties may be required shortly once determination of the best Goldfinger variants from the mutagenesis studies is completed. The industry will need to consider the most appropriate strategy to take selection(s) forward in the marketplace.

- **Its vital industry continues to actively seek opportunities to partner with government and private enterprise on varietal development that will benefit the whole of industry.** There have been significant plantings (more than 50,000 plants) of new selections of Cavendish owned by Rahan Meristem in Far North Queensland in the past 12 months. These varieties were privately imported into Australia so that Rahan can maintain full control over IP and commercialisation strategies. These varieties have been clearly demonstrated in our research trial at South Johnstone to have potential yield and fruit quality advantages over the industry standard Williams. In fact, some growers of these new varieties have made it clear that the opportunity to see plants and bunches in the research trial during extension activities, has been important in their decision making to implement their own plantings. Despite the expectation that these varieties do not have any resistance to TR4, the greater production efficiencies they should offer is tipping the balance in their favour. There has been concern about who should pay for such research but clearly DAF trials provide a measure of credibility/confidence for industry to make changes. The supply of planting material of the Rahan selections is not limited to a privileged few because these are Cavendish selections which fit readily into the existing market and supply chain, so all of industry can benefit. Project team efforts in fostering this industry relationship with Rahan Meristem will be instrumental in accessing their TR4 resistant Gal selections for objective scrutiny under Australian conditions. If these TR4 resistant selections tick the required boxes, they could eventually be made available to all growers that require them. 'Partnering' with private enterprise in this way demonstrates a new model in bananas of providing common good for the whole industry. We need to support models that work.
- **Further research is warranted to investigate why some varieties in their ratoon crops show a recovery in their disease response to TR4.** In our most recently completed TR4 varietal screening trial the variety High Noon, a variety identified in BA09041 with market potential, showed significant recovery in the ratoon crop. We need a better understanding of why this occurred which would potentially identify further crop management strategies to mitigate disease. Any strategies identified could then be applied more broadly to how we manage the disease, particularly once varieties with intermediate resistance like High Noon are deployed in TR4 infested locations.
- **Undertake an objective review of the mutation breeding program when assessments are completed.** Once the evaluation of the selections made by the BA14014 mutagenesis program is completed, in approximately 3 years time, the outcomes of this improvement approach should be reviewed to determine whether and when any further investments should be made. A comparison should be made of its cost effectiveness with that of the importation pipeline, given the high cost of the latter process, reduced numbers of suitable new varieties, restrictions on overseas access as well as eventual costs to industry once a new variety is commercialised (e.g. royalties).
- **Revise and update the banana variety development options paper (from BA14013) in the light of developments in past 4 years.**
- **Complete the review of the subtropical banana industry needs for variety development**, including assessment of how widespread Fusarium wilt Subtropical Race 4 (SR4) is relative to Race 1. A partly completed review of the subtropical banana industry needs from BA16001 requires upgrading and completing to provide clear direction for industry on the way forward and to give sharper focus to future varietal screening activities. This review should seek more detail on how widespread Fusarium wilt Subtropical Race 4 (SR4) is relative to Race 1, especially given that our current subtropical site only screens for Race 1, and resistance to one race does not mean resistance to all races of Fusarium wilt.

- **Investigate a shared funding arrangement or possibly a fee-for-service model to offset costs associated with variety field screening for TR4 resistance.** Some overseas breeding programs make use of greenhouse testing (mainly with Wageningen University & Research or Stellenbosch University) for determining resistance against TR4. However, results from this are not necessarily as accurate as screening performed well in the field. Australian field testing has been sought out by overseas programs but given the high costs of importation and evaluation there is a need to consider seeking shared funding arrangements with overseas breeding programs, or possibly fee-for-service arrangements if that were more applicable, to offset such costs.
- **Actively explore research opportunities that can test the efficacy of using glasshouse screening trials as an indicator of TR4 disease response in the field.** Field screening for Fusarium wilt disease resistance is seen by many as labour-intensive, time-consuming and expensive. However, the reliability of greenhouse studies compared to field reactions is still in question. Currently there are insufficient suitable and reliable studies comparing the two on which to base solid conclusions. This recommendation flags the need to maintain a watching brief and to highlight the potential research opportunity comparing field and greenhouse screening in a systematic manner.

Theme 2 – Ensure safe, disease-free importation of new and improved banana varieties

- **High throughput sequencing (HTS) technologies which include several methods for viral diagnostics should be investigated to realise any potential efficiency gains compared to current indexing methods.** There is a growing number of viruses known in banana, most of which are not present in Australia and are therefore of concern for safe importation of new germplasm. High throughput sequencing (HTS) for viral diagnostics is being implemented at the federal Department of Agriculture's post-entry quarantine screening facility in Victoria, as well as across the world. This increases confidence that viruses for which specific tests are yet to be developed can be detected and increases efficiency in conduct of the pest and pathogen screening. Several HTS pipelines have been developed for viral diagnostics and these should be evaluated against current indexing methods.
- **Additional research is required to resolve a number of issues with phytoplasma detection in banana.** Firstly, optimal sampling of infected, asymptomatic banana plants for the highest confidence in phytoplasma detection is yet to be determined. This is particularly an issue during post-entry quarantine screening as infected plants are yet to display symptoms. Secondly, a generic molecular test is currently in use, but this assay also amplifies some *Bacillus* sp and Sanger sequencing of amplicons is required to complete the diagnostic assay. From this, species of phytoplasma additional to the banana wilt associated phytoplasma are still being detected in banana, and information on whether these species cause disease in banana is not yet available.
- **Key industry stakeholders need to urgently address the future resourcing for Australia's banana quarantine facilities.** DAF provides the only accredited banana quarantine approved arrangements under an approved process management system in Australia through BA16001. If there is no industry support to maintain accredited banana quarantine facilities for all of industry, then no further banana cultivars can be imported through these facilities.
- **The future of Australia's *in vitro* Banana Germplasm Collection is in doubt and urgent discussions are needed with key industry stakeholders regarding its future resourcing.** The collection contains many valuable cultivars imported for a wide range of research activities, including needs outside of BA16001. Many of the cultivars were imported under Material Transfer Agreements (MTA) with strict conditions for research only access which must be controlled. Following research evaluation, wider commercial access to suitable cultivars is dependent on negotiation of additional MTAs for that purpose. The collection is maintained to provide these cultivars on request as a fee for service, providing fast access to support all Australian banana research and for commercial growers under conditions of each MTA, while other cultivars may be distributed without restriction. If resources are not available for its maintenance, it will impact on future Australian banana research.

Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options

- **It is strongly recommended that industry supports further research into the potential role of plant defence elicitor (PDE) products to reduce fungicide use in yellow Sigatoka management.** Project results have identified the potential for PDE products to reduce the total volume of fungicide applied for yellow Sigatoka control and is a significant positive development in leaf spot management. This potential reduction can have significant benefits for reduction of chemical use, improved reef water quality and resistance management, while maintaining effective disease control.
- **Undertake an evaluation of the impact of the modified micropropagation cutting technique on the incidence Bacterial corm rot in the field**. The modified micropropagation technique offers multiple potential benefits to producers, including the possibility of reducing the high BCR incidence in first ratoon crops of plantings established from tissue cultured plants.
- **More research is required to investigate the potential for biological control options such as entomopathogens and predatory mites & bugs to contribute to new IPM systems for bunch pests.** The preliminary glasshouse testing of predators for control of banana rust thrips showed promise for at least one predatory mite but the implementation of these in a field situation requires much more research to determine its potential role in managing a 4 species pest complex. Similarly, the role for entomopathogenic fungi and nematodes requires much more detailed research to determine their potential to contribute to bunch pest control.
- **Additional research is required to optimise the use of predatory mites to control pest mites.** Despite their potential in contributing to integrated mite management, the integration of the predatory mites with naturally occurring mite predators and commercial pest management practices requires more investigation.
- **Demonstrating the importance of an integrated management system for plant parasitic nematodes is needed and should be leveraged through the National Banana Development and Extension project (BA19004).** Non-chemical management of the most common plant parasitic nematodes (burrowing and root-knot nematodes) is achievable with the use of appropriate non-host fallows and replanting with clean planting material. Easy access to cost-effective clean planting material has been a barrier for some growers, particularly smaller growers. Investigations of planting material treatment suitable for small growers, such as hot water dipping, could help overcome this barrier. Demonstration of the importance of the integrated management system is now required to improve commercial adoption.
- **Key industry stakeholders need to develop a strategy on how industry will address the risk of chemical deregistration and lack of availability of new chemistries. This should be addressed as a matter of urgency, considering current APVMA reviews that could see the deregistration of heavily relied upon chemistries in the immediate future.** The banana industry rated accessing and screening new/alternative chemistries for pest and disease control as a high priority in the priority setting workshops conducted in BA16001, and this has been emphasised again in the results of the large-scale industry consultation activity conducted at the start of the National Banana Development and Extension project (BA19004). Grower expectations of the role for projects like BA16001 in addressing this seem unrealistic at times, and do not align with Horticulture Innovations boundaries and expectations for the project. There appears to be an urgent need for the key industry stakeholders to discuss the misalignment of current processes, project boundaries and industry expectations.
- **On-going monitoring of the status of BBTV strains capable of infecting non-banana hosts**. Current BBTV management in Australia and globally relies on host specificity, and these new strains in tropical garden and floriculture species (*Alpinia* sp and *Heliconia* sp) poses alternative infection pathways.

Theme 5 – Foster a cohesive plant protection RD&E program for the banana industry

- **Key industry stakeholders should explore opportunities to continue to deliver the Banana Scientific Symposium.** The success of the networking and communication activities, particularly the Banana Scientific Symposium, demonstrated an unmet need for a scientific forum for banana scientists to meet and share knowledge and information. This is obviously not being provided by the current Australian Banana Industry Congress format. The breadth and quality of banana RD&E being undertaken in Australia is highly regarded

internationally and there has been considerable interest from international banana R&D agencies to attend or participate in any future BSS events.

- **Networking and communication activities delivered by BA16001 were highly valued by banana scientists and should be supported in the future.** The inclusion of this theme enhanced the overall project and developed a significant and active network of scientists working in banana plant protection in Australia. Unfortunately, there is a significant risk that the momentum for improved cooperation and communication built in BA16001 will quickly dissipate in the absence of any further networking activities now that the project has finished.

Refereed scientific publications

Journal articles

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Intellectual property

The IP register for BA16001 has been included as Appendix 24.

Acknowledgements

I am extremely grateful for the professionalism and effort of the large and geographically spread project team members from 3 different agencies from Queensland, Northern Territory and New South Wales.

I gratefully acknowledge the generous contribution of time and input from the grower representatives and other members of the Project Reference Group and Banana Variety Subcommittee to help the project focus on the highest priority issues for the banana industry.

I am grateful to all the banana growers that contributed to the project with their time and honest feedback and allowed us to access their farms at a time when an on-going Fusarium wilt TR4 incursion was overlayed with a global human disease pandemic.

I also gratefully acknowledge the members of the broader banana research and development community in Australia that openly and enthusiastically engaged with this project in activities to build a more cohesive research and development network.

Thank you everyone – this project would not be possible without all these contributions.

Appendices

The appendices are supplied as a separate document

Appendices

Contents

Appendix 1 – Project Governance

Project Reference Group (PRG)

The PRG was established by Horticulture Innovation in September 2017 with agreement of the proposed nominees and development of the Terms of Reference for membership. The PRG was established with 8 members, structured around representation of the specific themes, including the project BA16005 (originally Theme 3) that came under this PRG due to the complementary nature of the research effort. The agreed structure was:

Table 1. Agreed PRG structure

	Number of positions	Nominees
Independent chair	1	Mr David Cliffe
Theme 1 Champions	1	Mr Andrew Serra, grower
Themes 2 & 3 Champion	1	Dr Rosie Godwin, ABGC
Theme 4 Champion	1 (shared)	Mr Matthew Abbott, grower Mr Peter Inderbitzin Jnr, grower
Theme 5 Champion	2	Mrs Astrid Hughes, Hort Innovation (2017-18) Mrs Naomi Abbott, Mackays' Banana Marketing
Project Leader (ex-officio)	1	Mr Stewart Lindsay, DAF
Hort Innovation R&D Manager	1	Dr Brenda Kranz, Program Manager (2017-20) Dr Michael Lang, Program Manager (2020-21) Dr Vino Rajandran, Program Manager (2019 onwards)

Other members of the project leadership team (Mr Jeff Daniells – Theme 1, Mrs Sharon Hamill – Theme 2, Prof Andre Drenth – Theme 3 (BA16005) and Mr Lynton Vawdrey/Ms Kathy Grice – Theme 4 were engaged with the PRG as required in an ex-officio capacity.

The PRG planned to meet twice per year during the period of the project, including at least 1 meeting in-person annually, with minutes recorded for each meeting. The advent of the COVID-19 pandemic in early 2020 and the associated health regulations restricting movement and group gatherings resulted in the PRG meeting less regularly and using on-line meetings instead. The on-line meeting was recorded and uploaded to the project SharePoint site for members to access at their convenience. The dates and attendance for the PRG meetings are presented in Table XX.

Banana Variety Subcommittee

The Banana Variety Subcommittee (BVS) was established in September 2017 through nominations for membership with representation reflecting a range of stakeholders actively interested in varietal development, such as banana producers and supply chain representatives. With the ratification of nominees by Horticulture Innovation the BVS was developed with the following structure:

Table 2. Agreed BVS structure

	Number of positions	Nominees
Independent chair	1	Mr David Cliffe
Industry representative	5	Mr Stephen Lowe, grower Mr Patrick Leahy, grower Mr Shannon Paton, grower Mr David Tate, grower (resigned 2020) Mr Andrew Serra, grower
Supply chain representative	2	Mr Richard Clayton, Mackays Marketing Mr Ben Franklin, Costa's Group
Industry Representative Body	1	Dr Rosie Godwin, ABGC
Project Leader (ex-officio)	1	Mr Stewart Lindsay, DAF
Hort Innovation	2	Ms Astrid Hughes, Industry Relationship Manager (2017-18)

		Ms Brenda Kranz, Program Manager (2017-20) Mr Michael Lang, Program Manager (2020-21) Dr Vino Rajandran, Program Manager (2019 onwards)

Other members of the project leadership team (Mr Jeff Daniells – Theme 1, Ms Sharon Hamill – Theme 2) were engaged with the BVS as required in an ex-officio capacity.

The BVS planned to meet in-person at least annually during the period of the project with minutes recorded for each meeting. Additional meetings were held as required to deal with emerging issues, such as the development of a Memorandum of Agreement with the Taiwan Banana Research Institute to access new TR4 resistant Cavendish lines. As a result, the BVS met more frequently until 2020 when health regulations restricted travel due to the COVID-19 pandemic, with no meeting during 2020 and 1 on-line meeting in 2021. The on-line meeting was recorded and uploaded to the project SharePoint site for members to access at their convenience. The dates and attendance for the BVS meetings are presented in Table XX.

Table 3. Record of PRG and BVS meetings during BA16001

Date	Project reference committee	Banana variety subcommittee	Participation	Comments
18/10/17	✓	✓	12	Joint meeting, South Johnstone, in person meeting
7/12/17		✓	12	Cairns, in person meeting
5/2/18		✓	13	BVS delegation & TBRI delegation Innisfail, in person meeting
22/3/18	✓		11	Brisbane, in person meeting
8/11/18	✓	✓	18	Joint meeting, South Johnstone, in person meeting
12/3/19	✓	✓	14	Joint meeting, teleconference
5/9/19		✓	10	Teleconference
May/Nov 2020				Deferred due to COVID-19
18/3/21		✓	11	On-line meeting
7/5/21	✓		9	On-line meeting

Project review

The external mid-project review planned by Horticulture Innovation for March 2020 was postponed due to COVID-19 restrictions on travel and group gatherings. Instead, Horticulture Innovation modified the Terms of Reference so that the review focused more closely on the future plant protection needs for the banana industry so that recommendations from the review could be used to inform future banana protection R&D investment.

In undertaking the review, the external reviewers participated on-line in parts of the Banana Scientific Symposium 2021, conducted large stakeholder interviews and interviews and discussions with key project team members on pathology/nematology (29/4/21), entomology (30/4/21) and variety importation and assessment (21/5/21) activities in the project.

Appendix 2 – Agenda - Banana variety development and screening for TR4 resistance webinar – Taiwan/Australia

Themes	Presentations	Presenters	Timing (Aust EST)
1. Introduction and overview	Welcome and overview of the webinar, including how the webinar will run (10 mins)	Dr Christine Chou and Mr Stewart Lindsay	1430 – 1440
2. Australian disease screening and agronomic trial activities	Performance of TBRI lines in Northern Territory TR4 screening site – 2016 to 2020	Dr Sharl Mintoff	1440 – 1500
	Agronomic performance of TBRI lines in north Queensland research trials	Mr Jeff Daniells	1500 – 1520
	Grower observation trials of TBRI lines in north Queensland	Ms Katelyn Ferro	1520 – 1540
Short break/intermission			
3. Evaluation trials of GCTCV's conducted in the Philippines and Taiwan	Evaluation conducted in the Philippines (Dole and PCARRD) in 2010's	Dr. Agustin B. Molina	1550 – 1610
	Evaluation of GCTCV-105, 215 (TC 1), and 217 in Taiwan (TBRI) in 1990s	Dr. Chih-Ping Chao	1610 – 1630
	Evaluation of 218 (TTP), improved 218, TC3, TC7, Dwarf Pisang Awak, 219 and improved 215 in Taiwan (TBRI) between 2000 and 2020	Dr. Chih-Ping Chao	1630 – 1650
4. Report on the current status of the Report on progress of DAF/TBRI collaboration	The status of the current 6 imported lines	Mrs Sharon Hamill	1650 – 1710
5. General discussion and close	Issues or opportunities arising	Mr Stewart Lindsay + all	1710 – 1730

Appendix 4 – Selected yield and plant characteristics of the varieties in the Ratoon 1 crop cycle – South Johnstone trial

Variety	Months planting to harvest	Bunch Wt (kg)*	Bunch Wt* /12 months	Fruit 22-26 cm (wt %)	Fruit 20-22 cm (wt %)	Fruit < 20 cm (wt %)	Pseudostem Ht (m)	Pseudostem Circum (cm)	Ht: Circum Ratio	Fingers/ bunch	Days BE-BH
Williams	17.0	35.3	40.9	45	35	20	3.0	67	4.5	185	80
Grande Naine	17.5	38.2	41.7	51	28	21	2.9	71	4.2 <	209	81
Asia Pacific #1[a]	25.3 >	18.9 <	20.8 <	0 <	6 <	94 >	2.5 <	76 >	3.3 <	163	124 >
Asia Pacific #3	19.8 >	31.1	37.8	46	31	23	3.4 >	63	5.4 >	192	101 >
Formosana	22.8 >	28.2 <	31.0 <	47	25	27	3.0	73 >	4.0 <	169	115 >
Formosana Selection	22.6 >	30.0 <	33.4 <	43	30	27	3.1	77 >	4.1 <	188	116 >
GCTCV 105	19.9 >	26.0 <	32.0 <	28 <	34	38 >	3.2	62	5.2 >	159	94 >
GCTCV 106[b]	24.8 >	16.5 <	15.4 <	14 <	44	42 >	3.1	63	4.8 >	135 <	117 >
GCTCV 119	23.7 >	22.4 <	25.7 <	32	38	30	3.6 >	72	5.0 >	139 <	129 >
GCTCV 215	21.2 >	25.9 <	28.6 <	35	26	38 >	3.4 >	69	4.9 >	171	120 >
GCTCV 217	21.3 >	28.1 <	33.5 <	47	25	28	2.4 >	65	5.3 >	186	115 >
GCTCV 247	21.0 >	23.8 <	26.7 <	36	33	31	3.3 >	67	5.0 >	153	121 >
CJ19	19.6 >	25.6 <	28.5 <	35	29	36 >	2.4 <	69	3.5 <	165	113 >
CJ19 Selection	18.6 >	25.9 <	29.2 <	52	29	19	2.7 <	64	4.2 <	139 <	87
Dwarf Cav	17.3	36.3	41.9	28 <	38	34	2.2 <	69	3.2 <	242 >	82
Brier	18.1	34.4	40.6	55	32	12	2.3 <	74 >	3.2 <	205	80
Short Fruit Williams	20.7 >	26.4 <	31.1 <	35	36	29	3.0	71	4.3	169	101 >
Suckerless Williams	21.4 >	34.9	40.2	55	25	17	2.8 <	63	4.4	190	85
Jaffa	18.2	38.0	44.6	61	22	16	3.0	74 >	4.1 <	222 >	86
Gal	17.6	36.3	43.0	62 >	29	9	2.9	69	4.2 <	189	83
Adi 9001	18.1	37.0	42.1	63 >	22	15	2.7 <	69	4.0 <	206	84
Adi 9168	18.5 >	33.7	38.4	60	26	13	2.3 <	71	3.3 <	196	90
CIRAD 03	16.9	22.6 <	25.6 <	n.a.	n.a.	n.a.	3.7 >	59 <	6.3 >	181	87
CIRAD 04	22.1 >	19.8 <	23.6 <	n.a.	n.a.	n.a.	4.5 >	71	6.4 >	243 >	123 >
CIRAD 05	16.7	23.5 <	27.6 <	n.a.	n.a.	n.a.	3.5 >	60 <	5.8 >	158	98 >
CIRAD 06	16.5	21.6 <	27.1 <	n.a.	n.a.	n.a.	3.6 >	63	5.8 >	125 <	88
Santa Catarina Prata	19.6 >	18.9 <	20.8 <	n.a.	n.a.	n.a.	3.7 >	74 >	5.0 >	141 <	142 >
Dwarf Lady Finger	17.8	18.0 <	20.5 <	n.a.	n.a.	n.a.	3.2	76 >	4.2	133 <	103 >

< = significantly less than Williams (95% confidence level); > = significantly more than Williams (95% confidence level)

a – all offtypes ; b – questions remains over its true identity given its susceptibility to TR4 in NT; * excludes bunch stalk weight

n.a. – not applicable as these 4 CIRAD hybrids are not Cavendish type bananas and most of their fruit is shorter than the 2 preferred Cavendish size classes

	TBRI derived Cavendish selections
	Rahan Meristem Cavendish selections

	Less desirable characteristic
	More desirable characteristic

Appendix 5 – Fusarium oxysporum f.sp. cubense Race 1 (Foc R1) Resistance Screening – Duranbah, NSW

Introduction

The Subtropical Banana Variety trial was established at Duranbah, NSW in February 2018 to examine the field resistance of several banana varieties in the presence of Fusarium oxysporum f.sp. cubense race 1 (Foc R1). The trial is a component of the Hort Innovation project 'Improved plant protection for the Banana Industry' designed to access and evaluate banana varieties with improved pest and disease traits.

The trial site at Duranbah in Northern NSW is one of three in Australia established to identify banana varieties with improved pest, disease, agronomic and consumer preference traits aimed at diversifying, increasing and improving resilience of production. The Subtropical Banana Variety Evaluation trial was initiated with a focus on screening varieties for their field resistance to Foc R1 with the aim of identifying cultivars that may be acceptable for commercialisation.

The assessment and evaluation of banana varieties undergoes two phases of screening prior to being considered for on-farm trials and their subsequent selection for commercialisation and include:

- Phase 1 - Foc R1 resistance screening: varieties are grown with the aim of determining the degree to which they possess resistance to R1.
- Phase 2 – Best Bests trial: standout varieties, called 'best bets', are grown in accordance with commercial practices to determine agronomic performance and handling conditions and to undertake consumer acceptance.

This report will present the results obtained from the Foc R1 resistance screening trial (Phase 1) and will recommend varieties that should be considered for initiation into phase 2 of screening, those that require further research and those that should be excluded from future research.

Methodology

Site selection

The site is located at Duranbah in northern New South Wales (28°18'49" S, 153°13'45" E, elevation ~62m with an average annual rainfall of 1800 mm) (Figure 1) and has a north-eastern aspect with a slightly sloping (5%) block. The soil at the site is characterised as a red Ferrosol (McKenzie et al., 2004), which is typical of the soils under commercial cultivation of bananas within the region.

Figure 1. Duranbah Resistance Screening Trial site location

The site was historically known to have Foc R1 present which was confirmed during previous trials conducted on the same site location as this trial during the BA10020 project. During the BA10020 trial tissue from 'Lady Finger' sentinel plants infected with Foc R1 were used to isolate the Foc R1 strain VCG 0124. The isolated Foc VGC 0124 was multiplied in vitro and used to create an inoculum of infected Japanese millet grain (*Echinochloa esculenta*). To ensure an equal exposure of plants to Foc R1 site 200 g the inoculum was incorporated into each hole during planting.

A randomised block design experimental design with three replicates of five plants of each variety where possible was used. Due to insufficient plant numbers some varieties some plots had less than five plants. The total number of plants included in the trial for each variety is included in Table 3.

Tissue culture plantlets provided by DAF TC laboratory were transplanted into pots composed of sphagnum peat moss and wood pulp November 13th, 2017. The trial was planted on February 2nd, 2018. Plants were planted in single rows with a 2.5m spacing between plants within a row and a 4m wide interrow. The planting configuration was developed in conjunction with NSW DPI biometricians.

Banana trial varieties

Varieties were sourced from overseas banana research and breeding programs. All varieties included in the trial are listed in Table 3. 'Dwarf Ducasse' (highly susceptible), 'High Noon' (intermediate susceptibility) and 'Williams Cavendish' (highly resistant) were used as reference varieties.

Data Collection

Assessments of both disease severity and agronomic characteristics for the plant crop of all varieties were collected during the field trial. All assessment techniques and the methods for data collection utilised during the trial are included in Table 4.

Disease assessments were made in two ways. Firstly, external symptoms of Foc R1 disease were rated. This was completed on four occasions viz. at three, six, nine and 12 months after planting. Details of this assessment are available in Table 4. Secondly, a more conclusive test was used to assess the internal symptoms of Foc R1. The rhizome of plants that produced a harvestable bunch was dug out of the ground at harvest and transversely cut into 5 equal segments. The apical side of cut sections were then visually rated for vascular discolouration on a scale from 1-5. This differs from the standard protocol which employs a 1-6 scale outlined by Orjeda (1998) in the technical guidelines published for the evaluation of Musa germplasm for resistance to Fusarium wilt.

In addition to the assessments of disease severity, several agronomic characteristics were also measured. These included pseudostem height at harvest, plant crop cycle, number of functional leaves, bunch weight, number of hands, fruit weight, and length of the third finger on the third hand on the bunch.

The trial was heavily impacted by the presence of Banana weevil borer (BWB) (*Cosmopolites sordidus*). High populations of BWB were identified on 8 February 2019 and were deemed to be having a significant impact on the plants in the trial. As a result, any data collected following this date has been excluded from the statistical analyses. Despite this it is reasonable to assume that BWB may have impacted the data obtained for disease severity and agronomic traits prior to this their presence being recognised. As such, the results discussed should be interpreted with this in consideration. As a result of the impact of BWB on the trial it was possible to obtain sufficient internal symptoms disease severity and agronomic trait data at harvest of the plant crop for only 7 of the 19 varieties. External disease severity data was collected for all varieties.

Results

A field trial comprised 19 banana varieties arranged in plots of 1 to 5 plants in a grid 6 rows wide by 45 plants deep. Varieties were allocated to plots so that sets of 2 rows contained a single replicate of each variety. Trees were visually assessed for disease damage on 4 occasions from 30/05/2018 to 08/02/2019.

Only data from a subset of the varieties and plants within each variety were available for a detailed agronomic assessment including, plant size and some yield parameters at harvest.

The statistical analyses completed test the null hypothesis that the variable 'variety' did not have an influence on the disease or agronomic variables evaluated. It was advised by the statistician engaged to analyse the data that a post-hoc test to determine significant differences between varieties for the disease assessments and agronomic traits evaluated was not advisable. As such, only descriptive data is available when describing differences for these traits between varieties.

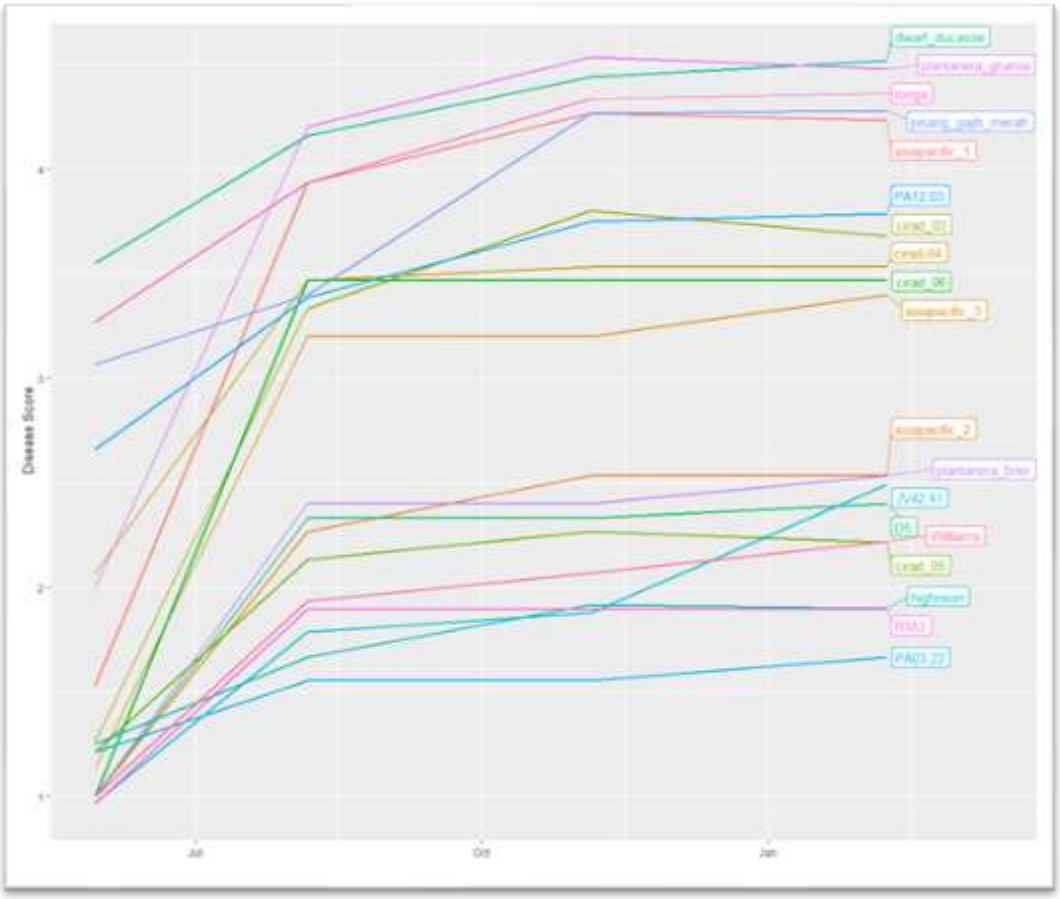
Disease assessments

Assessment of external Foc R1 symptoms

The ranking system was a 1-5 scale with score 1 = no symptoms and score 5 = complete death (assessment details available in Table 4). Assuming this represents an underlying continuous and evenly spaced gradient of disease, it seems reasonable to model these data similarly to the agronomic traits with additional terms to cover measurement date, the interaction between date and variety and the nesting of repeat measures within each plant.

The following figure shows progression of disease damage over time and suggests a broad grouping of the varieties into three susceptibility classes. Note that variety "Tonga" was only measured on 1 plant at the final date and this observation is excluded from the presentation due to low confidence in it. Shape declines or increases in disease ratings on the final assessment date (8 February 2019) are due to a reduction in sample size of specific varieties due plants impacted by BWB. Error bars or confidence regions not shown due to excess clutter but for broad comparisons, the 95% confidence interval for the estimates was +/- 0.63 units on average.

Figure 2. Progression of Foc R1 disease severity as measured by a visual assessment of external symptoms between May 2018 and February 2019.



Results of the statistical analysis indicate that there was significant effect (P > 0.05) of variety on the outcome of disease severity as measured by visual assessment of external symptoms. However, as a post-hoc test was not possible, significant differences between varieties in severity of external symptoms is not available.

As expected, the highly susceptible variety 'Dwarf Ducasse', included in the trial as a very susceptible reference variety, was rated as displaying the most severe external symptoms. 'Plantanera Gruesa', 'Tonga', 'Pisang Gajih Merah' and Asia Pacific #1 scored similarly (average external disease severity < 4 at final assessment timing) suggesting that under subtropical symptoms these varieties are susceptible to Foc R1. 'PA 12.03', 'CIRAD 03', 'CIRAD 04', 'CIRAD 06' and Asia Pacific #3 may be evaluated as exhibiting susceptible to intermediate susceptibility to Foc R1 (average external disease severity between 3 and 4 at final assessment timing). 'Plantanera Brier', 'JV 42.41', 'D5', 'Williams' and "CIRAD 5' can be rated as intermediate to resistant to Foc R1 (average external disease

severity between 2 and 3 at final assessment timing). Finally, the results suggest that the varieties 'High Noon', 'RSS5' and 'PA 03.22' demonstrated resistance to Foc R1.

It was not expected that 'High Noon', the intermediate reference variety, would demonstrate greater resistance to Foc R1 compared to 'Williams', which was included as the resistant reference variety. This indicates that the visual assessment of external symptoms may have been more closely correlated with a general measure of plant health rather than Foc R1 disease severity. A comparison with the data obtained from the internal assessment of disease severity is needed to determine whether this is the case, however this was only collected for only 7 of the 19 varieties.

Assessment of internal Foc R1 symptoms

With almost no information within the varieties, a formal statistical inference was not recommended for the data from the assessments of internal Foc R1 symptoms.

Table 1. Means of internal Foc R1 symptoms ratings from 5 transverse sections of the rhizome

Variety	Description	Mean of internal Foc R1 symptoms (1-5 scale)
Williams (Reference variety – R check)	Cavendish	1
Plantanera Brier	Cavendish	1
D5	Cavendish	1
R553	Cavendish	1
PA 03.22	Lady Finger hybrid	1
JV 42.41	Lady Finger hybrid	1
High Noon (Reference variety – I check)	Lady Finger hybrid	1.87

The table above indicates that there was no vascular discoloration of the rhizome for 'Williams', 'Plantanera Brier', 'D5', 'R553', 'PA 03.22', 'JV 42.41' indicating these plants had not been infected with Foc R1 which contrasts with the results from the external assessment of Foc R1 symptoms for these varieties.

Agronomic traits

A linear model was fitted to estimate variation in each trait associated with variety and field position as indicated by the replicate blocks. A random effect of plot was included to accommodate the nesting of single plant observations within sets of 1-5 plants in the design. An approximate analysis of variance was derived from the model for assessment of evidence against a hypothesis of nil effect due to variety. The following discussion describes results of the statistical analyses that assessed whether the variable 'variety' had a significant effect on each of the agronomic traits assessed and does not provide an indication of the variation between varieties. The models were also used to estimate a table of the mean response under each variety along with standard error and 95% confidence interval.

A significant effect ($P < 0.05$) of the variable 'variety' was found for the agronomic traits pseudostem height (cm), plant crop cycle (days), number of hands at harvest and on the length of the 3rd fruit located on the 3rd hand. There was no significant effect of the variable 'variety' observed on the number of leaves or fruit weight. Unexpectedly, there was no significant effect of 'variety' on bunch weight however there was a considerable trend towards significance ($P = 0.06$).

As a post-hoc test was not recommended it is not possible to determine the significant differences between varieties for the agronomic traits evaluated. Consequently, discussion of the differences in traits, between varieties, will be limited to a comparison of means (Table 5). Following the statistical analyses, bunch weight per year for all varieties was calculated as an additional metric to enable comparison of the yield of varieties over time (Table 2).

Table 2. Mean bunch weight per year

Variety	Description	Bunch wt/year (kg/year)
D5	Cavendish	14.98
Williams (Reference variety – R check)	Cavendish	12.86
RSS3	Cavendish	11.77
JV 42.41	Lady Finger hybrid	11.27
Plantanera Brier	Cavendish	11.04
PA 03.22	Lady Finger hybrid	10.53
High Noon (Reference variety – I check)	Lady Finger hybrid	9.53

The variety, 'D5', had the heaviest average bunch weight at 22.7 kg, with 'RSS3' following with 18.8 kg, which was 22% and 6% more than the commercial standard 'Williams' (17.8 kg) respectively. 'D5' was observed to have the highest mean number of hands (9.3) and finger length (21.4 cm) outperforming 'Williams'. As can be seen from Table 2, 'D5' yielded 14.98 kg/per year compared to 'Williams' 12.86 kg/year and despite the higher average bunch weight, the productivity of 'RSS3' was lower than the commercial standard (11.77 kg/year).

'Plantanera Brier' was observed as having the lowest mean pseudostem height (159 cm) and the highest average number of functional leaves (5.1).

'PA 03.22' had the fastest average plant crop cycle at 522 days, which was 10 days faster than observed for 'Williams'. However, 'PA 03.22' had the lowest average bunch weight (11.7 kg), number of hands per bunch (6.9), fruit weight (103.6 g) and finger length (16.3 cm) observed across all varieties.

Discussion

The trial investigated the degree of Foc R1 disease field resistance or susceptibility and collected data associated with a range of agronomic traits of banana varieties identified as having commercial potential in the subtropical growing regions of Australia.

It must be noted that the trial site received below average rainfall during 2018 and 2019 whilst research was being conducted, with the rainfall for many months during this period falling well below the long-term monthly mean (Figures 3 and 4). The drier conditions had a significant impact on the growth and development of the plants. This should be taken into consideration when interpreting the results of this trial.

The assessment of visual assessment external and internal Foc R1 disease severity gave conflicting results. The external disease severity data indicated a range of susceptibility through to resistance to Foc R1 across all varieties assessed. This however contrasts with the data obtained from the internal assessment of disease severity results.

A comparison of the data obtained for varieties for which an assessment of both external and internal Foc R1 symptoms indicates that one or both assessments were measuring a variable that is not correlated with Foc R1 disease severity. An assessment of external disease severity indicated that 'Williams', 'Plantanera Brier', 'D5', 'R553', 'PA 03.22', 'JV 42.41' all demonstrated symptoms that indicated they had been infected by Foc R1. This contrasts to the assessment of internal disease severity in which these same varieties were rated as being free from infection by Foc R1. As a result of these disparate findings, it is not possible to draw accurate conclusions as to the degree of field resistance the varieties screened in this trial possess, based on the data collected. It is recommended that all varieties be included in future trials so that an accurate evaluation of their susceptibility or resistance to Foc R1 can be obtained.

Based on the results obtained for the agronomic traits assessed and presented in the results section 'D5' and 'RSS3' scored similarly with 'Williams' for traits that evaluated yield which include bunch weight, plant crop cycle, bunch weight per yea, number of hands, fruit weight and finger length. As a conclusion could not be reached regarding the degree of resistance to Foc R1 these varieties possess, they should be included in future subtropical screening trials based on their favourable agronomic performance compared to 'Williams'.

Due to the poor agronomic performance of 'PA 03.22' it could be reasonable to recommend that this variety be excluded from future Foc R1 screening trials. However, due to the impact of drought and the confounding influence of BWB during this trial it could also be argued that the data and conclusions presented are not an accurate representation to varietal performance in the presence of Foc R1. Therefore, based on the low reliability of the data obtained it is recommended that all varieties be included in future Foc R1 screening trials.

Further research needs to be conducted in order to obtain results that are accurate and reliable enough to be able to make confident conclusions regarding the field resistance and agronomic performance of the varieties evaluated in this trial.

References

McKenzie, N., Jacquier, D., Isbell, R., Brown, K., 2004. Australian Soils and Landscapes: an Illustrated Compendium. CSIRO Publishing, Collingwood, Australia 416 pp.

Orjeda, G., 1998. Evaluation of Musa Germplasm for Resistance to Sigatoka Diseases and Fusarium Wilt, in: INIBAP Technical Guidelines 3. International Plant Genetics Resources Institute, Rome, Italy; International Network for the Improvement of Banana and Plantain, Montpellier, France; ACP-EU Technical Centre for Agriculture and Rural Cooperation, Wageningen, The Netherlands.

Table 3: Banana varieties included in Duranbah Foc 1 screening trial

Variety	Description	No. of plants in trial
Williams	Cavendish – *Foc R1* resistant (control)	15
High Noon	Lady Finger hybrid – *Foc R1* intermediate resistance (control)	12
Dwarf Ducasse	Pisang awak – *Foc R1* highly susceptible (control)	15
CIRAD 03	Novel hybrid ex French West Indies	15
CIRAD 04	Novel hybrid ex French West Indies	15
CIRAD 05	Novel hybrid ex French West Indies	15
CIRAD 06	Novel hybrid ex French West Indies	15
Plantanera Brier	Dwarf Cavendish selection from the Canary Islands	15
Plantanera Gruesa*	Dwarf Cavendish selection from the Canary Islands	15
Asia Pacific #1*	Cavendish selection from Taiwan Banana Breeding Institute	15
Asia Pacific #3	Cavendish selection from Taiwan Banana Breeding Institute	15
D5	Cavendish selection from South Africa	15
RSS3	Cavendish selection from South Africa	15
Pisang Gajih Merah	Cooking type popular in the Philippines and Indonesia	15
Tonga	Cooking type from Pacific	15
PA 03.22	Dwarf Lady Finger hybrid from Brazil	9
PA 12.03	Dwarf Lady Finger hybrid from Brazil	12
JV 42.41	Lady Finger hybrid from Brazil	12

*Note – identified as all off-type plants

Table 4: Assessments and method of data collection for attributes evaluated during Foc R1 resistance screening trial.

Assessment type	Scale	Method
External Disease Severity (plant)	1 - 5	1 = No symptoms 2 = Negligible, symptoms barely seen 3 = Moderate symptoms, leaf margins yellowing, basal splitting 4 = Severe symptoms, entire leaf yellowing and significant necrosis 5 = Plant death
Internal Disease Severity (rhizome)	1 – 5	1 = Corm completely clean, no vascular discolouration 2 = Discolouration of up to one-third of vascular tissue 3 = Between one-third and two-thirds vascular tissue discolouration 4 = Greater than two-thirds vascular discolouration 5 = Total discoloration of vascular tissue
Pseudostem Height	cm	Height (cm) from the soil surface to the growing point of the plant at harvest.
Plant crop cycle	days	Number of days from planting to harvest
Number of functional leaves	count	Number of functional leaves present at harvest
Bunch Weight	kg	Weight of bunch at harvest
Number of hands	count	Count of hands present from 1 bunch at harvest
Fruit Weight	g	Average fruit weight determined by dividing bunch weight by number of fruits
Third finger 3rd hand length	cm	Length of 3rd finger from the left side of the 3rd hand as viewed on the bunch

Figure 3. 2018 rainfall with long-term mean and long-term median rainfall data from nearest weather station (Kingscliff) (source: Climate data online, Bureau of Meteorology, copyright Commonwealth of Australia, 2020)

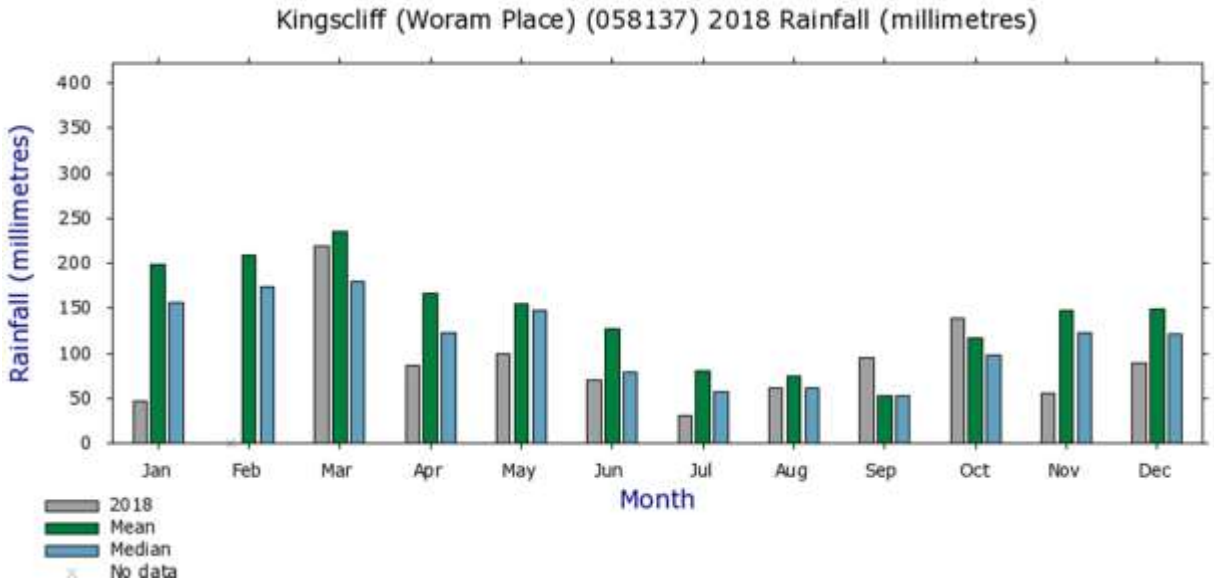


Figure 4. 2019 rainfall with long-term mean and long-term median rainfall data from nearest weather station (Kingscliff) (source: Climate data online, Bureau of Meteorology, copyright Commonwealth of Australia, 2020)

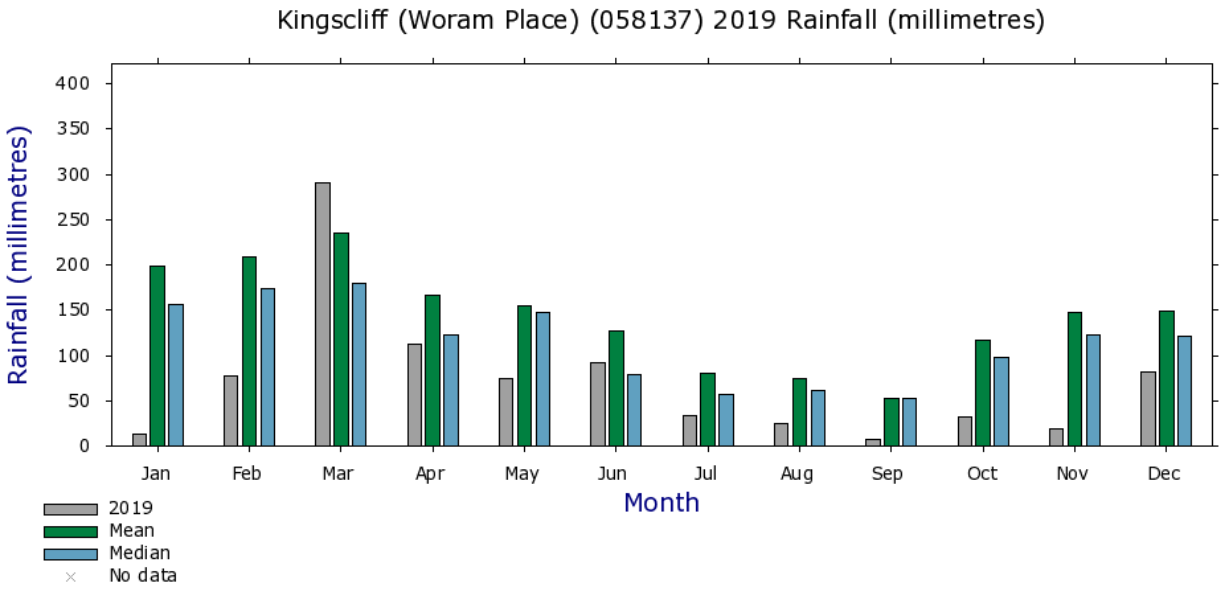


Table 5. Plant crop means and standard errors for the agronomic traits assessed in the presence of Foc R1 at Duranbah in the subtropics.

Variety	Pseudostem Height (cm)		Plant crop cycle (days)		No. of Functional leaves at harvest		Bunch weight (kg)		No. of hands / bunch		Fruit Weight (g)		Third finger, 3rd hand length (cm)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
D5	204.1	6.7	538.5	16.3	4.9	0.7	22.7	2.2	9.3	0.6	133.8	13.6	21.4	0.7
High Noon	262.5	6.4	617.5	15.8	3.7	0.7	16.2	2.1	7.1	0.6	162.5	13.6	20.7	0.6
JV42.41	308.3	7.4	565.5	17.2	4	0.8	17.6	2.3	7.7	0.6	158.9	14.6	20.2	0.7
PA03.22	204.4	6.0	522	15.4	4.6	0.7	11.7	2	6.9	0.5	103.6	12.7	16.3	0.6
Plantanera Brier	159.0	6.0	580.2	15.4	5.1	0.7	17	2	8.3	0.5	122.1	12.8	20.6	0.6
RSS3	210	7.2	585.3	16.8	3.6	0.8	18.8	2.3	8.3	0.6	129.2	14.6	20.9	0.7
Williams	204.7	8.4	532.4	18.3	4.5	0.9	17.8	2.9	7.8	0.7	125.8	19	21.1	1

Most desirable

Least desirable

Appendix 6 – 'Best Bets' agronomic trial – Duranbah, NSW

Introduction

The Subtropical Banana Variety 'Best Bets' trial was established at Duranbah, NSW in February 2018. It was conducted in order to evaluate the agronomic performance of varieties that have been assessed as having resistance to *Fusarium oxysporum* f.sp. *cubense* Race 1 (Foc R1) within a commercial management context. The trial is a component of the Hort Innovation project 'Improved plant protection for the Banana Industry' designed to access and evaluate banana varieties with improved pest and disease traits.

The trial site at Duranbah in Northern NSW is one of three in Australia established to identify banana varieties with improved pest, disease, agronomic and consumer preference traits aimed at diversifying, increasing and improving resilience of production. The pre-commercialisation trial was initiated with a focus on evaluating selected varieties cultivated using common commercial management practices with the aim of determining whether they should be pursued for commercialisation.

The assessment and evaluation of banana varieties undergoes two phases of screening prior to being considered for on-farm trials and their subsequent selection for commercialisation and include:

- Phase 1 - Foc R1 resistance screening: varieties are grown with the aim of determining the degree to which they possess resistance to R1.
- Phase 2 – 'Best Bets' trial: standout varieties from Phase 1, called 'best bets', are grown in accordance with commercial practices to determine ripening and handling conditions and to undertake consumer acceptance.

In February 2018 two "best bets" dessert varieties, 'PKZ' (Musa AAAA) and 'FHIA-17' (Musa AAAA), which had progressed through screening phases 1 and 2, were selected from the agronomy trial undertaken in BA13004 "National Banana Development and Extension Program" for further evaluation. The variety, FLF-1, was originally included in the trial but was removed prior to completion of the research and will not be considered in this report. The pre-commercialisation trial was established in a commercial style planting, cultivated using commercial practices under subtropical conditions and the agronomic performance of varieties assessed.

Two density treatments were incorporated with the aim of comparing the agronomic performance of same variety between the two planting configurations. The density treatment was based on the commercial planting configurations common to the subtropical growing regions and include single and double row plantings.

'PKZ' was selected in South Africa as a potential replacement for Cavendish but failed to gain acceptance in the South African market. Genetic assessment using SSR-markers indicate alignment with Musa AAAA (e.g. Highgate hybrid) (J. Daniells, personal communication, April 4, 2020). PKZ has been described as having improved bunch morphology and a taste reasonably comparable to Cavendish. Bunches are cylindrical, with all fruit of similar length, as opposed to semi-conical in Cavendish bunches, leading to easier packing and a reduction in waste resulting from fruit that are outside of market specifications.

'FHIA-17' is a Highgate hybrid with a large bunch and good resistance to *Pseudocercospora* leaf spot and Foc R1. The cultivar is being trialled as a dual-purpose cultivar (dessert and cooking), with further interest in processing this cultivar into preserves and sweets in Australia. The male buds of 'FHIA-17' also have market acceptance.

This report will present the results obtained from the pre-commercialisation trial (Phase 2). The agronomic performance data of the two varieties and a comparison of these results between the two planting density treatments will be presented. Based on these results and the results from a sensory analysis study of these varieties, a recommendation will be made as to whether these varieties should be considered for commercialisation.

Methodology

Site selection

The site is located at Duranbah in northern New South Wales (28°18'49" S, 153°13'45" E, elevation ~62m with an average annual rainfall of 1800 mm) (Figure 1) and has a north-eastern aspect with a slightly sloping (5%) block. The soil at the site is characterised as a red Ferrosol (McKenzie et al., 2004), which is typical of the soils under commercial cultivation of bananas within the region.

Tissue culture plantlets provided by QDAF Nambour TC laboratory were transplanted into pots composed of sphagnum peat moss and wood pulp 13 November 2017. The trial was planted on 2 February 2018.

Figure 1. Pre-commercialisation trial site location

Experimental Design

The trial was designed with the intention of collecting agronomic performance data from 'PKZ' and 'FHIA-17' under common commercial practices and to compare their performance between the two planting density treatments: single and double row plantings. 'FLF-1' which was originally included in the trial was removed during December 2018. The removal of these plants would have increased light available for some rows and will be considered when interpreting the results.

A total of four single rows, two rows of each variety, were planted. There were 25 plants included in each row for a total of 50 plants for each variety. The rows had an interrow gap of 2 m and a planting space of 2.5 m within the rows Figure 2.

Two double row plantings, 1 double row for each variety, were planted. There were 40 plants of a variety included in each double row. The rows had an interrow gap of 2 m and a planting space of 2 m within the rows Figure 2.

Data Collection

Assessments of agronomic characteristics for both varieties were collected during the field trial. All assessment techniques and the methods for data collection utilised during the trial are included in Table 2.

Selected agronomic characteristics were measured at harvest. These include pseudostem height at harvest, plant crop cycle, number of functional leaves, bunch weight, number of hands, fruit weight, length and girth of the third finger on the third hand.

Results

A field trial comprised 3 banana varieties with 2 of them planted in either a single or double row configuration to make 5 variety/spacing combinations.

Principals of experimental design for field trials such as replication, randomisation and interspersion were not strongly adhered to at this site. Plots comprised a single row of 19-25 trees. The double row entries were not replicated. All single row plantings were at the northern end of the trial.

Despite this, a statistical model can be fitted, and mean responses estimated. They should, however, be taken with a great deal of caution.

This report contains summary statistics for comparison of varietal performance.

A linear model was fitted to estimate variation in each trait associated with variety/spacing. A random effect of plot was included to accommodate the nesting of single plant observations within sets of 19-25 plants in the

design. An approximate analysis of variance was derived from the model for assessment of evidence against a hypothesis of nil effect due to variety. The models were also used to estimate a table of the mean response under each variety along with standard error and 95% confidence interval.

Results from the analyses indicate that the null hypothesis of nil effect due to variety, ignoring the impact of planting configuration, can be rejected for pseudostem height, number of functional leaves at harvest, bunch weight, fruit weight and third finger from the third hand girth. In contrast there was no evidence to indicate a significant difference in means for the two varieties for plant crop cycle, number of hands and finger length. These results do not allow us to determine which variety in either planting configuration performed better than others and therefore with not be discussed further.

It was advised by the statistician engaged to analyse the data that a post-hoc test to determine significant differences between planting configurations for the same variety for agronomic traits evaluated was not advisable. As such, only descriptive data is available when describing differences for these traits between planting configurations.

Following the statistical analyses, bunch weight per year for all varieties was calculated as an additional metric to enable comparison of the yield of varieties in different planting configurations over time (Table 1).

Table 1. Mean bunch weight per year

Variety	Planting configuration	Bunch wt/year (kg/year)
FHIA-17	Double	18.20
FHIA-17	Single	17.00
PKZ	Double	16.56
PKZ	Single	15.43

The mean and standard errors for the agronomic traits evaluated can be seen in Table 3. This data will be used to evaluate the difference between planting configurations for the same variety.

FHIA-17

The results show that 'FHIA-17' planted in double rows had a mean pseudostem height (287.1) that was shorter than single rows (294.1 cm), a shorter plant crop cycle (- 33.2 days), higher number of functional leaves (+ 0.7 leaves), slight heavier bunch weight (+0.4 kg) and on average 1 more hand per bunch. When planted in single rows it was slightly more productive than in double rows with average bunch weight per year 18.2 kg and 17 kg respectively. 'FHIA-17' planted in single rows had an average fruit weight that was heavy than when planted in double rows and slightly longer (+0.7 cm) and thicker fruit (+ 3.2 mm).

PKZ

Planted in double rows 'PKZ' had heavier bunch weights (+2.9 kg), slight longer (+0.9 cm) and 1 more hand per bunch when compared to averages of these traits in single row plantings. "PKZ" planted in double rows were also slightly more productive than single rows with averages of 16.56 kg and 15.43 kg respectively. Planted in single rows 'PKZ' possessed a shorter pseudostem (272.9 cm) than plants in double rows (287.4 cm), a plant crop cycle 25.2 days shorter, higher number of functional leaves (+ 0.7 leaves) and slight heavier fruit weight (+ 2.2 g).

Discussion

The trial investigated the agronomic performance of PKZ and FHIA-17 varieties which were identified as having commercial potential in the subtropical growing regions of Australia. The varieties were exposed to two density treatments, single and double row planting configurations determine if there were any differences in agronomic performance as a result.

It must be noted that the trial site received below average rainfall during 2018 and 2019 whilst research was being conducted, with the rainfall for many months during this period falling well below the long-term monthly mean Figures 3 and 4. The drier conditions had a significant impact on the growth and development of the plants. This should be taken into consideration when interpreting the results of this trial.

Based on the results 'FHIA-17 seemed to perform better when planted in doubles row in comparison to single

rows. The was a reduction in crop cycling for the plant crop and an increase in bunch weight resulting in greater bunch weight per year when compared to planting in singles rows. This result is similar to those found by Daniells et al. (1985 & 1987) where increasing plant density led to higher yield over time in faster plant cycling Williams in north Queensland. However, in their research they also found a decrease in bunch weight associated with increasing plant density that contrasts to the finding for 'FHIA-17' in this trial.

In contrast, 'PKZ' performed slightly worse when planted in single rows than when in double rows. Plants in single rows had short pseudostem height as would be expected and shorter cycling (Daniells et al. 1985 & 1987). However, there was a reduction in bunch weight, number of hands and bunch weight per year in single row plants compared to those in double rows.

As there were limited number of replicated plots across the trail site and 'FLF-1' was removed before competition of the trial these results may have been confounded due to variations in light gradients between plots. It would be recommended that this trial be undertaken again employing a robust experimental design and with aim of capturing data from at least three crop cycles. However, as a consumer acceptance study completed with these varieties has demonstrated that 'FHIA-17' and 'PKZ' do not have consumer appeal when compared to 'Williams' it is recommended that no further research into their commercial potential be conducted.

References

Daniells, J.W., O'Farrell, P.J. and Campbell, S.J., 1985. The response of bananas to plant spacing in double rows in North Queensland. Queensland Journal of Agricultural and Animal Sciences (Australia).

Daniells, J.W., O'Farrell, P.J., Mulder, J.C. and Campbell, S.J., 1987. Effect of plant spacing on yield and plant characteristics of banana in North Queensland. Australian Journal of Experimental Agriculture, 27(5), pp.727-731.

McKenzie, N., Jacquier, D., Isbell, R., Brown, K., 2004. Australian Soils and Landscapes: an Illustrated Compendium. CSIRO Publishing, Collingwood, Australia 416 pp.

Figure 2. Pre-commercialisation trial plot map

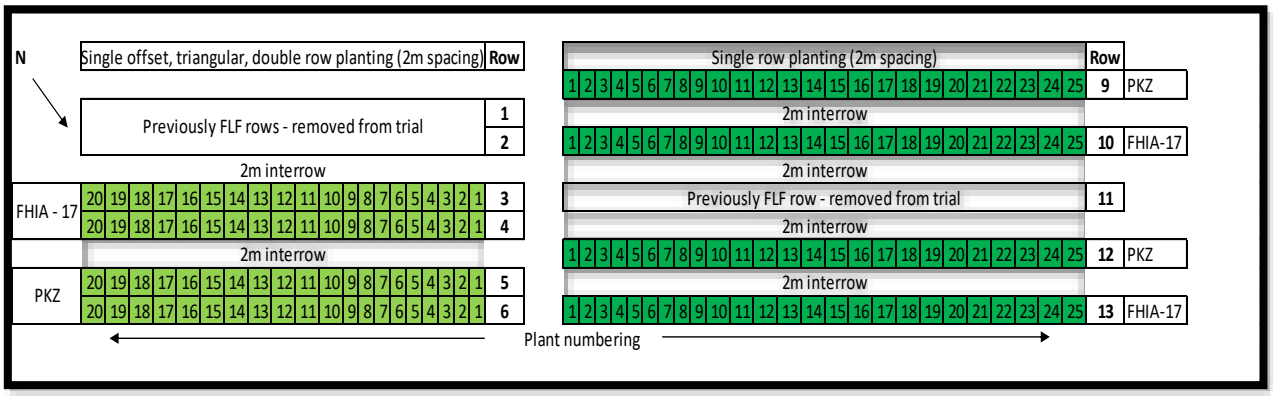


Table 2. Assessments and method of data collection for agronomic characteristics evaluated during the pre-commercialisation trial.

Assessment type	Scale	Method
Pseudostem Height	cm	Height (cm) from the soil surface to the growing point of the plant at harvest.
Plant crop cycle	days	Number of days from planting to harvest
Number of functional leaves	count	Number of functional leaves present at harvest
Bunch Weight	kg	Weight of bunch at harvest

Assessment type	Scale	Method
Number of hands	count	Count of hands present from 1 bunch at harvest
Fruit Weight	g	Average fruit weight determined by dividing bunch weight by number of fruits
Third finger 3rd hand length	cm	Length of 3rd finger from the left side of the 3rd hand as viewed on the bunch
Third finger 3rd hand girth	mm	Third finger 3rd hand girth using callipers at right angles to the curve of the fruit at a point one third from the flowering end

Figure 3. 2018 rainfall with long-term mean and long-term median rainfall data from Kingscliff (closest weather station to the trial site) (source: Climate data online, Bureau of Meteorology, copyright Commonwealth of Australia, 2020)

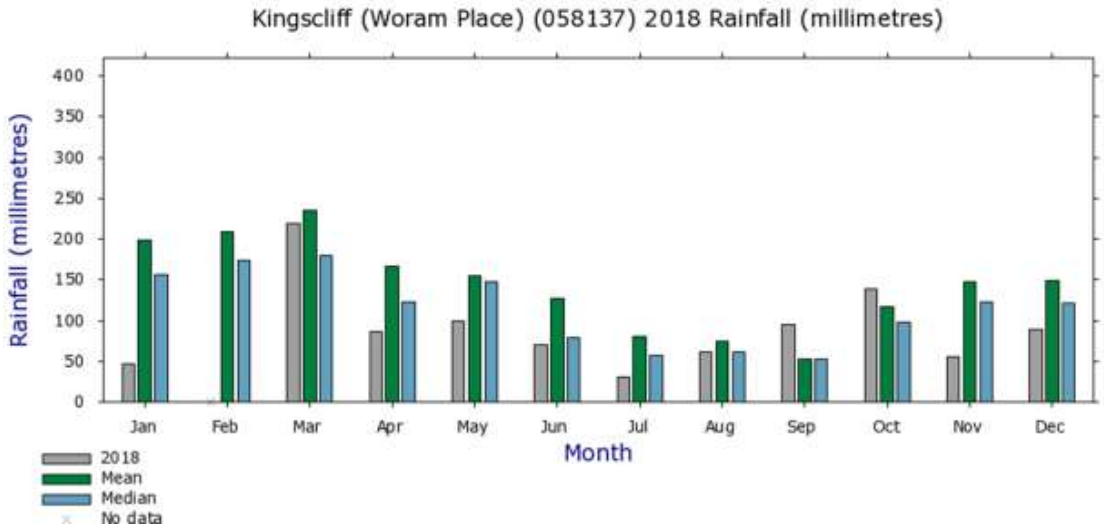


Figure 4. 2019 rainfall with long-term mean and long-term median rainfall data from Kingscliff (closest weather station to the trial site) (source: Climate data online, Bureau of Meteorology, copyright Commonwealth of Australia, 2020)

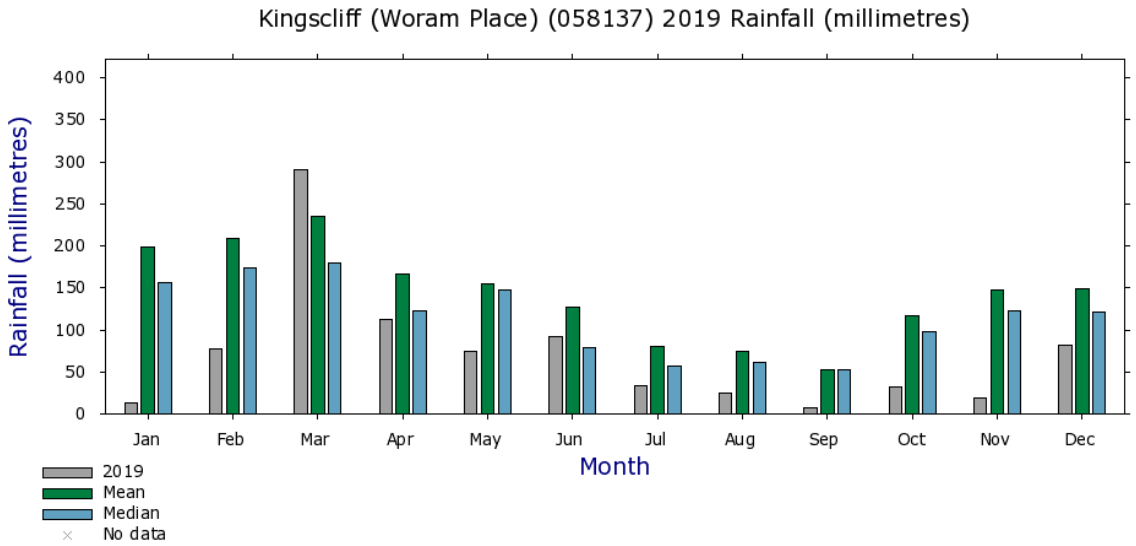


Table 3. Plant crop means and standard errors for the agronomic traits assessed for 'PKZ' and 'FHIA-17' planted in single and double rows at Duranbah in the subtropics

Variety	Planting configuration	Pseudostem Height (cm)		Plant Crop Cycle (days)		No. of functional leaves at harvest		Bunch weight (kg)		No. of hands / bunch		Fruit weight (g)		Third finger 3rd hand length (cm)		Third finger 3rd hand girth (mm)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
FHIA-17	Double	287.1	3	589.6	9.9	5.3	0.4	29.4	1.3	10	0.4	154.1	5.2	22.2	0.4	36.2	0.6
FHIA-17	Single	294.1	2.9	622.8	9.3	4.6	0.3	29	1.3	9	0.4	185.4	4.8	22.9	0.3	39.4	0.5
PKZ	Double	287.4	3	595.2	9.9	4.7	0.4	27	1.4	10	0.4	151.9	5.7	23.3	0.4	36.5	0.7
PKZ	Single	272.9	2.8	570	9.1	5.4	0.3	24.1	1.3	9	0.4	154.1	4.7	22.4	0.3	36.3	0.8

Appendix 8 – Pre-commercialisation trials

Introduction

Following-on from TR4 resistance screening trials in the Northern Territory, the two cultivars GCTCV 215 and GCTCV 247 were selected to be included in on-farm trials across several banana-producing regions. Growing 100-300 plants under commercial practices has allowed farmers to closely evaluate plant performance and assess the viability of these new varieties. Four sites have been planted in north Queensland since October 2019, with a fifth site established in the Northern Territory in October 2020.

Table 1. Location and plant numbers for the 5 pre-commercialisation trials

Location	Variety			
	GCTCV247	GCTCV215	CJ19	Williams
Tully south, NQ	200	200	-	yes
Tully north, NQ	200	200	-	yes (not co-located)
Innisfail, NQ	300	300	-	no
Walkamin, NQ	200	200	-	no
Lake Bennett, NT	75	75	75	yes

Tully south, NQ

Plant crop

In total, 210 'GCTCV 215' (blue) and 234 'GCTCV 247' (pink) plants were established in two double-rows on the edge of a 'Williams' plant block on 30 October 2019. Limited agronomic assessments were carried out on a sample (20 – 30 plants) of each variety when the population had reached approximately 50% bunch emergence. Plant height (from base of plant to peduncle arch) and girth (at approximately 1 m) were measured, along with hand and finger count (on the third and second last hand) to estimate total fruit number. After harvesting, bunch weight was taken as bunches moved through the packing shed, and average stalk weight was calculated after de-handing. With major assistance from the grower, packout rates were calculated by comparing the number of bunches harvested to the number of 15 kg boxes packed. It should be noted that the data is expressed in 15 kg cartons/bunch, however each box is packed to a gross weight of 16.2 – 16.5 kg to allow for shrinkage. It was not practical to determine how much waste resulted from each bunch (damaged or fruit not meeting specification), so the pack-out rates may be a slight under-estimate. The time from planting to bunch emergence was recorded, however bunch hang-time was not.

Table 2. Summary of agronomic assessments collected on the plant crop and ratoon one. Data is displayed as an average ± SEM.

Crop Cycle	Measurement	Williams	GCTCV 215	GCTCV 247
Plant	**Height (m)**	2.5 ±0.01	2.8 ±0.03	2.6 ±0.02
R1		3.2 ±0.03	3.2 ±0.05	3.2 ±0.05
Plant	**Girth (cm)**	52 ±0.3	48 ±0.6	47 ±0.3
R1		71 ±1.0	63 ±1.0	63 ±1.3
Plant	**Est. Finger Count**	135 ±3.2	111 ±3.0	118 ±3.5
R1		185 ±3.6	126 ±5.0	127 ±5.0
Plant	**Fruit weight (bunch - stalk)**	22.1 ±0.5	21.9 ±0.4	20.2 ±0.4
R1		31.6 ±1.2	20.5 ±0.8	20.5 ±1.5
Plant	**Pack out (15kg cartons/bunch)**	0.9	0.8	0.8
R1		1.2	0.75	0.7
Plant	**Planting to bunch emergence (weeks)**	27 ±0.2	36 ±0.3	35 ±0.3

Grower feedback has indicated the plants have performed better than expected, with plant and bunch characteristics not too different from Williams so far. The owners both noted that there appeared to be fewer suckers on the new varieties (making de-suckering less labour intensive). However, one drawback is the slower cycling time. It was also noted that the increased plant height and thinner pseudostems of the varieties made them more prone to snapping and extensive stringing is required to minimise losses. The first ratoon crop will provide greater clarity on plant performance.

Figure 1. An example of heavily leaning GCTCV 247 plants being held up by string.

With assistance from Mackays' Marketing, some post-harvest assessments were performed on the fruit, including ripening behaviour, shelf-life testing, %Brix, palatability and taste testing. Results were generally positive and in all areas the fruit was comparable to the standard set by Williams Cavendish. There was evidence that the GCTCV 215 fruit was more prone to developing marks on the peel due to handling, however it is something which needs to be investigated further. Ensuring fruit will be well-received by consumers is an essential component of the commercialisation pipeline. This data offers confidence that these varieties would be able to enter the market with relative ease.

First ratoon crop

By mid-April 2021, 82% of the Williams control plants had bunched in the first ratoon, while only 19% and 13% of the GCTCV 247 and 215 plants respectively had bunched. It was not until a trial visit in early July that more than 50% of the GCTCV plants were recorded as having thrown a bunch. This reiterates the slower cycling of the two TR4 resistant varieties observed in the plant crop.

Agronomic data collected on first ratoon plants showed that all varieties increased in height, as would be expected, to an average of 3.2 m (Table 2), however the girth remained thinner in the TR4 resistant varieties compared to the Williams. Bunch size of Williams increased notably more, 27% more fingers and a 30% increase in weight. While the GCTCV 215 and GCTCV 247 varieties may have had marginally more fingers in the first ratoon than the plant crop, bunch weights did not increase.

The pack-out rate was estimated for Williams at the end of May, however there were not enough GCTCV bunches ready for harvest to warrant pack-out rate calculations until the start of August. Again, the larger Williams bunches resulted in a higher number of 15 kg cartons being filled per bunch compared to the plant crop (1.2 vs 0.9 cartons/bunch), while there appeared to be a slight decrease in the pack-out of the GCTCV varieties, both falling to 0.7 cartons/bunch.

In recent months, the grower has made the comment that these two TR4 resistant varieties appear to be less tolerant to extreme heat and more susceptible to breaking over in hot conditions. He has also observed higher levels of leaf spot disease on these varieties compared to Williams.

Second ratoon crop

Second ratoon bunches began emerging from the Williams plants in October 2021, and 31% had emerged by 9 December 2021. Only one bunch had emerged from the GCTCV 215 plants and none from the GCTCV 247. Again, once 50% bunch emergence is reached, data will be collected on a sample of plants.

Tully north, NQ

Plant crop

Planted in January 2020, plants started bunching in October 2020 with around 5% of the GCTCV 215s and none of the GCTCV 247s on 21 October 2020. This contrasted with 69% for the Williams planted at the same time but in rows somewhat distant from the TR4 resistant varieties. The farm manager advised that the TR4 resistant varieties were very tall at planting time and were trimmed back (resembling sticks) before planting, which may have contributed to them being slower to reach maturity than the more robust looking Williams.

Figure 2. The two rows of trial plants at Tully north on the 21 October 2020, LHS: GCTCV 247, RHS: GCTCV 215.

Figure 3. A plant leaning severely (foreground), while many other plants snapped in the strong wind (background), Tully north. (Dec 2020)

On 15 December 2020 an isolated storm caused severe damage in the trial. Damage was assessed two days later noting those plants snapped by the wind and those leaning severely (Table 3). Both bunched and un-bunched plants were casualties. More mature bunches had been supported with twine which would have helped some of the older bunched plants to remain standing. The TR4 resistant varieties have had to be nurse suckered whilst the Williams were not, so we will no longer have suitable Williams control plants available for comparison. There is evidence that the GCTCV 215 and 247 are more prone to wind damage than Williams. Better bunch support may help remedy some of this.

During out last visit in September 2021, 55% of GCTCV 247 and 43% of GCTCV 215 had bunched. Data collected from a sample of the GCTCV 247 plants indicate they are a notably taller than the plants grown at the Tully south site – averaging a height of 3.9 m and girth of 79 cm, with an estimated finger count of 162 fruit. A questionnaire developed for the growers to provide feedback on the new varieties was left with one of the farm managers to complete but has not yet been returned.

Table 3. Summary of condition of the pre-commercialisation trial plants and the two rows of Williams being monitored as a control (plant crop, 17 December 2020).

Variety	Total plants	% harvested	% pseudo-stem snapped	% still with bunch hanging (not leaning)	% Unbunched (not leaning)	% bunched and unbunched leaning severely
Williams	236	44	7	44	5	0
GCTCV 215	231	0	47	11	35	6
GCTCV 247	230	0.4	44	15	35	5

Innisfail, NQ

Plant crop

This trial was planted in March 2020 and the grower commented that the material was perhaps left a little too long before planting and was not in the best condition. Potentially due to miscommunication, no planting

of Williams occurred at the same time (the closest was November 2019). The plants were situated at the end of an established Williams block near a creek and we had concerns the riparian strip may interfere with plant growth (particularly in the end row).

Figure 3. The trial block at LMB Farming.

Figure 4. Destruction of the Innisfail pre-commercialisation trial in March 2021 by strong winds

The two GCTCV varieties commenced bunching in February 2021, however, a developing tropical low in early March 2021 all but flattened the trial block (Figure 4). Eighty-five percent of the GCTCV 215 plants and 76% of the GCTCV 247 plants were knocked down, and importantly significant proportions of plants damaged had rolled out of the ground as opposed to kinking of the pseudostem (37% of the GCTCV 215 and 55% of the GCTCV 247). Nurse suckering, as has been done at the Tully north site, was not a feasible option for this location as the uprooting of plants meant that there was no corm material left in the ground for a sucker to grow from. Consequently, the block was no longer worth persevering with as one of the trial sites and was abandoned.

Walkamin, NQ

Plant crop

This was the final north Queensland site to be planted (28 May 2020). Like at Innisfail, no Williams were planted at the same time and plants were in poor condition when they went in the ground. Plants were quite small (approximately 50 – 60 cm tall) when the site was visited in mid-September 2020. Wallabies had damaged about 8% of GCTCV 247 plants and 5% of GCTCV 215 plants by eating the cigar leaf. Some had grown back, but development may be compromised. The farm manager drew attention to the cold damage on the GCTCV 215 plants (he said they seemed more susceptible than the GCTCV 247s). However, there was also cold damage visible on a couple of the GCTCV 247s.

Figure 5. The GCTCV 247 (first two rows) and GCTCV 215 plants (second row and a half) at the Walkamin trial site on 16 September 2020.

Figure 6. The trial site May 2021 as it commenced bunching.

Figure 7. An example of a GCTCV 247 plant damaged by a hungry wallaby

Figure 8. Cold damage (browning on Cigar leaf) on GCTCV 215

Figure 9. A row of GCTCV 247 plants leaning/fallen from strong winds in Walkamin, noted on our visit 24 Sep 2021

Figure 10. GCTCV 215 bunches being processed in the packing shed

Harvesting commenced in the trial block in late August 2021, meaning the crop cycle was, at shortest, 15 months. We visited on 24 September 2021 to collect yield data (summarised in Table 4) and talk with the farm manager about how they thought the plants were performing. He noted that there had recently been strong winds and a handful of plants had snapped. As we walked down the rows, many plants were leaning heavily and may have also snapped if they had not been strung (Figure 9).

Table 4. Summary of the agronomic and yield data from plant crop in Walkamin

	GCTCV 215	GCTCV 247
Height (m)	3.7 ±0.06	3.4 ±0.03
Girth (cm)	66 ±0.8	64 ±0.6
Est. Finger count	185 ±8.9	163 ±4.8
Fruit weight (bunch - stalk)	29.8 ±1.2	29.0 ±1.0

Lake Bennett, NT

Plant crop

This trial was established in November 2020 at Lake Bennett, approximately 85 km south of Darwin. The trial consists of 75 plants of each of varieties CJ19, GCTCV247, GCTCV215 and Williams Cavendish. It provided the additional feature of observing how the varieties perform in a commercial cropping system in the presence of TR4. The Cavendish variety CJ19 was added to this site as it seems to perform better agronomically in the NT than on Queensland's wet tropical coast. With limited capacity to visit the trial regularly the Queensland based project team negotiated with the owner regarding some limited observations and data collection he may be able to undertake on our behalf, with occasional visits from project staff based in Qld.

The trial was established in a block which had originally been reserved for a private TR4 screening trial. A heavily infected crop of Williams had been grown in the block to increase the inoculum load for the trial. It has been incorporated only 1 month prior to planting the trial. Thus, the site was not ideal for our purposes because the aim was not to kill the plants but rather to see how they performed (compared to Williams) when best management practice was in place (e.g. a fallow period to reduce the inoculum load before planting). Due to this high disease pressure, several plants of the resistant varieties have begun displaying some disease symptoms.

In between border closures, an opportunity to travel to the Northern Territory arose in September 2021. DAF's Katie Robertson and Ashley Balsom were accompanied by Sharl Mintoff (NT DITT Plant Pathologist) to the Lake Bennett trial site to assess the plants for TR4 symptom development. They walked through the block and rated the parent plants on a simple scale of 0 (no external TR4 symptoms evident), 1 (external symptoms evident), or 2 (plant dead) (Table 5). The number of bunched plants and possible off-types were also noted. Destructive assessments often performed to confirm disease presence obviously weren't appropriate. External symptoms were defined as yellowing *upright* leaves. If only the down-leaves were chlorotic, but the upright leaves were still green, a rating of '0' was recorded as this may have just been due to normal leaf

senescence. It should also be noted that plant death may not have been exclusively due to TR4 infection. The TR4 symptoms on GCTCV 215, GCTCV 247 and CJ19 plants were relatively mild in many cases.

Table 5. Summary of the performance of plants at Lake Bennett where, '0' = no external TR4 symptoms, '1' = external symptoms observed, '2' = plant dead.

Variety	Rating score – percentage of plants			Bunched (%)
	0 (%)	1 (%)	2 (%)	
GCTCV 215	81	14	5	26
GCTCV 247	93	0*	8	43
Williams	16	36	48	13
CJ19	87	8	4	45

*This figure is possibly a slight underestimate of infected plants, however there were no noticeable yellow upright leaves.

An update from a third-party visit in July suggested that around 50% of the Williams had bunched. The discrepancy in the data may be because he had counted bunches in the rest of the Williams plants being grown in the block. We only examined the one row of 66 plants between the GCTCV 247's and the CJ19's.

Despite there being less symptoms and plant death, the grower was not that impressed by the two GCTCV varieties and said he "*wouldn't rate them*" and he didn't think they were worth growing as a commercial Cavendish variety on a TR4 infested property. Another comment he made was that they produced fewer suckers and that the follower selection was poor, making it difficult to walk the ratoon crop in the desired direction.

He also noted that the pseudostems of the GCTCV varieties were thinner than Williams. He thought it could be due to them being affected by disease but then growing out of it. However, our observations in north Queensland, where TR4 was not present, suggests this may just be a feature of these varieties. It was very windy during our visit which the grower said wasn't unusual for the time of year. On the day of our visit, gusts up to 44 km/hr were recorded at the nearest weather station in Batchelor, about 24km away from Lake Bennett. The plants were planted in single rows (as is standard practice on the farm) and had no bunch support. The GCTCV 247 plants were leaning much more than the other plants in the block despite the GCTCV 215's being on the outer row. Surprisingly very few plants had snapped or fallen over, like has occurred in north Queensland. The grower said for the first few months after planting he hadn't fertilised the block because he didn't realise we were interested in agronomic data from the plants. He also noted that the trial was established in December which is not an ideal time of the year for planting (40+ degree days), and this also could have impacted their development. He suggested that, in future, tissue culture material should be sent at a time which would allow planting in a more suitable month. Leaf disease such as yellow Sigatoka does not appear to be an issue on his farm during the dry season, and it doesn't appear that de-leafing is incorporated into his management practices.

On the 5th of October 2021, the grower notified us that there had recently been strong winds for a period of five days and that all plants with bunches had snapped. He has subsequently ploughed the plants in to inoculate the ground for another trial agreement he has outside of DAF.

Figure 11. The trial site at Lake Bennett, NT.

Figure 12. Both the GCTCV 247 and GCTCV 215 are displaying infection symptoms, but to a much lesser extent than Williams, Lake Bennett, NT.

GCTCV 247 Williams GCTCV 215

Appendix 9 – Postharvest evaluation of two TR4 tolerant Cavendish banana cultivars - DAF H&FS development concept

Introduction

The Australian banana industry is predominantly based on the variety 'Williams' Cavendish, which is highly susceptible to the tropical race 4 (TR4) strain of Fusarium wilt. With the industry supplying the entire domestic market of fresh-eating bananas and worth an estimated $600 million dollars, TR4 poses a serious threat. Identification of commercially viable replacement varieties with disease resistance is important.

The DAF banana variety team (Jeff Daniells, Katelyn Ferro and Ashely Balsom) maintain a banana germplasm collection at the South Johnstone Research Facility. As new varieties are imported from international breeding programs, they undergo agronomic evaluation in north Queensland and are concurrently screened for TR4 resistance in the Northern Territory. Two Cavendish varieties which have demonstrated reasonable levels of resistance include GCTCV 215 and GCTCV 247. However, if they are to be integrated into the current 'Williams' dominated market, their postharvest performance needs to be elucidated. DAF is currently overseeing several pre-commercialisation trials, in which these two varieties are being grown on farms in north Queensland to gain grower feedback on their performance. This created the opportunity to access a large amount of fruit which had been grown, harvested, and packed under commercial conditions for post-harvest assessment.

The DAF Supply Chain Innovations team, through a separate project with the Fight Food Waste CRC, is developing a robust protocol to determine the postharvest quality response of Cavendish fruit to real-world handling scenarios which can be used to inform best practice guidelines for domestic and export markets. We propose to use this methodology to examine the performance of new varieties under current commercial postharvest handling practices.

Aim

The aim of this project was to assess the postharvest performance, shelf life, quality, and consumer satisfaction of two TR4 resistant Cavendish banana varieties GCTCV 247 and GCTCV 215. It also aims to build confidence within the banana industry that the potential TR4 resistant candidates are of comparable eating quality to Williams Cavendish. The significance of this research is to provide growers with options if they can no longer produce Williams Cavendish economically, assuring that this $600 million industry remains viable and can supply the domestic market.

Methodology

Harvesting and storage

The GCTCV 215 and GCTCV 247 fruit were planted on the 30/10/2019 at a commercial farm in the Tully Valley in Far North Queensland. Bunches were harvested upon reaching maturity from S. Lowe and Sons farm in Euramo (near Tully) over 8 weeks from July – September 2021. The fruit followed standard on-farm harvesting and packing procedures, which involved being transported to the packing shed on a padded trailer, off-loaded, rinsed, de-handed, washed, sorted, and then packed to 15kg carton specifications Cartons were immediately driven to Cairns (approximately a three-hour transit period) and held in a cool room at DAF's Redden Street Facility until ripening (7 days maximum post-harvest). Mean finger number per cluster was 6-7 fingers per hand across the three consignments. The cold rooms were monitored using a Build Maintenance System (BMS) to maintain temperature and humidity (95%).

Ripening

GCTCV 215, GCTCV 247 were ripened along with Williams to examine if there were differences in the rate of colour change. Three cartons of each variety were assessed for consignments 1, 2 and 3.

Four clusters from each carton were randomly picked and marked to follow through the ripening process. Each cluster and finger were numbered and pulled out each second to third day to be photographed for changing colour stage. They were then placed back in their respective carton and returned to the ripening room.

Fruit was maintained at 14^{o} C for 7 days after harvest. On the 8th day the fruit was moved into the ripening room at 14^{o} C and the protocol outlined in Table 3 was followed. On the 9th day they room was maintained at 16 ^{o}C and ethylene was injected using 100ppm ethylene over 2 full days. On the 11th day the fruit was removed and placed into 14^{o} C for two days and then 13 ^{o} C for two days. On the 15th day the fruit was moved to 20 ^{o} C until considered over-ripe (colour stage 7). The ripening room was as mobile unit delivering 100 ppm

volume of 3.8 % C_2H_4 in N_2 with average temperature, relative humidity and CO_2 concentration monitored using a Pacific Data System custom controller.

Shelf-life assessments

After the ripening protocol, the cartons were removed to ambient temperature (20^{o}C) to simulate conditions at the supermarket and then at-home storage. Fruit was monitored every 2nd – 3rd day until end-of-shelf-life (EoSL) was reached or an equivalent of colour stage 7. Days to EoSL were compared for each variety. Residual shelf life was estimated as the time after treatment and time to colour stage 7 from entering the 20^{o}C temperature conditions.

Fruit quality assessments

At intake

At intake, seven clusters from each of the three cartons for each variety was labelled and used for assessments. Four hands were monitored at each ripeness stage and for weight loss determination, while three clusters were used for destructive sampling. At intake the four hands were assessed for the following parameters:

- Cluster weight
- Finger number and length
- Finger colour score
- Finger firmness score
- Finger defect score and post-harvest disorders (defects)
- During ripening

The box was removed from the cold room and placed into an air-conditioned room at each assessment (intake, pre-ripening, post-ripening assessments (1-5), eating ripe and at end of shelf life). Fruit was photographed to record colour and development stage for cultivars cartons at each sampling stage and for clusters 1-4 at each assessment time.

Table 1. Summary of the assessment stage linked to the time after harvest for each consignment.

Assessment time	**Days after harvest**		
	Consignment 1	**Consignment 2**	**Consignment 3**
Intake	1	1	1
Pre-ripening 1	9	7	7
Post-ripening 1	13	10	20
Post-ripening 2	15	14	14
Post-ripening 3	17	16	16
Post-ripening 4	20	18	18
Post-ripening 5	22	21	21

Destructive sampling

Three fruit clusters (5,6 and 7) were marked for use in destructive sampling and one finger from each sample were used for:

- dry matter at intake,
- starch assessments at intake and colour stage 6
- and for brix and total acidity at eating ripe (colour stage 6)

Table 2. Summary of the TR4 banana consignments delivered throughout the project.

Consignment	Harvest date	Replicates	Variety	Assessments	Comments
Consignment CJ1	23rd February 2021*	1 box only	CJ 19	No	Cyclone damaged ripened only to ascertain residual shelf life – also poor quality due to mites
Consignment 0 ripening trial	28th June 2021	1 box of each variety	GCTCV 215, GCTCV 215, Williams Cavendish	No	Ripened to determine approximate residual shelf life
Consignment 1	3rd August 2021	3 boxes of each variety	GCTCV 215, GCTCV 215, Williams Cavendish	Yes	Full fruit quality and consumer assessment
Consignment 2	16th August 2021	3 boxes of each variety	GCTCV 215, GCTCV 215, Williams Cavendish	Yes	Full fruit quality and consumer assessment
Consignment 3	30th August 2021	3 boxes of each variety	GCTCV 215, GCTCV 215, Williams Cavendish	Yes	Full fruit quality and consumer assessment

*CJ 19 fruit was harvested after Cyclone Niram, all other fruit from the original site were damaged by winds at South Johnstone Research Station associated with Cyclone Niram. Because the damaged trees fruit was not ready to harvest fruit from this experiment was sourced from an alternate farm.

Table 3. The ripening protocol for TR4 resistant varieties assessment

Days of experiment	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Phase	Harvest	Simulated transport								Simulated Ripening												End of shelf life assessments (EoSL)
Days of phase		1	2	3	4	5	6	7	1 CR	2 Coldroom (weekday)	3 Coldroom (weekday)	4 CR	5 CR	6 CR	7 CR	8	9	10	11	12	13	14
Temp	Ambient	14°C							14°C	16°C	15°C	14° C	14° C	13° C	13° C	20°C	20° C	20°C	20°C	20°C	20° C	20°C
Ripening	No gas								No gas	Gas (100ppm)	Gas (100ppm)	No gas										
Days after harvest	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Residual days after harvest	Ripening treatment															1	2	3	4	5	6	7

Consumer acceptance taste panel

At colour stage 6 - 6.5 consignments 0,1, 2 and 3 were assessed by a volunteer panel in which were asked to rate the three varieties. The survey originally created for examining the eating characteristics of new variants produced in the Goldfinger mutagenesis project Figure 14. A total of 109 people participated in the four taste panels.

Assessment protocols

Hand weight, finger number and length

Clusters 1-4 were weighed for each variety and assessment time. At intake, the number of fingers on each cluster were counted and given an individual number. For each fruit, finger length was measured along the convex curve (from the beginning of the fruit pulp to the flower end) at intake only. Cluster weight, finger colour, firmness score, defect score and the presence of any post-harvest disorders were also recorded. Details of each parameter are outlined below.

Colour assessments

Each finger on cluster 1-4 were rated for colour stage at each assessment. There are two assessments for colour - subjective assessment which rates the fruit based on a colour stage of 1-7 (Figure 1) and objective assessments which measures the lightness, chroma and hue of the skin.

Subjective colour score

Colour scores rates the fruit based on a stages from 1-7 (Figure 1). Half points were awarded based on the percent of green and yellow at each stage (Figure 2).

Figure 1. Banana ripeness colour stages for Australian Cavendish Banana.

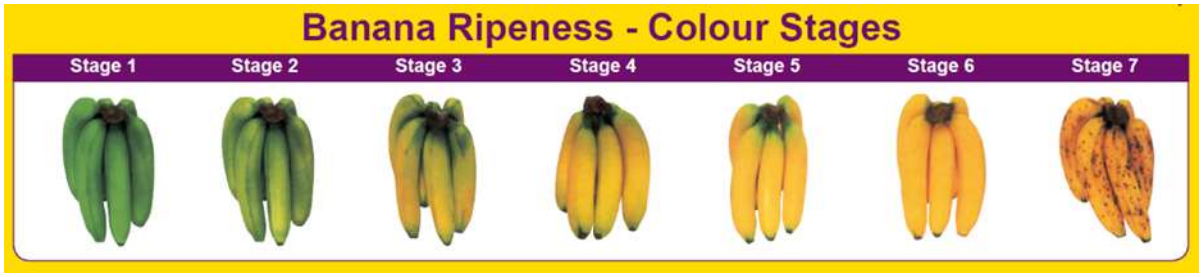


Figure 2. Subjective determination of the banana ripeness colour stages for Australian Cavendish Banana (Source: Coles Australia).

Objective colour score

Objective colour measurements was taken at eating ripe (colour stage 6) using a Konica Minolta CR-400 Chroma Meter in the L*C*h colour space. Each fruit was measured twice and averaged to provide a colour representative of the average fruit colour at 16 days after harvest (still green) and at 5 days after ripening treatment (19 days after harvest) (colour stage 6).

Firmness

Each finger on clusters 1-4 were assessed for a firmness score according to the following scale (Figure 3).

Figure 3. Fruit firmness scores for Cavendish Bananas

0 = hard
1 = rubbery with slight 'give'
2 = sprung, flesh deforms by 2-3 mm with extreme thumb pressure
3 = firm soft, whole fruit deforms with moderate hand pressure
4 = eating soft, whole fruit deforms with slight hand pressure.

Ripeness assessments

Ripeness score and days to end of shelf life

The major stages of banana ripening were assessed every two days during weekdays were possible and the results were compared for days to EoSL between the cultivars. The days to EoSL is assessed as days from harvest to the point where all bananas reach colour stage 7.

Defect score

Each finger on each of the clusters 1-4 were assessed for defect using the following scale (Figure 4):

Figure 4. Skin defects rating for skin of banana fruit

5	Extreme; Extremely poor, more than 25% surface area.
4	Severe; Excessive defect, limit of acceptability, less than 25% surface area.
3	Moderate; Slightly to moderately objectionable defect, lower limit of attractions, less than 10% surface area.
2	Slight; minor defect, not objectionable, and affecting less than 5% of the surface area
1	None; essentially free from defect.

Defects included mechanical damage during harvest or bruising during the ripening stages and for the presence or absence of rots or fungal growth. No determination of the type of rot or fungal growth was assessed as they were minor and related to post-harvest conditions.

Destructive assessments

Three cluster were labelled in each box (5, 6 and 7) for continuous destructive sampling at different ripening stages (intake, ripe and over-ripe).

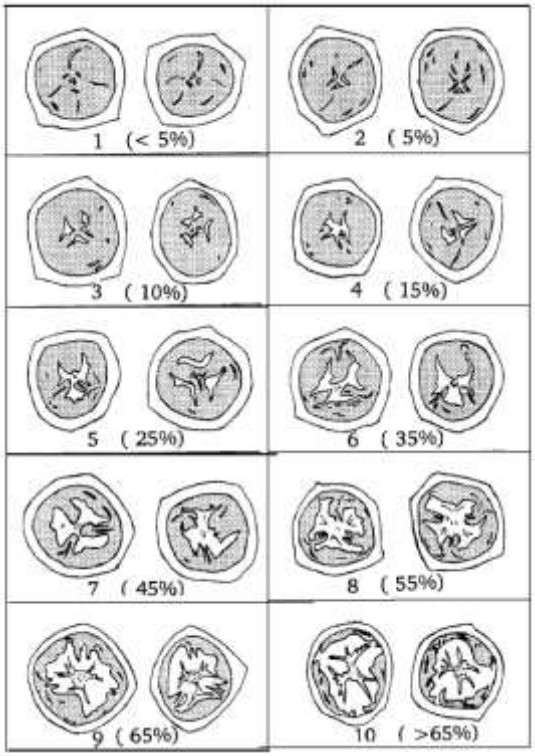
Dry matter

Dry matter assessment was performed using a cross-sectional slice from the middle 1/3rd of the fingers from hand 5, 6 and 7. A 20-30 g slice was cut into 0.5 cm^3 pieces and weighed in an empty pre-weighed and numbered vessel. Vessels with fruit pieces were placed into a drying oven at 60°C for 48 hours. At dry, the final weight was recorded. The vessel weight was subtracted from the dry weight to calculate the percent dry matter as a total dry weight/ total wet weight x 100.

Starch assessments

Starch assessments were done according to method of Blakenship (et al 1993). Briefly, a 1cm piece from the middle 1/3rd of a single finger (from hands 5-7) was cut across cross-section of the fruit for starch assessment. The blossom end of the fruit section was placed into a vessel containing 5mm in height of 1% potassium iodide and 0.1 % iodine solution. The fruit was left for 3-5 minutes using a timer and removed from the solution onto paper towel with blossom end up. The area of unstained pulp (white) was estimated according to Blakenship (et. al 1993) which calculates an index of starch in the fruit in the sample (see Figure 5). When assessing at intake (colour stage 1, green), each sample was soaked for 5 minutes in a 1% solution of Phosphorus free detergent and water to reduce the sap interfering with the uptake of the iodine solution.

Figure 5. Starch content patterns of banana ripening stained with 1% iodine solution Bracketed values refer to the unstained pulp area.



Total soluble sugars (TSS)(Brix°)

To measure Brix a digital refractometer was calibrated prior to use using distilled water. Samples for TSS were performed using the lower 1/3rd of fruit. Fruit was blended to smooth pulp (approx. 30 seconds with stick blender) and a sample free of lumps was placed onto the lens and assessed. The homogenising step was only done immediately before taking measurements as exposed samples oxidise and change colour.

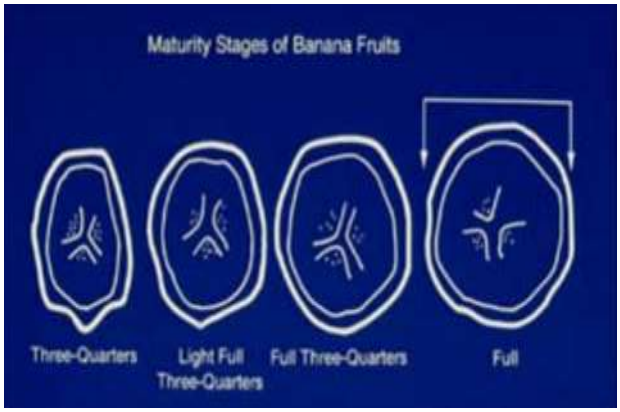
Total acidity

A 5 g sample of blended pulp (top 1/3rd of fruit) was used to determine the titratable acidity. Samples were titrated to an endpoint pH of 8.2 with 0.1 N NaOH and expressed as % citric acid using a Mettler Toledo T50 autotitrator with a DG115-SC pH electrode.

Angularity

At intake, during dry matter assessments, the cross-section of fingers was assessed for maturity. Angularity is measured on scale of 1-4 where 1 = developing three quarters, 2= light full three quarters, 3 = full three quarters, and 4 = round shape (fully mature)(Sommer and Arpaia, 1992). Figure 6 shows the variation between three quarters and fully ripe.

Figure 6. Finger angularity on scale of 1-4 where1 = developing three quarters, 2= light full three quarters, 3 = full three quarters, and 4 = full, round shape. (Source: http://postharvest.ucdavis.edu/files/259413.pdf)



Consumer acceptance survey

When fruit had reached colour stage 6 – 6.5 (yellow all over with some black spots) each variety was assigned a number (1, 2 or 3) and randomised on a plate. Participants were asked to complete a short the survey to rate the fruits', size, peelability, ripeness, tartness, sweetness, firmness, as well as giving each variety a score (1 – 9) for its overall eating experience. Participants were also asked if they would purchase the fruit (Yes/No) and if they had any other comments about each variety. The purpose was to determine if the eating characteristics of these new Cavendish cultivars were comparable to 'Williams'. The taste test survey can be found in Figure 14.

Statistical analysis

Data was analysed using Genstat 21st edition (VSN International 2021). Weight loss, subjective colour score, hand firmness and defect were analysed using a repeated measures analysis of variance (ANOVA). Defect was log10 transformed to meet the assumption of normality. ANOVA was used to assess fruit number and length, objective colour scores, dry matter, starch index, total soluble sugars, total acidity and angularity. All significance testing was performed at the 0.05 level, and where a significant effect was found, the 95% least significant difference (lsd) is used to make pairwise comparisons.

Results

Shelf life

End of shelf life

End of shelf life (EoSL) was defined as when the fruit reached colour stage 7. There was no significant difference between varieties for the end of shelf life ($p = 0.216$, standard error of the difference (sed) = 0.107). EoSL for Williams was 21.13 days, GCTCV 215 was 21.22 days while GCTCV 247 was 20.99 days.

Residual shelf life

Residual shelf life is the day to the EoSL minus the 14-day treatment period (from when fruit come to 20°C). There was no significant difference between varieties for the residual shelf life ($p = 0.216$, sed = 0.107). Residual shelf life for Williams was 7.13 days, GCTCV 215 was 7.22 days while GCTCV 247 was 6.99 days.

Fruit quality assessments

Fruit weight over time

There was no significant difference between varieties ($p = 0.716$, sed = 0.115) for change in fruit weight over time but there was a significant difference between each assessment time ($p < 0.001$, sed = 0.165). The interaction between variety and assessment time was not significant ($p = 0.367$, sed = 0.288). Figure 7 shows the percent of initial weight over time for each variety at each assessment time.

Fruit length

Mean finger length was not significantly difference between the varieties ($p = 0.299$, sed = 0.158) where all varieties ranged between 21.7 - 21.9cm in length.

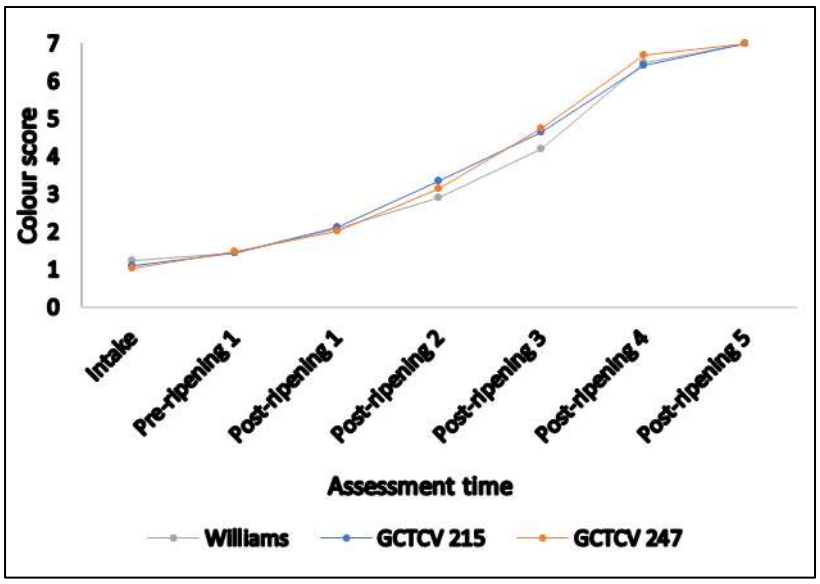
Figure 7. Change in fruit weight from intake to end of shelf life*. Each consignment was harvested two weeks apart with consignment 1 harvested on the 3th Aug 2021; b) consignment 2 harvested on 16th Aug; and c) Consignment 3 was harvested on the 30th of August 2021.

Colour assessments

Colour score

There was no significant difference between varieties (p = 0.083, mean sed = 0.070) for the colour scores at each time point but there was a significant difference between time points (p < 0.001, sed = 0.151) (Figure 8). While intake and pre-ripening assessments had similar colour scores, each subsequent assessment had a significantly higher mean as time progressed. The interaction between variety and assessment time was not significant (p = 0.697, sed = 0.253).

Figure 8. Colour score for fruit from intake to end of shelf life averaged from 3 consignments.



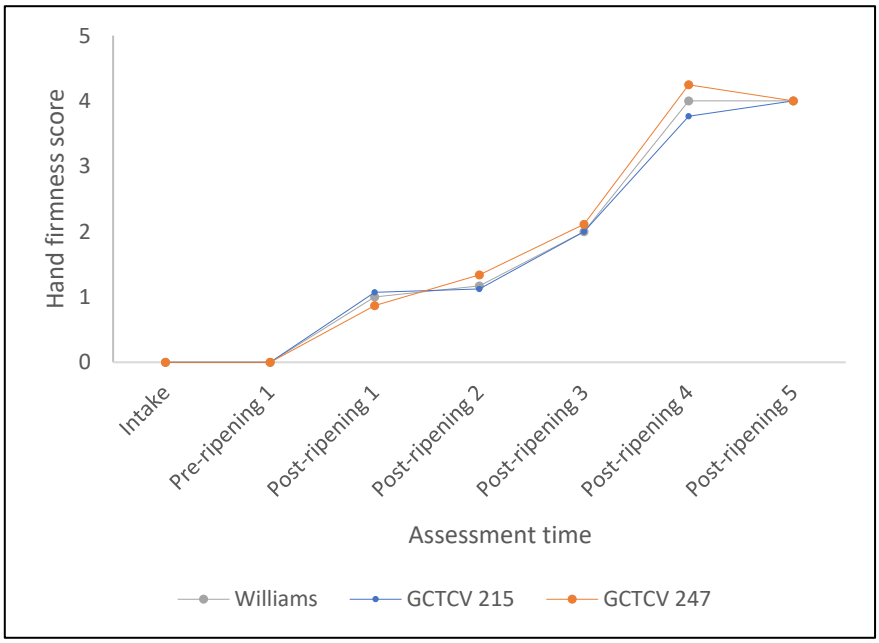
Objective colour score

Colour was measured at 16 days after intake and at 19 days after intake. Assessment time was the only variable which had a significant effect on the lightness (p = 0.015), chroma (p = 0.028), and hue (p < 0.001). The individual variety, and the variety by assessment time interaction, were not significant (p > 0.05). This suggests that the ripening progression was similar for each variety.

Finger firmness

There was no variation in finger firmness at intake and pre-ripening, and as a result these assessment times were excluded from the analysis. There was no significant difference amongst the varieties (p = 0.142) for hand firmness at each assessment, however hand firmness did vary between the assessments (p < 0.001, sed=0.222) (Figure 9). Mean hand firmness increased significantly as time progressed. The interaction between variety and assessment time was not significant (p = 0.856).

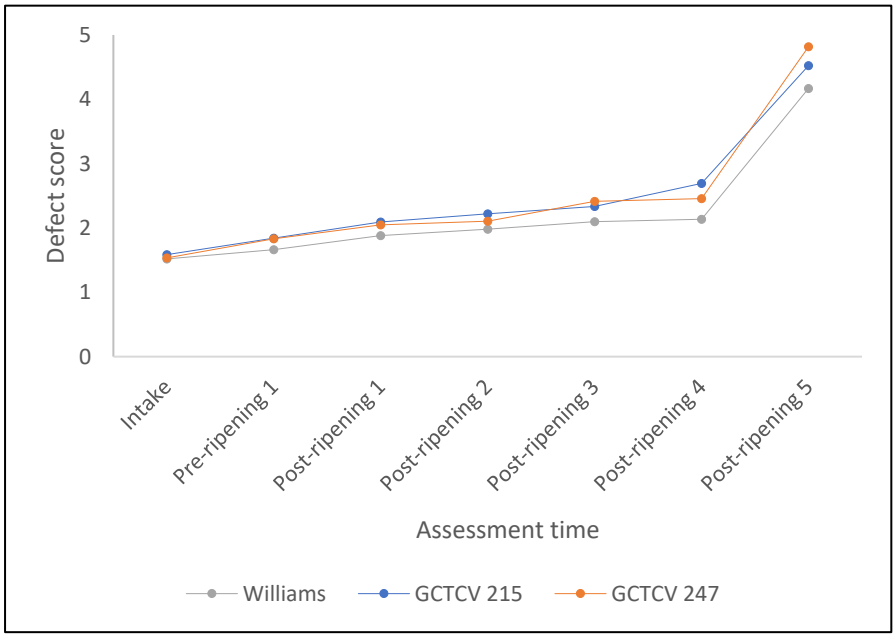
Figure 9. Fruit firmness for fruit from intake to end of shelf life.



Defect score

Defect was measured on a scale of 1-5, where a score of 1 represented low defect and a score of 5 represents extreme defect covering more than 25% of the fruit. There was no significant difference between varieties (p = 0.060, sed = 0.066) for defect at each time point but there was a significant difference between assessment times (p = 0.006, sed = 0.225). Defect observed at intake significantly differed from the defect at post-ripening assessments 4, while fruit at post-ripening assessment 5 had a significantly higher defect rating than all other assessment times (Figure 10). The interaction between variety and assessment time was not significant (p = 0.978, sed = 0.366).

Figure 10. Defect for fruit from intake to end of shelf life.



Destructive assessments

Dry matter and angularity

Dry matter was measured at intake and was not significantly differ ($p = 0.223$, sed = 0.553) amongst the varieties. There was also no significant difference for angularity amongst the varieties ($p = 0.373$, sed = 0.1). Means for dry matter and angularity for each variety are shown in Table 4. The average angularity status at intake was between full-three quarters and light full three quarters.

Table 4. Mean values for dry matter (%), Angularity, starch index and total soluble solids (Brix °) for two TR4 resistant varieties compared to William cavendish as the industry standard.

Assessment stage	Variable	GCTCV 215	GCTCV 247	Williams	Mean
Intake	Dry matter (%)	30	31	29	30
	Angularity	2	3	3	3
	Starch	2.0	1.6	2.2	1.9
Eating ripe	Starch	7.3	7.3	7.6	7.4
	TSS (Brix °)	23.8	23.6	23.5	23.6
	Total acidity (g/L)	0.53	0.56	0.56	0.55

Starch index assessment

The starch index scale starts at 1 (indicating < 5 % sugar) through to 10 (which is > 65 % sugar). There was no significant difference amongst varieties for starch index ($p = 0.361$, sed = 0.28), however starch significantly decreased with assessment times ($p < 0.001$, sed = 0.23). The mean starch index for all varieties at intake was 1.9 (approximating to < 5 % sugar), increasing to 7.4 at eating ripe (between 45 – 55 % sugars). The interaction of variety by assessment time was not significant ($p = 0.853$, sed = 0.40).

Total soluble sugars (TSS)(Brix°)

Total soluble sugars using the Brix scale (°) was measured at eating ripe. There was no significant difference for TSS amongst the varieties ($p = 0.730$, sed = 0.39). The mean TSS for each of the varieties at eating ripe is outlined in Table 4.

Total acidity (TA)

Total acidity was also measured at eating ripe. There was no significant difference for TA amongst the varieties (p = 0.533, sed = 0.026). The means for TA are outlined in Table 4.

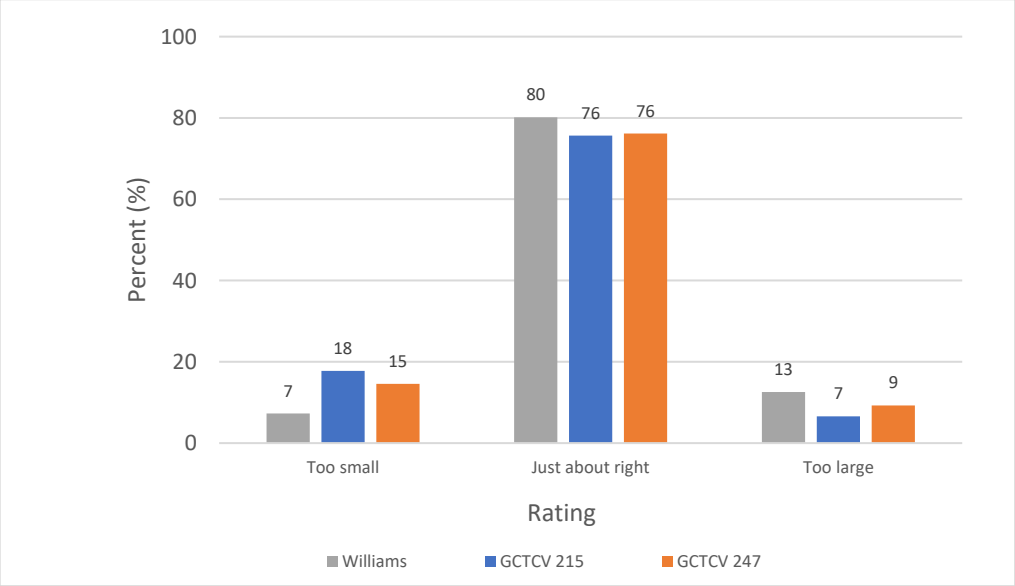
Consumer acceptance surveys

A total of 105 people completed 152 surveys over 4 consignments. Fruit were sampled at colour stage 6-6.5. The survey questions are shown in Figure 14.

Fruit size

Question 1 asked – "*In your opinion, is the size of this fruit: too small, just about right or too large"*. Fruit size had a 76-80% rating of 'just about right'. GCTCV 215 and GCTCV 247 had less fruit that were too large 7-9% compared to Williams at 13%. GCTCV 215 and GCTCV 247 had more fruit that were considered to small 15-18% compared to Williams at 7%. One participant indicated that they thought the GCTCV fruit was a little small, while another participant commented that all fruit was perfect for lunch boxes and was not too small. Figure 11 shows the rating for fruit size.

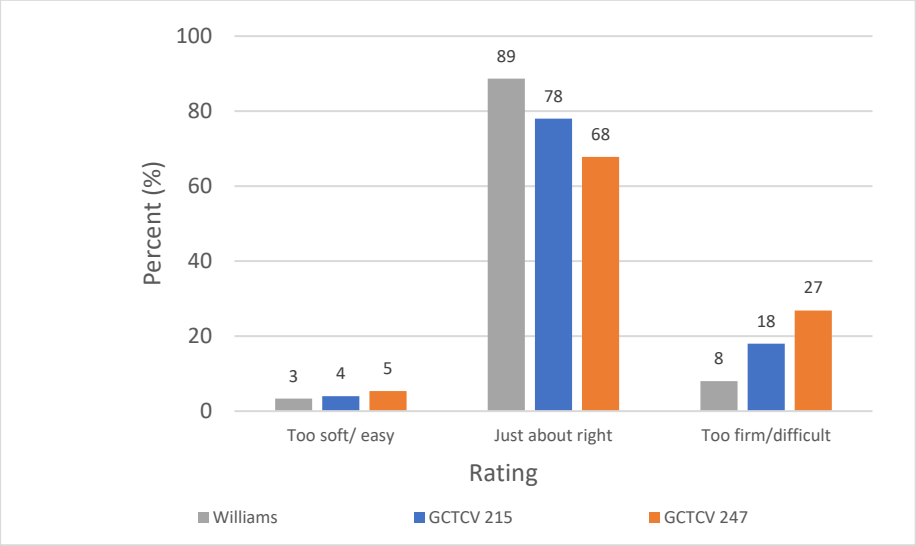
Figure 11. Results for fruit size from the taste testing of TR4 Banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Fruit peelability

Question 2 asked – "*How do you rate the 'peelability' of this fruit: too soft/easy, just about right or too firm/ difficult*". Fruit peelability had a 68-89 % rating of 'just about right'. GCTCV 215 and GCTCV 247 had more fruit that were too firm/ or difficult to peel (18-27 %) compared to Williams at 8 %. All varieties had similar rating for too soft/ easy to peel (between 3-5 %). Figure 12 shows the rating for fruit peelability.

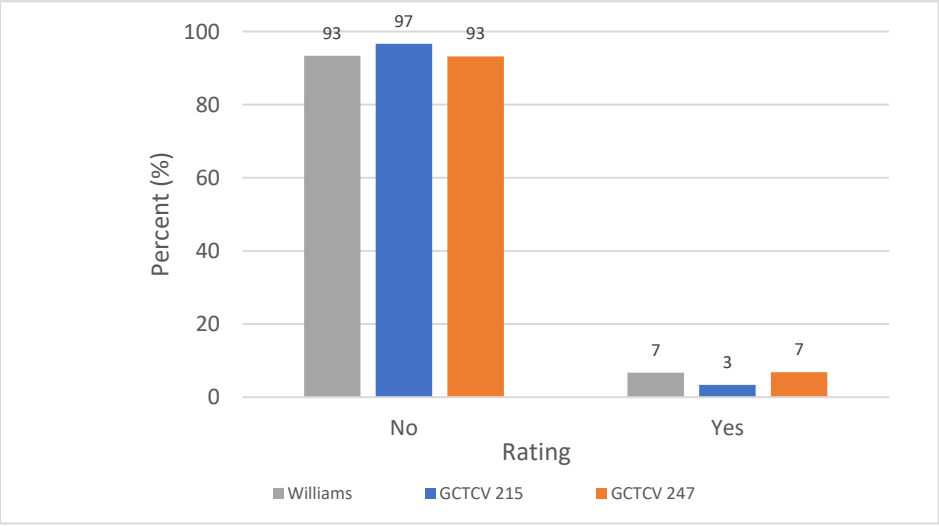
Figure 12. Results for peelability from the taste testing of TR4 Banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Fruit stringiness

Question 3 asked – "*Upon peeling, does the amount of 'string' remaining on the fruit negatively affect your eating experience?"* All varieties had a rating of between 93-97 % for 'stringiness that did not negatively impacting their eating experience'. Williams and GCTCV 247 had more stinginess (both 7%) when compared to the GCTCV 215 (3%). Figure 13 shows the scores for the measure of stringiness when peeling fruit.

Figure 13. Results for stringiness from the taste testing of TR4 Banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Overall eating experience

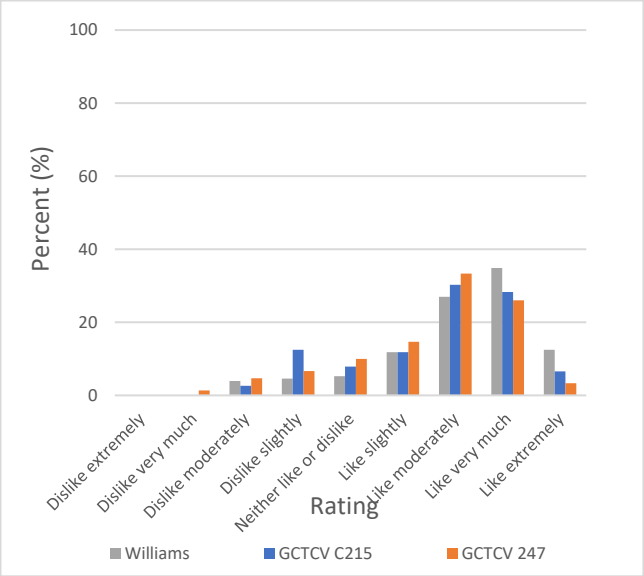
Question 4 asked participants to rate their overall eating experience and gave 9 ratings. 1 – dislike extremely, 2 - dislike very much, 3 - dislike moderately, 4 – dislike slightly, 5 – neither like or dislike, 7- like moderately, 8 – like very much, 9 – like extremely. The results show that the Williams cultivar had higher eating ratings in the categories of 'like extremely' and 'like very much'(Figure 14a).

This was confirmed when the results were grouped into three main groups of 'like', 'dislike' or 'neutral', where 77 % of participants liked both GCTCV 215 and GCTCV 247 compared to Williams which had an 86 % 'like' rating (Figure 14b). Both GCTCV 215 and 247 had a similar rating for the combined results of 'dislike' and

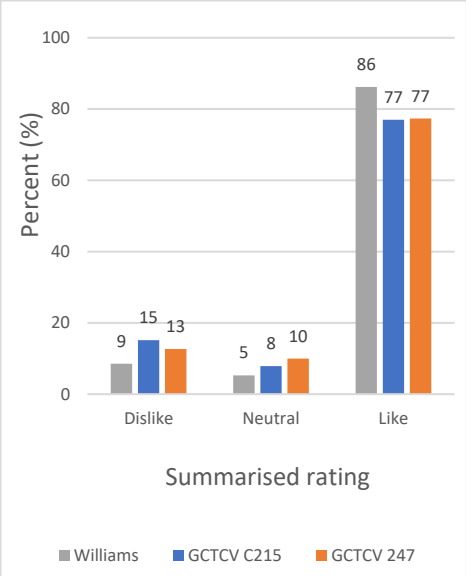
'neutral' (23 % each) compared to Williams (14 %). Figure 8 shows the result for overall eating experience and the summary for participants ratings of 'like', 'neutral' or 'dislike'.

Figure 14. Results for (a) overall eating experience from a taste testing of TR4 resistant Banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and (b) the summary of the like, neutral and dislike classes (n=105).

(a)



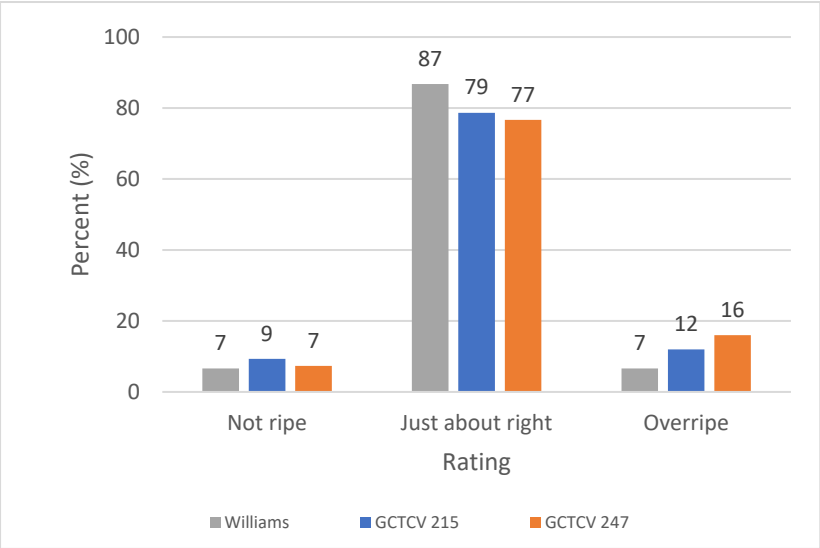
(b)



Ripeness

Question 5a asked the participants opinion about fruit ripeness. The options to respond were that fruit was 'not ripe enough', 'just about right' or 'overripe'. Between 77 - 87 % of participants thought the fruit was 'just about right' for ripeness. The GCTCV 215 and GCTCV 247 were considered slightly 'over-ripe' by 12 - 16% of participants respectively, compared to Williams (7%) while 7 - 9% of participants considered fruit across each cultivar as 'not-ripe enough'. When we look at the comments this variable was very personal as some of the participants like greener and some like over-ripe bananas.

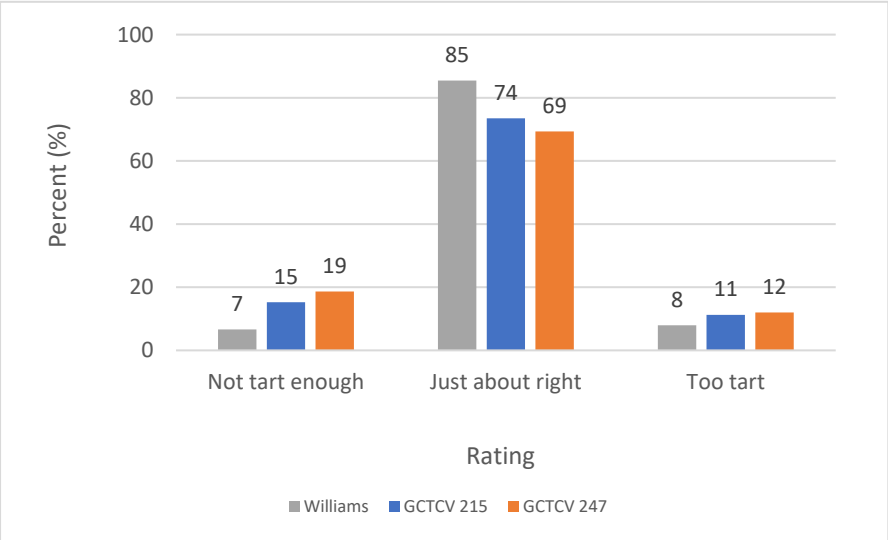
Figure 15. Results for rating ripeness at taste testing of TR4 resistant banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Tartness

Question 5b again used the 'just about right' scale to assess tartness. The variety variation in the responses to this characteristic were larger than the other sensory qualities. Eighty-five percent of participants rated the tartness of Williams as 'just about right'; this dropped by 16% and 11% for the GCTCV 215 and GCTCV 247 varieties, respectively (Figure 16). A comparable number of people considered Williams as 'not tart enough' and 'too tart', while slightly more respondents thought the GCTCV varieties were 'not tart enough' rather than 'too tart'. Comments about the fruit indicated that GCTCV 247 was too floury, dry and bland and lacked flavour. At the same time, other participants preferred the mildness of GCTCV 247 while Williams had the greater tartness (sourness or acidic component to taste) of the three varieties fruit.

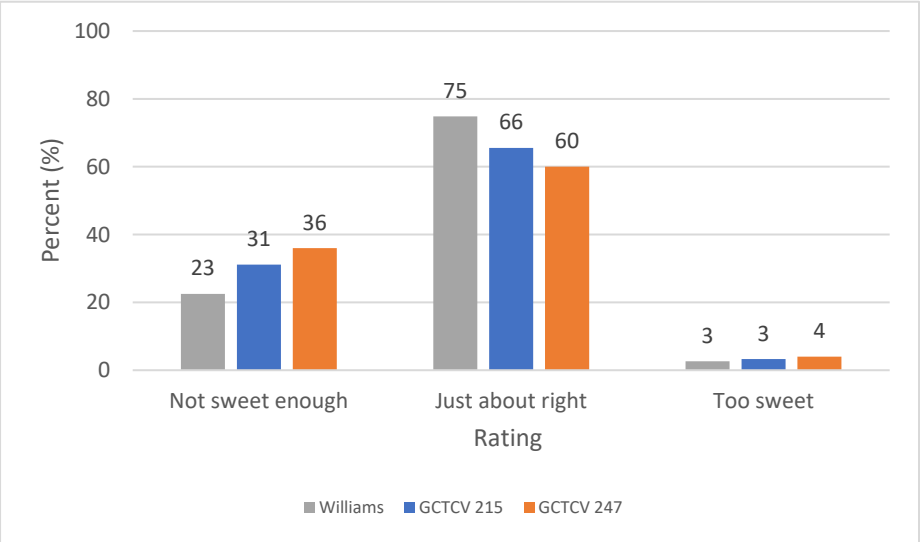
Figure 16. Results for rating tartness at taste testing of TR4 resistant banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Sweetness

Question 5c asked participants how they rated the sweetness level of the fruit using the 'just about right' scale. Again, Williams had the greatest rating for 'just about right' (75 %), and the least amount who thought it was 'not sweet enough' (23 %). This was higher compared to GCTCV 215 and GCTCV 247 varieties which had 66 % and 60 % for 'just about right' and 31 % and 36 % respectively for 'not sweet enough'. Very few respondents thought any of the varieties were too sweet (≤ 4 %). Comments about the fruit indicated that participants thought both GCTCV 215 and GCTCV 247 were also sweet but not as sweet as the Williams.

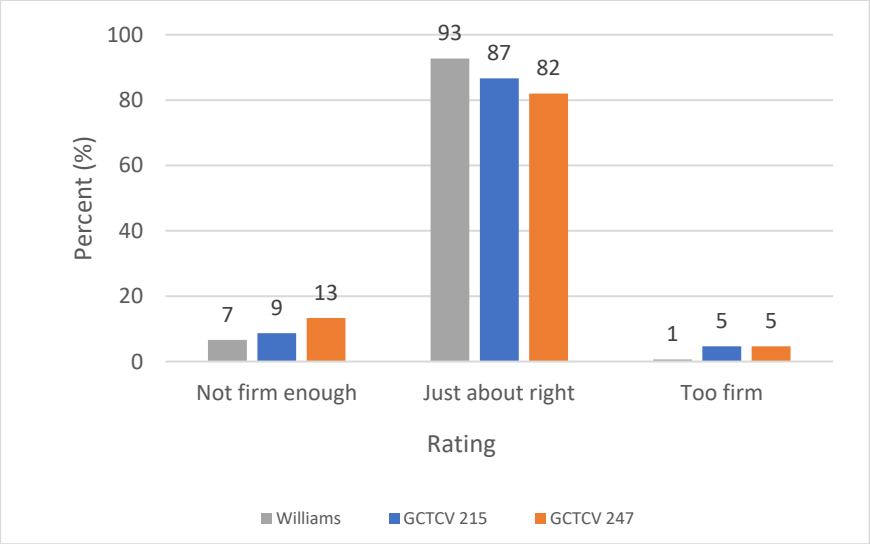
Figure 17. Results for rating sweetness at taste testing of TR4 Banana varieties GCTCV 215 and GCTCV 247 compared to Williams cavendish and combining all surveys (n=105).



Firmness

Question 5d asked participants whether fruit texture was firm enough, using the options 'not firm enough', 'just about right' or 'too firm'. Williams had the most favoured firmness, with 93% responding with 'just about right', while GCTCV 247 and GCTCV 215 had 82 % and 87 %, respectively. GCTCV 247 had the highest 'not firm enough' rating (13%). This fruit was slightly riper than the other varieties at each of the surveys, so this may have contributed to the variation in firmness.

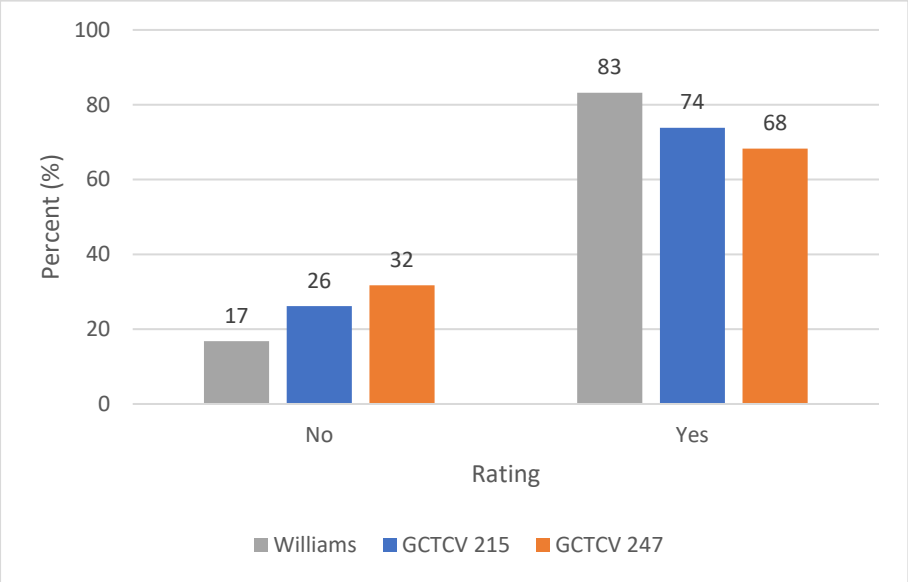
Figure 18. Results for rating firmness at taste testing of TR4 resistant banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Purchasing potential

The final question in the taste survey asked participants "If this product was commercially available, would you choose to purchase it?". Responses available were 'Yes' or 'No'. The purchasing responses were positive with 74% indicating they would buy GCTCV 215, while 68% indicated that they would purchase GCTCV 247, compared to 83% who said they would purchase Williams. Comments made by participants suggested that there could have been a 'maybe' class in the question, while others indicated they would like to see more variety when it came to selecting bananas in their supermarket.

Figure 19. Results for rating purchasing from a taste testing of TR4 resistant banana varieties GCTCV 215 and GCTCV 247 compared to Williams Cavendish and combining all surveys (n=105).



Further comments

There was space at the end of the survey for participants to add further comments if they wished. Often, the comments reflected personal preference for sensory qualities and people's preference for each variety was specific to their personal taste preferences. Some participants loved GCTCV 215 and others loved GCTCV 247 while some knew there banana's and were able to pick the cavendish flavour characteristics among the three varieties. GCTCV 247 did ripen a day quicker than Williams and GCTCV 215 which may have contributed to the variation in ripeness on the day of tasting. Some comments specific to variety have been summarised in Table 5.

Table 5. Further comments provided by the taste survey participants

Williams	GCTCV 215	GCTCV 247
Good	Dry taste underripe but also overripe Good eating acceptable	A little overripe for me, fairly mild taste Too dry
I don't think think this fruit was quite ripe it was a bit sappy'	Good texture	A little sweeter, physical features excellent, nice after taste, stand out compared to 1 and 2 otherwise little difference.
I quite enjoyed this banana for its flavour and texture	I didn't like the texture of this banana it was a bit under-ripe, there wasn't much flavour either	Bit of a waxy taste, showed some internal blackening beneath the skin
Just how I like them overall this banana #2 was the best of all 3 tasted	It tasted slightly overripe	Floury
Very nice	Less flavour than number 1	Good taste favourite
Least favourite	Size could be a bit bigger otherwise good to eat	I felt this one was a bit bland and lacked flavour
Possibly taste would improve with more ripening	Lacks flavour and is a bit bland The flavour is not obvious at the start	Like only slightly less than banana #1 or 2 Very slightly over-ripe but otherwise good

Pretty cavvy to me	This was my preferred fruit it was at the right ripe and sweetness stage	Looks good
Slightly underripe for me	Typical commercial Banana good sweetness and no 'aftertaste which is unpleasant.	
Smaller strings, less sweet. Slight furry after taste, similar to other in the samples		
There is an after-effect on the tongue. Its not sappy but slightly drying. Totally acceptable to consumers.		

Discussion

This study examined the post-harvest performance and consumer acceptance of two TR4 resistant varieties, GCTCV 215 and GCTCV 247, and how they compared to the industry-standard Williams Cavendish. The results show very little variation of the post-harvest characteristics including taste, texture and physio-chemical characteristics (dry matter, total acidity, total soluble sugars and starch content) of the three banana varieties included in this study. There was also similar shelf-life of the two new varieties compared to Williams although GCTCV 247 had a day less shelf life compared to Williams and GCTCV 215. While this study used a single ripening protocol, enhancing shelf life could be further refined with combinations of post-harvest environmental condition monitoring, different combinations of storage time and temperature and modified air packaging.

Further work could also investigate the components linked to the variations in sensory characteristics of the different banana varieties. While there were strong personal perceptions from the tasting surveys, overall the consumer acceptance survey indicated that the new TR4 resistant varieties were of acceptable eating quality and would be purchased if available in supermarkets. This is positive considering the potential risks TR4 disease poses to the Australian Banana Industry. With 94 % of Banana production in Australia and area of approximately 11, 280 ha of bananas producing 364,970 tonnes of banana's (ABGC 2018), scaling up this volume of production would take considerable time and resources. Perhaps a staged approach with plantlet availability and integrating commercial sized plantings could provide industry confidence in the new varieties. This however should not limit further varietal assessment because post-harvest assessment should be linked to suitable agronomic performance and potential risks associated with growing banana in the environmental conditions experienced in the tropical north Queensland.

Further consumer acceptance could be taken out to the retail outlets to encourage further awareness of the TR4 issue to Queensland so that consumers also have confidence in the new banana products. This is assuming the agronomic characteristics of the varieties are robust for growing in the tropical Queensland environment. Interestingly, many participants welcomed new banana varieties indicating that there were only ever two choices for bananas, and this did not reflect the great variation of uses for bananas consumption by consumers in general.

Conclusion

This preliminary study aimed to assess the post-harvest performance of two TR4 resistant varieties GCTCV 215 and CGTCV 247 against the industry standard cavendish banana 'Williams'. These results show very little post-harvest difference in end of shelf life or residual life (1 day but not significant) when stored and ripened in similar conditions. The fruit amongst the varieties also looked the same and tasted similar according to 105 participants over 4 taste surveys for consumer acceptance. This survey did reveal some consumer preferences in the new varieties and some subtle flavour differences among the three varieties. Overall, these results should be linked to agronomic performance and consumer education/marketing to encourage adoption of high performing varieties in North Queensland conditions and consumer acceptance and education of the potential impacts of TR4 more broadly.

References

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Sommer, N.F., Arpaia, M.L. (1992) Post harvest handling systems: Tropical fruits. In Kadar AA (Ed) Postharvest Technology of Horticultural Crops, Division of Agriculture and Natural Resources, University of California, Oakland, California pp241-251.

VSN international (2018) Genstat software 21st edition. UK.

Figure 14. The consumer acceptance survey questionnaire

Name: _____ **Date tasted:** _____

Sample ID: _____ **Tasting sequence:** _____

In your opinion, is the size of this fruit *(please tick one)*:

	Size of fruit	Fruit #1	Fruit #2	Fruit #3
1	Too small			
2	Just about right			
3	Too large			

How do you rate the 'peelability' of this fruit *(please tick one)*:

	Peelability	Fruit #1	Fruit #2	Fruit #3
1	Too soft/easy			
2	Just about right			
3	Too firm/difficult			

Upon peeling, does the amount of 'string' remaining on the fruit negatively affect your eating experience? **Y / N (please circle):**

	Stringyness	Fruit #1	Fruit #2	Fruit #3
1	Too soft/easy	**Y / N**	**Y / N**	**Y / N**

How would you rate the overall eating experience of this banana? please circle one)

	Fruit #1	Fruit #2	Fruit #3
1	Dislike extremely	Dislike extremely	Dislike extremely
2	Dislike very much	Dislike very much	Dislike very much
3	Dislike moderately	Dislike moderately	Dislike moderately
4	Dislike slightly	Dislike slightly	Dislike slightly
5	Neither like nor dislike	Neither like nor dislike	Neither like nor dislike
6	Like slightly	Like slightly	Like slightly
7	Like moderately	Like moderately	Like moderately
8	Like very much	Like very much	Like very much
9	Like extremely	Like extremely	Like extremely

In your opinion, this fruit is *(please circle one from each)*:

	Ripeness	**Fruit #1**	**Fruit #2**	**Fruit #3**
1	Not ripe enough			
2	Just about right			
3	Overripe			

	Tartiness	**Fruit #1**	**Fruit #2**	**Fruit #3**
1	Not tart enough			
2	Just about right			
3	Too tart			

	Firmness	**Fruit #1**	**Fruit #2**	**Fruit #3**
1	Not firm enough			
2	Just about right			
3	Too firm			

	Sweetness	**Fruit #1**	**Fruit #2**	**Fruit #3**
1	Not sweet enough			
2	Just about right			
3	Too sweet			

If this product was commercially available, would you choose to purchase it? **Y / N (please circle)**

	Repurchase	Fruit #1	Fruit #2	Fruit #3
1	Repurchase	**Y / N**	**Y / N**	**Y / N**

Further comments (optional)

_____

Figure 15. Variety CJ19 harvested as a result of Cyclone Niram February 2021. The fruit can be seen with defect caused by banana rust thrips.

Figure 16. Variety GCTCV 215, GCTCV 247 and Williams in the Redden Street Post-harvest laboratory prior to assessment.

Figure 17. Variety GCTCV 215, GCTCV 247 and Williams at intake and through to eating ripe

Figure 18. a). Participants conducting a taste test for one of the consignments and, b). fruit prepared for the consumer acceptance survey for TR4 resistance banana varieties GCTCV 215, GCTCV 247 and Williams.

a)

b)

BRS Tropical	Brazil	2337	May-20
BRS Japira	Brazil	2338	May-20
BRS Pacovan Ken	Brazil	2339	May-20
Pacovan	Brazil	2340	May-20
BRS Pacoua	Brazil	2341	May-20
BRS SCS Belluna	Brazil	2342	May-20
017041	Brazil	2343	May-20
028003	Brazil	2344	May-20
042079	Brazil	2345	May-20
GCTCV 218 True to Type Formosana	Taiwan	2346	Jul-20
GCTCV 218-2 Improved Formosana	Taiwan	2347	Jul-20
Tai Chao 3	Taiwan	2348	Jul-20
Tai Chao 7	Taiwan	2349	Jul-20
Phillipines selection variety 219	Taiwan	2350	Jul-20
Phillipines Dwarf Pisang awak	Taiwan	2351	Jul-20
MA13	France	2470	Oct-21
PRAM01	France	2471	Oct-21

Table 2. Cultivars Released from Quarantine for BA16001

Cultivar	Origin	Accession No.	Date Released
Plantanera Brier	Canary Is	1823.2	Dec-16
Flhorban hybrid 924	France	1945.1	Dec-16
Flhorban hybrid 925	France	1946.1	Dec-16
Flhorban hybrid 931	France	1947.1	Dec-16
Flhorban hybrid 938	France	1948.2	Dec-16
Flhorban hybrid 940	France	1949.2	Dec-16
GCTCV 105	Taiwan	1950.3	Feb-17
GCTCV 217	Taiwan	1951.2	Feb-17
Asia Pacific No. 1	Taiwan	1952.2	Feb-17
Asia Pacific No. 3	Taiwan	1954.2	Feb-17
Plantanera Gruesa Palmera	Canary Is	1822.3	Aug-17
GCTCV 105	Taiwan	1950.4	Aug-17
Asia Pacific No. 3	Taiwan	1954.3	Sep-17
Flhorban hybrid 918	France	2226.7	Apr-20
Flhorban hybrid 918	France	2226.8	Apr-20
Flhorban hybrid 925	France	2227.3	Apr-20
Flhorban hybrid 925	France	2227.9	Apr-20

Flhorban hybrid X17	France	2228.1	Jul-20
Flhorban hybrid X17	France	2228.6	Feb-19
Flhorban hybrid L9	France	2229.2	Jul-20
Flhorban hybrid L9	France	2229.4	Apr-20
Santa Catarina	Brazil	2314.3	Oct-21
BRS Princesa	Brazil	2336.3	Oct-21
BRS Tropical	Brazil	2337.3	Nov-21
BRS Japira	Brazil	2338.2	Nov-21
BRS Pacovan Ken	Brazil	2339.1	Oct-21
BRS Pacoua	Brazil	2341.4	Nov-21
017041	Brazil	2343.1	Nov-21
042079	Brazil	2345.1	Nov-21
042079	Brazil	2345.3	Nov-21
GCTCV 218 True to Type Formosana	Taiwan	2346.5	Nov-21
GCTCV 218 True to Type Formosana	Taiwan	2346.7	Nov-21
GCTCV 218-2 Improved Formosana	Taiwan	2347.1	Nov-21
Tai Chao 3	Taiwan	2348.2	Nov-21
Tai Chao 3	Taiwan	2348.3	Nov-21
Tai Chao 7	Taiwan	2349.1	Nov-21
Philippines selection variety 219	Taiwan	2350.1	Oct-21

Mutation breeding

In the parallel project BA 14001 Sharon Hamill gamma irradiated TR4 Fusarium wilt tolerant Cavendish plants and the population of unique individuals were evaluated in Northern Territory trials. Individual plants of both GCTCV-215 (14 plants) and CJ19 (2 plants) retained resistance/tolerance and also showed improved agronomic traits. Those unique individual plants require further study evaluation in Queensland and NT with an aim for further distribution if plants show promise. However, since TR4 Fusarium wilt is endemic in the NT movement of the material from NT to QLD requires lengthy consideration to gain access with very low biosecurity risk. After lengthy discussion and scientific review over a year and with all associated partners involved including ABGC, a Restricted Matter Permit was developed by Sharon Hamill and Kathy Crew and approved. Processes of the Restricted Matter Permit allow collected suckers to be tested for BBTV and under strict process plants to be cultured in tissue culture in the NT. These plants can then be sent to Sharon Hamill at Maroochy Research Facility for two inspections by Biosecurity staff to ensure freedom from fungal contamination before entering the QBAN Tissue Culture Laboratory. Over 400 cultures from 15 mother plants and 71 individual suckers have been received and processed from the NT to date, and are being maintained at the MRF QBAN Tissue Culture Laboratory.

With the aim to improve fruit quality of the highly productive and disease resistant Goldfinger, a population of irradiated plants was sent and evaluated at South Johnstone research Station where they showed a wide range of changes. After preliminary post-harvest testing and consumer evaluation, a population of 20 individual plants of the best Goldfinger selections with improved fruit quality were chosen and they have been initiated into tissue culture for further evaluation as required.

Banana germplasm

The banana collection was used widely during this project for research within this project, by other Australian banana researchers and relied on heavily by commercial growers.

Cultivars required for use in research were requested 473 times. Growers requested specific cultivars 389 times. Overall **30,403** plants of many different cultivars were provided for research and industry development, the supply of plants is not a commercially viable activity. Plants are no longer provided to backyarders as QBAN plants can now be purchased at retail outlets.

To maintain the quality of the banana collection 178 accessions were replaced by initiation of new cultures from True-to-type plants sourced from South Johnstone Research Station not including the new mutated plants lines that have entered the collection (39 so far). At project end there are 418 accessions in the Australian *in vitro* collection and approximately 70 accessions from the NT of the individual suckers from the selected mutated plants.

Due to the importance of banana varieties to the Australian banana industry, in 2020 DAF renovated the culture rooms and replaced the HEPA filters so that the plants can continue to be cultured in clean growth room conditions.

Plants for Project Research Trials.

There was a total of **8,523 plants** provided for the variety evaluation trials in this project. The supply details are below.

Table 3. Plants supplied for BA16001 variety evaluation trials

Research Variety Evaluation Trials	No. plants
A) Research - NT Varieties Trial 1	**829**
Asia Pacific #1	30
Asia Pacific #3	30
CIRAD 03 (924)	30
CIRAD 04 (931)	24
CIRAD 05 (938)	30
CIRAD 06 (940)	30
CJ19 selection B	30
Dwarf French Plantain	30
Formosana	45
GCTCV 105 new	30
GCTCV 217	30
Goldfinger	45
Heva	15
High Noon	30
Hom Thom Moko	30
Inarnibal	15
M53	15
Manang	15
Nzumoheli	15
Paka	15

Pisang Bangkahulu	15
Pisang Batu	15
Pisang Ceylan	30
Pisang Madu	15
Pisang Oli	15
Pisang Pipit	15
Pisang Sapon	15
PKZ	30
Sinwobogi	15
Tjau Lagada	15
Williams	115
B) Research - NT Varieties Trial 2	**854**
2390-2	30
Agutay	36
Asia Pacific # 1 TTT	30
Buccaneer (T12)	30
Calcutta	35
CIRAD 01 (925)	30
CIRAD 02 (918)	30
CIRAD 07 (L9)	30
CIRAD 08 (X-17)	30
Formosana	31
Formosana superior (selection 1)	30
GCTCV 106 Selection	30
Goldfinger	60
JV 42.41	30
Madang (M61) - Guadalope	30
Mutant Goldfinger 144	16
Mutant Goldfinger 417	20
Mutant Goldfinger 544	34
Niukin	28
PA 03.22	30
PA 12.03	30
PV 03.44	30
Short Fruit Williams	28
Williams	110
Yangambi KM5	36

C) Research - SJRS Varieties Trial 1	1162
ADI 9001	60
ADI 9168	60
Asia Pacific No. 1	30
Asia Pacific No. 2	30
Asia Pacific No. 3	30
Bell from Williams Sucker	30
Bobby Tannap	5
CIRAD 03 (924)	30
CIRAD 04 (931)	30
CIRAD 05 (938)	30
CIRAD 06 (940)	30
CJ19	30
CJ19 selection B	30
DPM 25	3
Dwarf Cavendish	30
Dwarf Ducasse	30
Dwarf Lady Finger	30
Dwarf Red Dacca	3
FHIA 02	3
FHIA 03	3
FHIA-17	3
FHIA 18	3
FHIA 23	3
Formosana	30
Formosana superior (selection 2)	30
GAL	60
GCTCV 105 new	30
GCTCV 105/106 original	30
GCTCV 119	30
GCTCV 215	30
GCTCV 217	30
GCTCV 217/247 original	30
Grand Naine	30
Inarnibal	30
JAFFA	60
JD Dwarf	3

Kluai Hom	3
Lakatan	3
Malaccensis 826	5
Pacific Plantain	3
PKZ	3
Plantanera Brier	30
Plantanera Gruesa	30
Santa Catarina Prata	30
SH 3641	3
SH 3656	3
Short Fruit Williams	30
Williams	60
D) Research - SJRS Varieties Trial 2	**372**
Ainu	3
Asia Pacific # 1 TTT	30
CIRAD 01 (925)	30
CIRAD 02 (918)	30
CIRAD 07 (L9)	30
CIRAD 08 (X-17)	30
Dwarf Ducasse	30
Formosana superior (selection 2)	30
GCTCV 106 Selection	30
High Noon	30
High Noon Clean Rachis	30
M. acuminata ssp. banksii	3
Pacific Plantain	30
Pendulous lady finger	6
Williams	30
E) Research - NSW Varieties Trial 1	**1158**
Asia Pacific No. 1	22
Asia Pacific No. 3	22
CIRAD 03 (924)	22
CIRAD 04 (931)	22
CIRAD 05 (938)	22
CIRAD 06 (940)	22
D5	22
Dwarf Ducasse	22

Dwarf French Plantain	4
Dwarf Red Dacca	4
FHIA-17	220
FHIA 25	107
FLF	113
GCTCV 105 new	22
GCTCV 105/106 original	22
GCTCV 217	44
High Noon	11
JV 42.41	11
Kirkirnan	4
Kluai Hom	3
Kluai Khai Bonng	3
PA 03.22	9
PA 12.03	11
Pacific Plantain	11
Pisang Gajih Merah	22
Pisang Susu	3
PKZ	211
Plantanera Brier	22
Plantanera Gruesa	22
RSS3	22
Santa Catarina Prata	11
Tonga	22
Williams	22
Yangambi KM5	4
F) Research - NSW Varieties Trial 2	**520**
CIRAD 02 (918)	25
CIRAD 03 (924)	25
CIRAD 05 (938)	25
CIRAD 06 (940)	25
Dwarf Ducasse	25
Goldfinger	25
High Noon	25
Mutant Goldfinger 144	25
Mutant Goldfinger 211	25
Mutant Goldfinger 521	25

Mutant Goldfinger 544	25
Mutant Goldfinger 903	25
Pisang Gajih Merah	25
SCS 451 Catarina	25
Tonga	25
Williams	145
G) Research – Pre-commercialisation Trials	**3,598**
Asia Pacific No. 3	180
CJ19	375
GCTCV 215	1360
GCTCV 217	260
GCTCV 217/247 original	50
GCTCV 247	1040
JV 42.41	21
Plantanera Brier	36
Williams	276

Plants Supplied to Other Australian Banana Researchers (non-project).

The collection is also required to support banana research by all other Australian banana researchers with **10,187** plants supplied as described in the table below. The plants for research outside of this project were supplied under a Fee for service and contract labour was used for this under direction of project staff. Project staff also organised permission to move in line with plant health regulations.

Table 4. Plant supplied to other Australian banana research projects

H) Research - Other Australian Research	**10,187**
Calcutta	23
Cam020	3
CJ19	870
CJ19 selection B	105
CJ19 selection E	105
CJ19 Superior	165
DPM 25	317
Ducasse	1611
Dwarf Cavendish	25
Dwarf Ducasse	122
Dwarf French Plantain	12
Dwarf Nathan	30
FHIA 01	25
FHIA 02	112

FHIA 03	23
FHIA 18	58
FHIA 23	3
FHIA 25	226
FHIA 26	28
FLF	10
Formosana	15
GCTCV 106	25
GCTCV 119	493
GCTCV 215	645
GCTCV 217	530
GCTCV 217/247 original	100
Goldfinger	477
Gros Michel	21
Igisahira gsanzwe	12
IV9 Calcutta 4	7
Khae (Phrae)	4
Lady Finger	102
Lakatan	5
M. acuminata ssp. banksii	25
M. balbisiana Butuhan	40
Madang (M61) Guadeloupe	5
Madang Guadeloupe	5
Malaccensis 826	2
Malaccensis 845	8
Malaccensis 846	15
Malaccensis 848	14
Malaccensis 850	16
Malaccensis 851	13
Malaccensis 852	13
Menei	10
Musa balbisiana	25
Musa Zebrina	8
Niukin	4
Pacific Plantain	22
Pahang	7
Paka	4

Pisang Bangkahulu	8
Pisang Ceylan	22
Pisang Gajih Merah	55
Pisang Jari Buaya	24
Pisang Madu	4
Pisang Mas/Terema/Senorita/Sucrier	78
Pisang Raja	4
PKZ	200
Rimina	8
Saba	15
Sar 219	20
SH 3142	53
SH 3217	35
SH 3362 (2010)	28
SH 3362 (2013) autotetraploid	3
SH 3436	25
SH 3641	49
SH 3656	35
SH 3748	37
Tjau Lagada	5
Tonga	11
Truncata	4
Tuu gia	3
Utafun	10
Wain	20
Williams	2886

Plants for Australian Banana Growers.

Banana cultivars have been constantly requested by commercial growers for diversification and niche markets. **11,641 plants** were supplied to commercial growers during this project under a fee for service and contract labour was used for this under direction of project staff. Project staff also organised permission to move in line with plant health regulations. Plants are not supplied to back yard growers as there are now supplied of QBAN produced banana plants sold at retail outlets.

Table 5. Plants supplied to Australian banana growers

I) Grower	**11,641**
Blue Java	262
Bluggoe	250
Calypso	5

Cardaba	1
Cavendish-K.Lindsay select.	5
Chinese Cavendish	30
Double banana	5
DPM 25	103
Ducasse	434
Dwarf Cavendish	158
Dwarf Ducasse	1829
Dwarf French Plantain	163
Dwarf Kalapua	2
Dwarf Lady Finger	36
Dwarf Nathan	70
Dwarf Red Dacca	1256
FHIA 02	14
Goldfinger	1802
Gros Michel	167
Heva	5
Hom Thom Moko	44
Hua Moa (Puerto Rican Dwarf plantain)	338
Igisahira gsanzwe	3
Inarnibal	2
JD Dwarf	25
JD Yangambi	3
Kalapua	2
Kirkirnan	5
Lady Finger	1604
Lakatan	52
Malaysian Blood	8
Mangaro Torotea	15
Monthan	5
Ney Poovan	16
Niukin	3
Pacific Plantain	638
Pisang Ceylan	181
Pisang Gajih Merah	293
Pisang Madu	3
Pisang Mas/Terema/Senorita/Sucrier	605

Pisang Raja	2
Red Dacca	76
Rimina	3
Saba	200
Santa Catarina Prata	51
Silver Bluggoe	3
Sugar	13
Tonga	348
Valery	6
Vunamami	2
Wain	3
Williams	482
Yenai	5
Zillman	5

Virology Diagnostics for Banana Germplasm

Background & Methods

Approved arrangements Q2325 (post-entry quarantine glasshouse) and Q2272 (diagnostics laboratory) process leaf samples and plants from Tissue Culture Laboratory Q2264. Leaf samples from in vitro plants were pre-indexed to exclude any lines in which a virus is detected. Clonal plantlets of lines in which viruses were not detected could then be grown in the glasshouse with regular inspections for pathogen symptoms. Leaf samples were collected at three and six months after deflasking for further pathogen screening.

Imported germplasm samples were indexed using specific molecular tests for banana bunchy top virus (BBTV), banana bract mosaic virus (BBrMV), banana mild mosaic virus (BanMMV), cucumber mosaic virus (CMV), five species of banana streak virus (BSV), and the banana picorna-like virus using previously established protocols. Additionally, partial purification and concentration of samples was undertaken, and samples were analysed by immunosorbent electron microscopy (ISEM) to check for viruses not included in the specific tests listed above. Following completion of virus testing, staff in project BA16005 destructively sampled the plants and conducted phytoplasma indexing. Their results were collated by BA16001 staff and test were provided to Q2264 for release of sibling clonal plants of pathogen free lines.

Suckers used for tissue culture initiation by the Australian banana germplasm in vitro collection were tested for the endemic viruses (BBTV, BanMMV, CMV and five species of BSV) to ensure this collection comprises accessions of the highest health status.

QBAN samples were tested only for BBTV, as were samples from the Northern Territory ahead of their entry to the QBAN scheme.

Results

Table 6 summarises the virus diagnostics conducted for germplasm samples in BA16001. BBTV, CMV and BBrMV were not detected in any sample. BanMMV, BSOLV and BSGFV were detected in a small number of germplasm samples. The novel banana picorna-like virus was detected in one sample.

Table 6. Virus diagnostic testing for banana germplasm.

Sample type	BBTV	CMV	BBrMV	BanMMV	BSV	picorna-like virus	EM
Post-entry quarantine	0/166	0/166	0/166	6/166[A]	2/166[B]	1/132[C]	5/163[D]
Germplasm	0/221	0/221	--	1/221[E]	7/221[F]	--	--
QBAN	0/1925	--	--	--	--	--	--
NT samples	0/55	--	--	--	--	--	--

[A] all BanMMV detected in tissue culture: five lines of one accession of 'BRS SCS Belluna' ex Brazil; one line of 'Phillipines Dwarf Pisang awak' ex Taiwan

[B] 1 accession with BSOLV detected in 'Flhorban hybrid X17' ex France; 1 accession with BSGFV detected in 'Santa Catarina' ex Brazil

[C] 1 accession with banana picorna-like virus detected in 'Flhorban hybrid 925' ex France by ISEM

[D] 3 accessions with flexuous rods in accessions positive for BanMMV by IC-RT-PCR; 1 accession with bacilliform particles in accession positive for BSGFV by IC-PCR; 1 accession with 26 nm isometric particles from which the banana picorna-like virus genome was sequenced and a diagnostic assay was designed

[E] 1 accession in which BanMMV was detected in 'Asupina'

[F] 2 accessions with BSOLV detected in 'Kofi' and 'FHIA-03'; 5 accessions with BSGFV detected in 'SH3640-10/High Noon' (x2), 'Goldfinger,' 'JV42.41' and 'FHIA-03'

Appendix 12 – IPDM Priority setting workshop results

The IPDM strategy developed by the project took consideration of a range of information and meeting outputs that have identified priorities for industry, including the outputs of the Strategic Agrichemical Review Process (SARP) meeting and the priority setting workshops conducted with producers and industry service providers in the major production region in NQ.

Three separate priority setting workshops were held with producers and industry service providers on 10/5/2017, 26/5/2017 and 22/1/2018 and the results are presented below.

Banana Agri-business Managers discussion group – IPDM prioritisation (10/5/17) % allocated votes (n=25)					
Research area	**Leaf spot**	**Nematodes**	**Mites**	**Bunch pests**	**Other**
Chemical	13.4	1.9	7.2	37.2	0
Biological	0	7.8	4.7	5.6	0
Resistance	1.3	0	6.9	3.4	0
Knowledge	0	1.6	0	0	0
Nutrition	0	0.3	0	0	0
Fallow crops	0	4.1	0	0	0
Other	2.2	0	0	1.3	1.3
Total	**17%**	**16%**	**19%**	**47%**	**1%**

Grower workshop – IPDM prioritisation (22/01/18) % allocated votes (n=13)				
Research area	**Leaf spot**	**Nematodes**	**Insects & mites**	**Other**
Chemical	16.2	0.7	8.4	0
Biological	15.8	0.7	20.1	0
Resistance	0	0	0	0
Knowledge	2.6	1.3	15.8	0
Other	0	0	13.2	5.3
Total	**35%**	**3%**	**57%**	**5%**

NextGen growers group meeting – IPDM prioritisation (26/5/17) allocated votes (n=6)	
1 Bunch pests (thrips)	4 votes for #1 priority
2 Post-harvest disease (crown rot)	3 votes for #2 priority
3 Leaf spot (yellow Sigatoka)	2 votes for #3 priority

From these sources the identified priority pests and diseases were bunch pests, mites, leaf diseases and nematodes, which were identified in the original project proposal.

Entomology research activities

Flower thrips, banana rust thrips, banana scab moth and pest mites were reported as the highest concerns to tropical banana growers, with emphasis on research activities investigating elements of an IPM approach employing chemical, biological and cultural control strategies to manage pests.

Consequently, the research activities focused on screening biological and new mode of action chemical products against bunch pests (thrips and caterpillars), investigation of cultural controls and pheromones for thrips, checking the genetic diversity of banana scab moth to investigate the host/race interactions and surveying and measuring the efficacy of biological control agents for banana rust thrips, banana scab moth and spider mites.

Leaf disease research activities

Management of yellow Sigatoka is dependent on the use of cultural practices (removal of diseased leaves, leaf trash and drainage management) and timely applications of systemic and protectant fungicides. Issues identified as priorities included potential loss of current fungicides through de-registration and resistance development, as well as a better understanding of the role of pre- and post-infection activity of existing products to improve efficacy during the wet season when spray intervals are regularly disrupted.

Consequently, the research activities focused on screening an identified suite of fungicides, plant defence activators and biological products with varying levels of efficacy against yellow Sigatoka, to evaluate new 'softer chemical' options. The post-infection activity of systemic fungicides and oils was also investigated to identify when and which type of systemic fungicide would provide the best level of control during the wet season. The project will also support varietal leaf spot screening work conducted at South Johnstone to identify resistance levels in newly imported banana germplasm.

Nematode research activities

The most damaging nematode pest of bananas worldwide is the burrowing nematode (Radopholus similis), however there are other major nematodes increasing on farms in all of the Australian banana growing regions, as identified by recent surveys of banana farms in Qld, WA and NSW. The pathogenicity and impact of these species is not well understood in bananas and more investigation is needed. The banana industry has been successful in reducing the amount of nematicides used to manage burrowing nematode through crop rotations and soil health management, however little is known about the host-status for these emerging nematode pests, and nematicide options have reduced significantly due to de-registration and loss of manufacturing capacity.

Consequently, the research activities focused on assessing the pathogenicity of identified nematode species and developing new tools and information required to provide integrated management options for all nematode pest species, particularly investigating the host status of popular fallow crop species and identifying possible biological control products.

Diagnosis of endemic plant diseases and pests

The ability for banana producers or service providers to access local pest and disease diagnostic services was supported from the Mareeba and South Johnstone offices with access to other diagnosticians as required. Samples are expected to be submitted for testing from a range of sources and will be undertaken in order to monitor the local banana growing areas. This provided information and data on the status of endemic pests and diseases, and potentially incursions of exotic threats.

Appendix 14 – Bacterial corm rot investigations

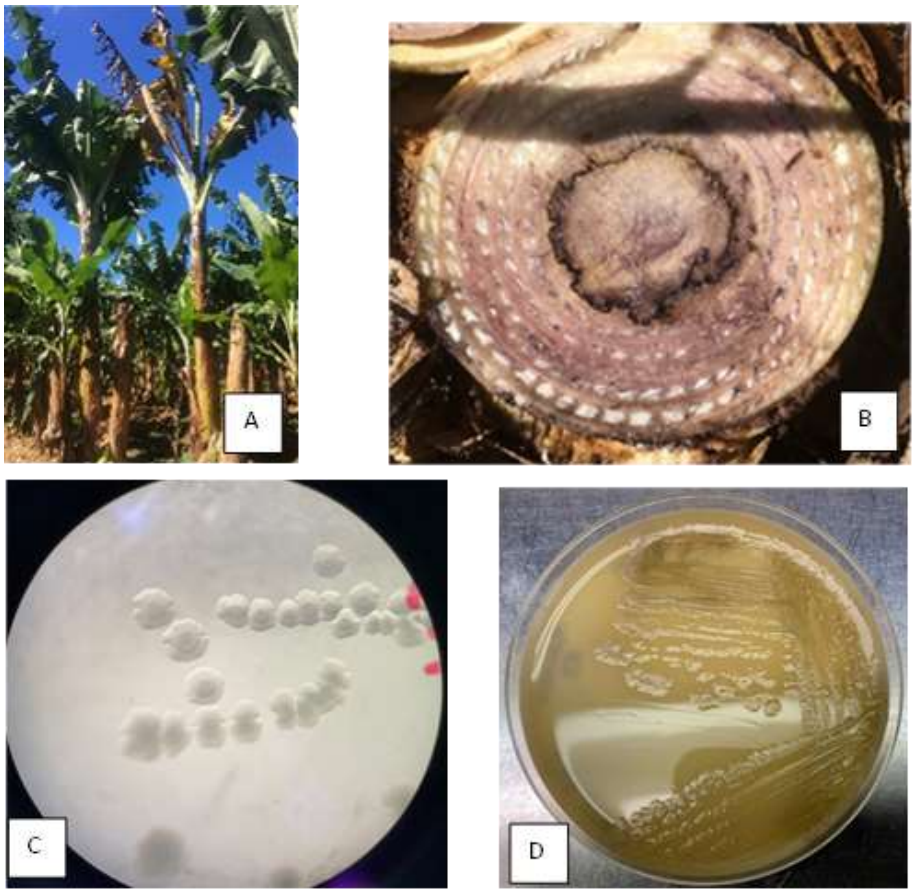
Introduction

Banana corm rot (BCR) is destructive and among the least recognised bacterial diseases. Symptoms are very similar to those of Panama disease, nematode damage, and other rhizome associated pests such as banana weevil borer. It reduces water and nutrient uptake, resulting in decreased productivity. In addition, BCR affected plants are vulnerable to wind and soil saturation, resulting in increased rates of tip over or toppling (Young et al. 2007).

Banana corm rot (BCR) caused by *Dickeya* (formerly *Pectobacterium*) *chrysanthemi* and *Pectobacterium* (formerly *Erwinia*) *carotovora* subsp. *carotovora* have been reported as the main bacterial pathogens from commercial banana plantations in north Queensland (Akiew *et al*. 1998, Akiew *et al*. 2001 and Young *et al*. 2007). The industry uses tissue cultured plants to provide disease free planting stock, these plants can be more susceptible due to higher sucker/pseudostem production. Reported increase in plant losses where growers used tissue culture over bits or suckers are estimated at 20-40% in the first ratoon and 15 – 20% in subsequent ratoon crops. The highest incidence of disease is reported to be between January and April and in first ratoon crops that coincide with favourable environmental conditions; hot and wet, ideal for disease development and the build-up of inoculum potential. This study was conducted to determine if (*Pectobacterium* and *Dickeya* species) are still the primary organisms implicated with corm rot symptoms.

Dickeya chrysanthemi is considered widespread and endemic in Australia. However, different strains of *Dickeya* spp. have been recovered from banana corm rot samples from north Queensland (South Johnstone Research Facility - SJRF). Plant symptoms included yellowing and browning of the lower leaves, black discoloration and rotting within the corm and roots (Figure 1).

Figure 1. BCR symptoms and culture characteristics **A**. leaf yellowing and browning **B**. black discoloration between healthy and diseased tissues **C.** fried egg-shaped colonies on Nutrient agar (NA) D. production of blue pigment on Yeast extract dextrose calcium carbonate medium (YDC).



The finding of genetically different strains associated with BCR was reported to Biosecurity Queensland. The bacterial culture J 5284 -1 (LIMS ID E20_570_1) from South Johnstone Research Facility was submitted to the Plant Biosecurity Laboratory for species identification. The culture was identified as *Dickeya fangzhongdai* and determined by multilocus sequence analysis of partial DNA sequences of glyceraldehyde-3-phosphate dehydrogenase A (gapA) and dnaX genes (Figure 2 and 3). The phylogenetic analyses included sequences from ex-type or reference strains of *Dickeya,* including those published in Oulghazi *et al*. (2019), Suharjo *et al*. (2014), Tian *et al*. (2016) and Van der Wolf *et al*. (2014).

Figure 2. Phylogenetic tree of BCR isolate E20_571_1_dnaX Assembly consensus sequence

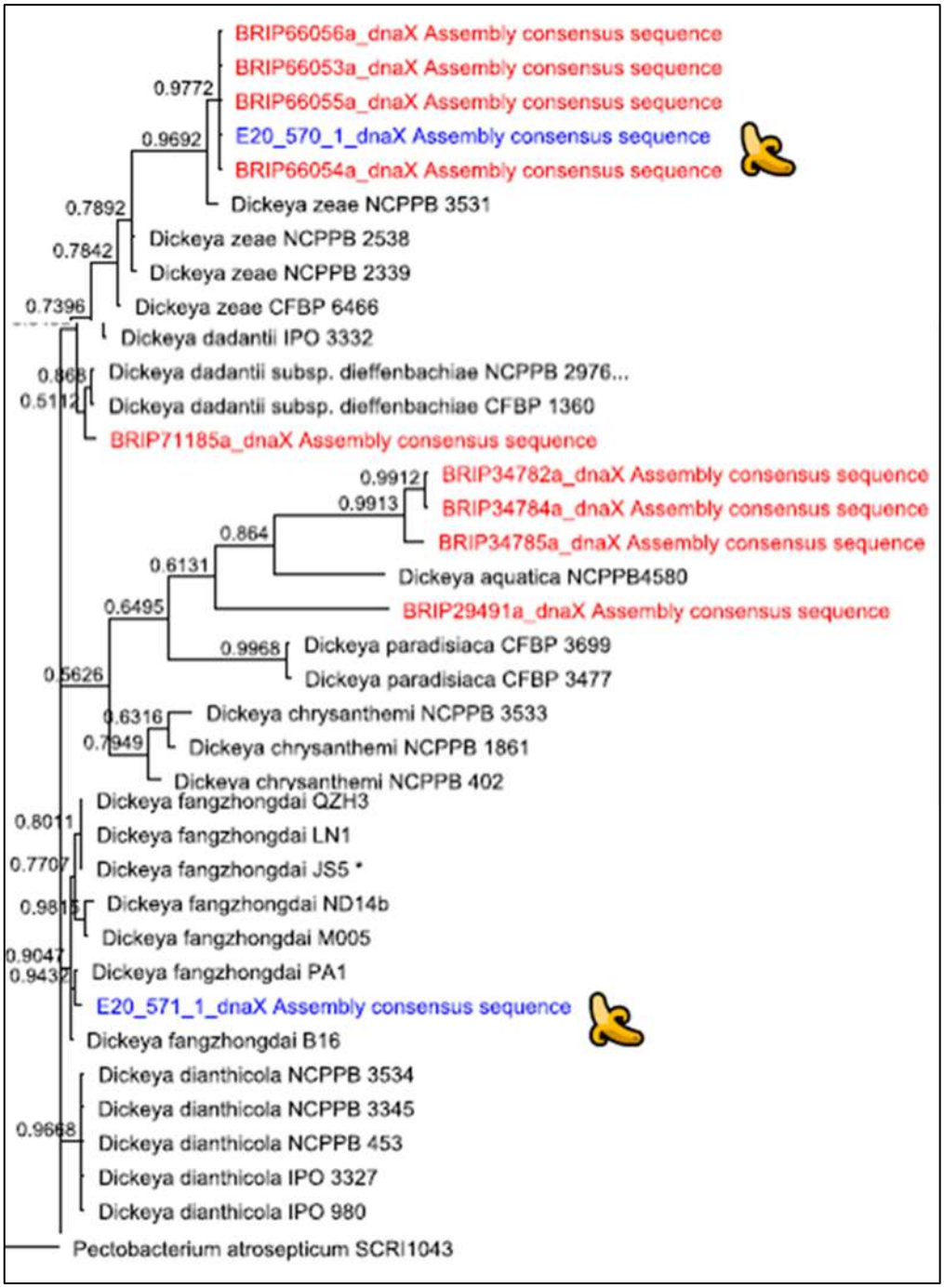
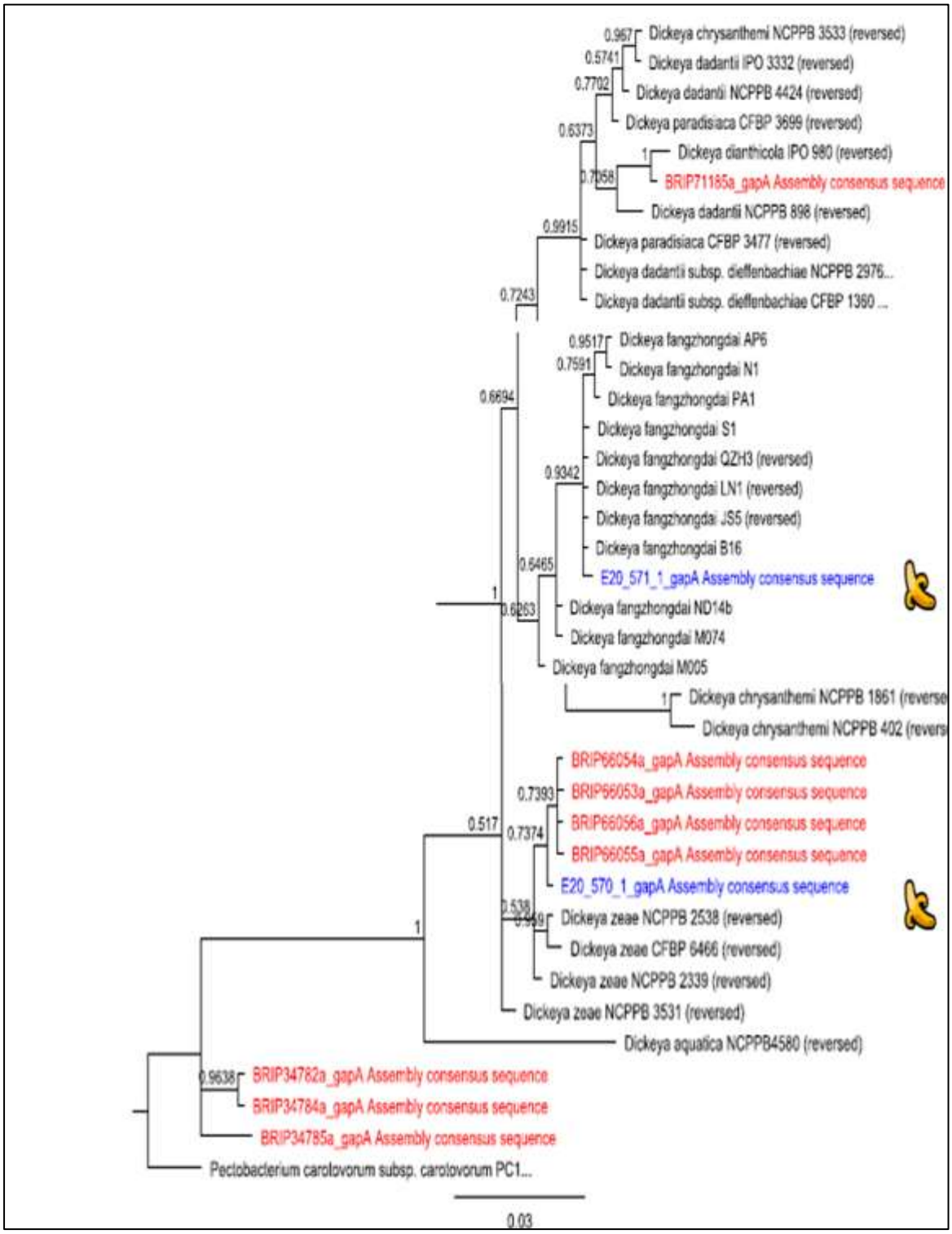


Figure 3. Phylogenetic tree of BCR isolate E20_570_1_gapA assembly consensus sequence



Pathogenicity testing

Koch's postulate was proved to confirm the identity of *Dickeya fangzhongdai* by inoculating, four Cavendish tissue culture plants (24 weeks old). A cork borer was used to create hole/wound at the base of the stem into the corm and cotton wool was soaked with 1 ml of 10 ^{7}cfu/ml) bacterial suspension of *D. fangzhongdai* and plugged into the hole ensuring bacteria firmly contact with wound. Similarly, control plants (4) were inoculated using sterilized distilled water. Inoculated plants were covered with polythene bags and incubated at 28 °C in a

growth chamber. The polythene bag was removed after 48 hrs of inoculation and each plant was observed for external symptoms at weekly intervals. Plants were dissected and observations of corm rot symptoms conducted when 60% of the plant leaves turned yellow/brown in colour. Isolations and identification were made from inoculated and uninoculated plants to prove pathogenicity. The inoculated plants showed initial marginal yellowing of lower leaves after 10 days, these turned brown in colour and progressed to young leaves after five weeks. After 7 weeks, plants were dissected and exhibited black discoloration (no putrid smell), like those observed in naturally infected plants. No symptoms were observed in the control treatment, stem tissue healed at the point of wound that was created with cork borer.

Isolations and recovery of *D. fangzhongdai* from symptomatic corm tissue confirmed its pathogenic nature. This proved the presence of other *Dickeya* spp./strains, in addition to earlier reported *Dickeya* species that could cause heavy losses to banana production under certain environmental conditions. This is the first report of *D. fangzhondai* causing banana corm rot in Australia (Pathania *et al.*, 2021). The genus *Dickeya* has recently been reclassified, with new species described, therefore, molecular studies with available historical BCR isolates are required to determine the accurate identify of species associated with BCR disease, to establish if previous BCR isolate(s) are endemic to Australia and have been previously misidentified.

Bacterial Corm Rot management

Evaluation of tissue culture propagation techniques

Two banana tissue culture cutting techniques were evaluated, aimed at limiting sucker production and thereby reducing desuckering and plant exposure to BCR. In this study, the standard tissue culture *in vitro* cutting technique was manipulated to determine if sucker production could be reduced, leading to potential BCR management and cost savings.

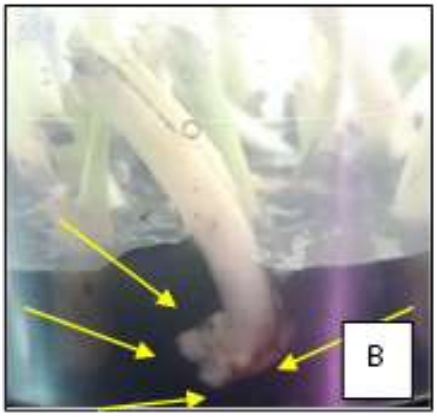
Materials and Methods

The micropropagation process of Williams Cavendish was assessed at tissue culture laboratories in north QLD, to determine if an innovative cutting technique could reduce early sucker production of TC plants (Figure 4) in the field conditions. Two techniques 1) standard - large portion of callus or excess tissue was left below the growing point and 2) modified - basal callus was minimized (cut below the growing point) before treatments were transferred to *in vitro* rooting media (Figure 5A-C). Seventy-five plants of each technique were potted and grown at SJRF and assessed for sucker production. Assessments were conducted at 3-month intervals recording sucker numbers in addition to growth parameters e.g., stem diameter and plant height at the second and third assessments and the proportion of plants with two or more suckers were evaluated at each assessment. Six plants of each treatment were transferred for in-field evaluation and uprooted after four months and assessed for number and origin of suckers, peepers, and buds.

Statistical analyses were conducted on the mean number of suckers per plant, stem diameter and plant height. The proportion of plants with 2 or more suckers was also analysed.

Figure 4. Excessive sucker/pseudostem production in tissue culture plants

Figure 5. A. In vitro cutting B. Standard callus below growing point and C. Callus bare minimum below growing point



Results and Discussion

The reduction in early suckering of tissue culture plants was of primary concern in this study. The observations conducted at three months interval showed a significant effect on sucker production between two cutting techniques (Figure 6).

Figure 6. Sucker development, A. Standard B. Modified technique, after 1st assessment (3 months)

Percent plant survival and number of Suckers per Plant

The i*n vitro* modified cutting technique was compared to the standard technique, if removing large tissue or callus below the growing point of plantlet before transferring into the rooting media had a negative impact on plantlet survival rates and reduction in sucker development.

The studies conducted on 75 plantlets that were cut through both the techniques showed 100 percent survival rate *In* vitro (rooting media) and in pot experiment. Though some concern was mentioned by local Tissue culture facility Manager that modified cutting technique requires extra care of technicians for plantlet growing point, otherwise cutting above the growing point may lead to considerable losses.

The results showed significant reduction in sucker numbers in the modified technique from 1 to 0.2 per plant at the first assessment as compared to standard technique. However, no significant differences between the cutting techniques were found at the second and third assessments respectively. Across all three assessment times, the overall mean proportion of plants with suckers is significantly higher for the routine cutting technique (Table 1).

Table 1. Effect of cutting technique on sucker production (per plant).

Technique	Sucker assessment /sampling Time					
	1St (August 2020)		2nd (October 2020)		3rd (January 2021)	
	Mean	se	Mean	se	Mean	se
Modified	0.20 a	0.089	0.32 ab	0.113	2.30 d	0.339
Routine	1.00 b	0.200	0.62 bc	0.154	2.33 d	0.333
p-value	< 0.001		0.120		0.944	
95% lsd	0.440		0.383		0.961	

**Means with a different letter within a sampling date are considered significantly different.

Stem Diameter and Plant Height

The effect of modified and standard cutting technique was assessed on plant growth parameters, stem diameter and plant height. The stem diameter of plants was evaluated at the second and third assessments. A linear mixed model (REML) was fitted to the data from each assessment individually, with cutting technique as the fixed effects model and no random model was fitted. Results found a significant difference at the second assessment ($p < 0.001$), but not at the third ($p = 0.264$). A $\log_{10}$ transformation was required for the analysis of stem diameter recorded at the third assessment. The transformed means are presented in the table below, with the back-transformed means shown in brackets (Table 2). The results found a significant difference at the second but not at the third assessment (Table 2). The stem diameter at the second assessment for the routine cutting technique was significantly larger compared to the modified technique . A significant treatment effect was also detected for mean plant height recorded at the 2nd observation. The mean plant height for the routine cutting technique was significantly higher than the modified technique (Table 2). However, no adverse effect on plant growth was observed in modified technique.

Table 2. Effect of cutting technique on plant growth parameters: stem diameter and plant height

Technique	Stem Diameter (mm)				Plant Height (mm)	
	October 2020		January 2020		October 2020	
	Mean	se	Mean	Se	Mean	se
Modified	34.70 a	0.769	1.62 (42.00)	0.020	304.4 a	7.03
Routine	38.86 b	0.754	1.66 (45.21)	0.020	335.0 b	6.89
p-value	< 0.001		0.264		0.003	
95% lsd	2.165		0.057		19.77	

**Means with a different letter within a sampling date are considered significantly different. Data in parenthesis is back transformed means.

Proportion of Plants with Two Or More Suckers

The number of sucker production per plant was assessed over time in modified and standard cutting techniques. The results revealed that none of the plant with modified technique produced two or more suckers by the second assessment (Table 3). The proportion of plants that produced two or more suckers was significantly higher for the routine cutting technique at the first two assessments. At the third assessment time, there was no significant difference between the two cutting techniques ($p = 0.627$).

Table 3. Sucker development) over time in two cutting techniques

Technique	Sucker assessment (number per plant) /sampling time					
	1St (August 2020)		2nd (October 2020)		3rd (January 2021)	
	Mean	se	Mean	se	Mean	se
Modified	0.000 a	0.0006	0.000 a	0.0006	0.800	0.0894
Routine	0.200 b	0.0800	0.154 b	0.0708	0.857	0.0759
p-value	0.006		0.017		0.627	
95% lsd	0.1609		0.1422		0.2373	

**Means with a different letter within a sampling date are considered significantly different.

Similarly, in-field planting showed 50% reduction in early sucker development and stronger connection point with the mother plant in the modified technique compared to standard technique (Figure 7 and 8).

Figure 7. Sucker development in-field - Standard v's modified technique

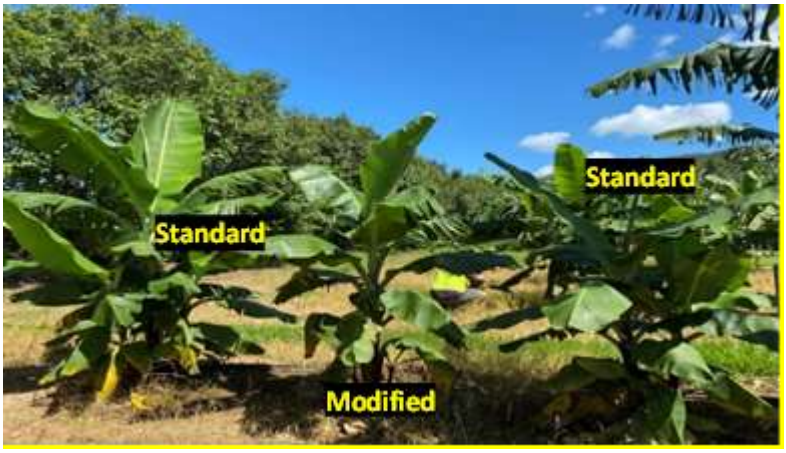


Figure 8. Suckers, peepers and buds - Standard v's modified technique

Conclusion

Tissue culture banana plants are prone to excess sucker production in the early phase of plant development compared with bits or suckers (Smith *et al*. 2001). Early sucker production in tissue culture plants could be reduced by manipulating in vitro plantlet cutting technique and was successful in this study (Pathania *et al.*, 2021).

The technique and results have been discussed with the local banana tissue culture laboratories, growers, and industry at both the Banana congress, and SJRF field walk, in 2021. This research needs to be further evaluated on a commercial scale in collaboration with local tissue culture facilities. These preliminary findings indicated that reduced sucker production and stronger attachment point with parent plant will of benefit and assist in decreasing BCR incidence. In addition, and plant tip over problem leading to potentially reducing BCR incidence, the technique will also result in significant economic benefits (time, labour, and overall cost savings).

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Appendix 18 – Pest and disease diagnostics

Summary

Unseasonal weather conditions, the Panama TR4 outbreak and the COVID-19 pandemic impacted on the number of diagnostic samples received during the project. However, 414 samples were received for pathology (290), entomology (17) and virology (107). No exotic pathogens or pests were reported throughout the project, but there were new findings including two *Dickeya* species associated with bacterial corm rot and a caterpillar (*Pyroderces* sp.) commonly referred to as 'pink scavenger'. The latter was only identified in the Lakeland region causing damage to the fruit peel on a number of farms.

Introduction

Diagnostics is an essential component to any pest and disease project, as this enables researchers to identify and determine the status of pests and diseases in the local area and across growing regions. DAF has expertise in all areas of diagnostics including fungal and bacterial taxonomy, nematology and virology. If expertise was required in other areas e.g., phytoplasma identifications and banana freckle species identifications, these were outsourced to key personnel in BA16005. Diagnostics is essential to ensure that the banana industry can confidently prove that the growing regions are absent from the presence of exotic diseases. This is achieved through surveillance and subsequent diagnostics to ensure 'area freedom' is maintained, as this is imperative for the industry to continue trading nationally.

Diagnostics is also pertinent to the north Queensland productions areas for several reasons. Weather conditions are highly conducive to disease development, particular on the wet tropical coast where greater than 90% of the Australian banana industry is located. Also, the proximity of the region to previous known outbreaks of exotic disease incursions (black Sigatoka and Panama TR4) and the risk of plant movement due to the population diversity (Torres Strait and Pacific Islander communities). Insect pests (banana skipper butterfly) are also present in Papua New Guinea, therefore diagnostics allows for early detection and subsequent eradication or containment.

Materials and methods

Visual assessment

In some instances, visual assessment is the primary form of identification for diseases such as Banana leaf speckle (*Mycosphaerella musae*). Unlike other leaf diseases, visible fungal structures are not produced on leaf material and isolations for symptomatic material are not effective at recovering the causal organism. Leaf symptoms are quite distinctive, therefore visual assessment is the main form of identification.

To a trained diagnostician, visual assessment is also useful to distinguish between yellow and black Sigatoka at the early lesion development stages. A detailed description of how to differentiate between the three closely related Sigatoka diseases (*Pseudocercospora musae*, *P. fijiensis* and *P. eumusae*) using symptomology, microscopic examination and molecular assay is available in the Sigatoka leaf spot disease diagnostic manual (Henderson *et al*., 2006).

Visual assessment can also be a valid method for the determination of insects, particularly adults, allowing identifications to varied levels including family, genera and species.

Microscopic examination

Most of the endemic fungal leaf pathogens can be identified using standard microscopy techniques. The endemic diseases encountered include yellow Sigatoka (*P. musae*) rust (*Uredo musae*), tropical speckle (*Metulocladosporiella musae* and *Ramichloridium* spp.), Cordana leaf spots (*Neocordana musae* and *Neocordana johnstonii*) and Deightoniella leaf spot (*Corynespora torulosa*). The same applies to exotic pathogens with Malayan leaf spot (*Haplobasidion musae*) and black cross (*Phyllachora musae*) easily identified microscopically.

Trained diagnosticians can also identify insect pests microscopically and in some cases to genera and species level. For identification of immature stages of insects and some groups (mites, thrips, scale and mealybugs), specialist taxonomists are required often using molecular taxonomic methods to confirm identifications.

Isolations (bacterial and fungal)

Isolations are required to identify the causal organism, particularly in the case of bacteria, and in situations where fungal structures are not evident on plant material. The process involves the surface sterilisation of plant material in 1% sodium hypochlorite for one to two minutes depending on the type of tissue, then allowed to dry. In the case of bacterial isolations, portions of plant tissue (zone between healthy and infected) are placed into vials containing 9ml of sterile distilled water to allowed bacterial to naturally exude from the material into the water. A sterile wire loop is dipped into the vial and streaked generally onto nutrient agar medium or specific culture media. The culture media will vary depending on the suspected bacterial genera.

In the case of fungal isolations, once the plant material has dried after sterilisation, small portions of plant tissue (zone between healthy and infected) are plated onto potato dextrose agar with the addition of the antibiotic streptomycin, this is a general-purpose media. Culture plates are incubated at 25-26^{o}C and monitored for fungal growth. Once fungal growth has occurred, plates are placed under near ultraviolet light (12 hr light/12 hr dark) to induce the fungal cultures to produce sporing structures to allow identification.

Biochemical and physiological tests

The identification of bacterial diseases was made using, MicroPlate test panel of 94 biochemical tests. The standard protocol was followed as per microplate reader and Biolog GEN III instructions to generate phenotypic fingerprints of the microorganism and Biolog microbial identification system, GEN III database version 2.8 was used to identify bacteria at genera and species level. Where the system gave low similarity (0.50) or no bacterial identification, molecular assays were used for identification (16S rRNA gene sequencing and multilocus sequence typing).

Real-time PCR, gel electrophoresis, sequencing and microbial profiling

Molecular assays were used for the identification of a range of banana diseases. The application of real-time PCR is essential to differentiate between yellow and black Sigatoka when fungal structures were absent from infected leaf material. In addition, high resolution melt (HRM) is used to distinguish between three closely related species of banana freckle, the endemic strain (*Phyllosticta maculata*) and two exotic species (*P. cavendishii* and *P. musarum*). Either plant material or DNA extracted from symptomatic material was provided to EcoScience Precinct (ESP) for analysis and confirmation of the species. Samples were also forwarded to EcoScience Precinct for sequencing through BA16005 to exclude Banana Wilt Associated Phytoplasma (BWAP). Extractions of DNA were also provided to Australian Genome Research Facility (AGRF) for microbial profiling to determine if unculturable fungal or bacterial organisms were present in samples. Two primer sets (V1-V3 and V3-V4) were used to verify the presence of bacteria (Table 1 and 2). In the case of bacterial diseases, gel electrophoresis was used for the identification of isolates associated with bacterial corm rot and a disorder termed 'internal finger rot' to determine the genera.

Table 1. Primer pair sequences for V1-V3

Target	27F
Forward Primer	AGAGTTTGATCMTGGCTCAG
Reverse Primer	GWATTACCGCGGCKGCTG
Application	Amplicon sequencing
Read Length	300bp

Table 2. Primer pair sequences for V3-V4

Target	341F
Forward Primer	CCTAYGGGRBGCASCAG
Reverse Primer	GGACTACNNGGGTATCTAAT
Application	Amplicon sequencing
Read Length	300bp

Virology indexing

The majority of the 107 virology diagnostic samples were from banana, however two samples were from *Alpinia* sp., one from *Heliconia* sp. and one from *Canna* sp. Samples were received from growers, colleagues, ABGC BBTV inspectors, Biosecurity Queensland and the Department of Agriculture. Standard molecular banana virus indexing assays were conducted for banana bunchy top virus (BBTV), cucumber mosaic virus (CMV), banana bract mosaic virus (BBrMV), banana mild mosaic virus (BanMMV) and five species of banana streak virus (BSV; De Clerck *et al.,* 2017). Where required, amplicons underwent Sanger sequencing to confirm BSV species identity. To check for unknown viruses, partial virus purification and concentration and immunosorbent electron microscopy was performed for 11 samples.

Insect molecular taxonomy

It is not possible to identify some insect pests and beneficials using standard visual or microscopy techniques. In these instances, there is a reliance on specialists and molecular taxonomists based at ESP to determine genera and species. The level of identification is dependent on the availability of already published sequence data.

Results and discussion

Fungal leaf diseases

Samples were received throughout the life of the project from growers, consultants, ABGC liaison officer, wholesale, and supply chain sectors of the banana industry. A total of 137 fungal leaf disease samples were received for diagnostics from the wet tropical coast (Innisfail and Tully), Atherton Tablelands, the Far North, Torres Strait and Coffs Harbour (NSW). It was not uncommon to find multiple fungal organisms on an individual leaf sample. However yellow Sigatoka was the most frequently identified organism (> 81%), followed by Cordana leaf spot (22%) and 18 % of samples with symptoms of banana leaf speckle (Table 3). A lower frequency of Tropical and Cladosporium speckle, Southern Cordana and Deightoniella leaf spot were observed in samples. There were also single identifications of algal leaf spot (*Cephaleuros virescens*) Banana Blast (*Pyricularia angulata*) and Stenella leaf spot (*Zasmidium* sp.), together with eight samples that the cause of leaf symptoms could not be determined, not included in Table 3. Two additional samples received were infested with scale insects (one confirmed as pink wax scale) and associated fungal organisms identified visually as sooty mould and *Cladosporium tenuissimum*.

The DAF laboratory at Mareeba also provided a diagnostic service for Northern Australia Quarantine Strategy (NAQS) personnel based in Cairns up until 2018. From this point they acquired their own equipment and conducted testing themselves. This collaboration provided diagnostic staff with an opportunity to see diseases that are normally only seen offshore. Samples were only received from Papua New Guinea (PNG) and Timor Leste (Table 4).

A total of 25 gamma irradiated leaf samples were received from PNG (13) and Timor Leste (12). As with leaf samples from Australia, multiple fungal organisms can be present on one sample. The most frequently identified diseases are listed in Table 4. Limited or no sporing structures were observed microscopically on suspect Sigatoka samples, therefore DNA extractions were required, followed by real-time PCR diagnostics. Results confirmed the presence of black Sigatoka on 12 of the 13 samples from PNG. In comparison, yellow Sigatoka was identified on five of the 12 samples from Timor Leste. These results are interesting, in that both countries were only identified as having black or yellow Sigatoka and not both. It is also worth noting that the number of countries like Australia where yellow Sigatoka is the dominant fungal leaf spot are on the decline, particularly once black Sigatoka or Eumusae leaf spot is detected.

Banana freckle symptoms were observed on samples received from PNG (2) and Timor Leste (2). Not all samples were identified to species level as NAQS had already provided material for molecular diagnostics. One sample from PNG and Timor Leste was identified as *Phyllosticta maculata*, whereas two additional samples from Timor Leste were confirmed as *P. cavendishii* which was recently eradicated from the Northern Territory and is considered as an exotic pathogen to Australia.

Table 3. Identification of the most prevalent fungal leaf samples from various banana growing regions in Australia.

Region	Samples	Yellow Sigatoka (*Pseudocercospora musae*)	Cordana leaf spot (*Neocordana musae*)	Banana leaf speckle *(Mycosphaerella musae)*	Tropical speckle (*Ramichloridium* spp.)	Cladosporium speckle *(Metulocladosporiella musae)*	Southern Cordana *(Neocordana johnstonii)*	Deightoniella leaf spot (Corynespora torulosa)
Queensland								
Tully *(incl. Kennedy)*	18	15	4	3	3	1		
Innisfail (Gordonvale to Mission Beach)	71	61	16	6	2	1		5
Atherton Tablelands	22	14	3	8	1		1	
Far North (Mossman to Lakeland)	10	6	2	3				2
Torres Strait Islands	1			1				
NSW (Coffs Harbour**)**	1						1	
Total	**123**	**95**	**25**	**21**	**6**	**2**	**2**	**7**

Table 4. Identification of fungal leaf samples received from Papua New Guinea and Timor Leste.

Country	Sample (no.)	Black Sigatoka (*Pseudocercospora fijiensis*)	Yellow Sigatoka (*Pseudocersospora musae*)	Banana freckle (*Phyllosticta* spp.)	Cordana leaf spot (*Neocordana musae*)	Black cross (*Phyllachora musae*)	Banana leaf speckle (*Mycosphaerella musae*)	Cladosporium speckle (*Metulocladosporiella musae*)
Timor-Leste	12		5	6	2	2	3	
Papua New Guinea	13	12		2	4	3	1	3
Total	**25**	**12**	**5**	**8**	**6**	**5**	**4**	**3**

Other common diseases identified include Cordana leaf spot, Black cross and the speckle diseases caused by *Mycosphaerella musae* and *Metulocladosporiella musae*. In addition to those listed in Table 4., other leaf diseases were identified at a low frequency. These included one record each of *Deightoniella torulosa* and rust caused by *Uredo musae* in PNG. From Timor Leste, two samples were identified with Malayan leaf spot (*Haplobasidion musae* – Figures 1-2) and Ramichloridium speckle and two with no known disease association. There was also one sample identified with *Uredo musae* (rust).

Figure 1. Fungal bearing structures are present on the under surface of leaf lesions

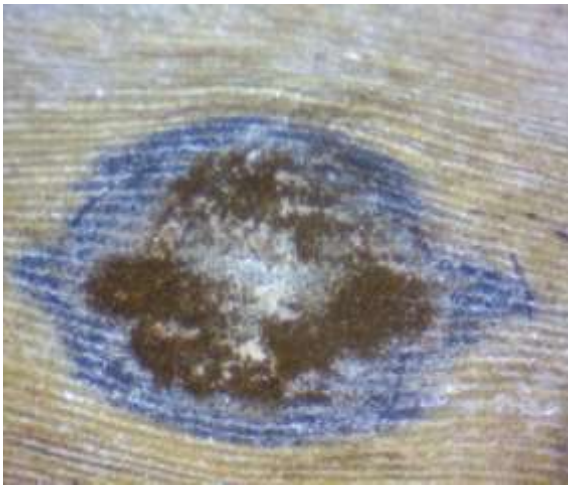
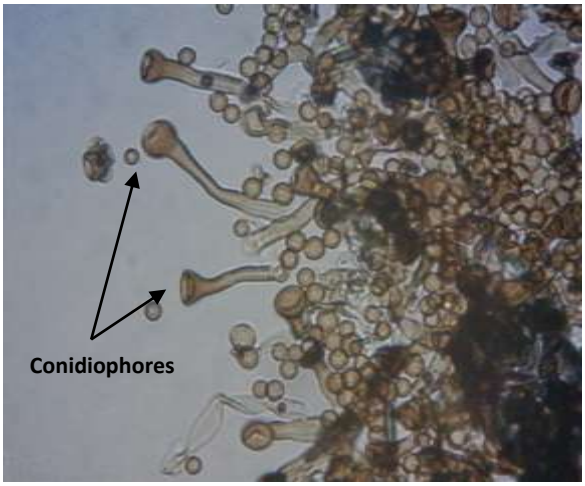


Figure 2. Close up of Haplobasidion musae with distinctive swollen spore bearing structures.



Fruit diseases and disorders

Most fruit samples (67) were received from north Queensland and three from northern NSW. Samples displayed superficial blemishes on the skin or symptoms consisted with speckle, Mokillo or large necrotic lesions leading to fruit splitting. In the last 2-3 years an influx of fruits with symptoms including unfilled or distorted fingers, pinched flower ends or enlarged flower scars (Figures 3-4) were also observed throughout north Queensland and to a limited extent in NSW. In some instances, the occurrence was only one or two fingers per hand (Mokillo), whereas in other cases all fingers in a hand or bunch exhibited the above external symptoms and in combination with internal discolouration (Figure 5). Varying levels of internal discolouration was observed, some symptoms were minor and only present at the flower end of the fruit (Figure 6). Severe symptoms were also evident in the fruit pulp, turning it blackish brown, hollowing of the seeded area of the fruit (Figure 7) and undeveloped locules. Samples were categorised based on symptoms, these included: distorted fingers with internal discolouration (Table 5), or other symptoms (e.g., crown rot, fruit speckle or soft rot).

Figure 3. Banana hand with obvious distorted finger

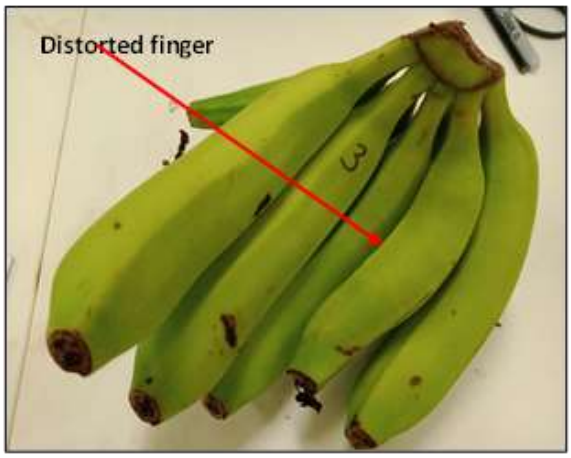


Figure 4. Unfilled finger with accentuated pinched flower end

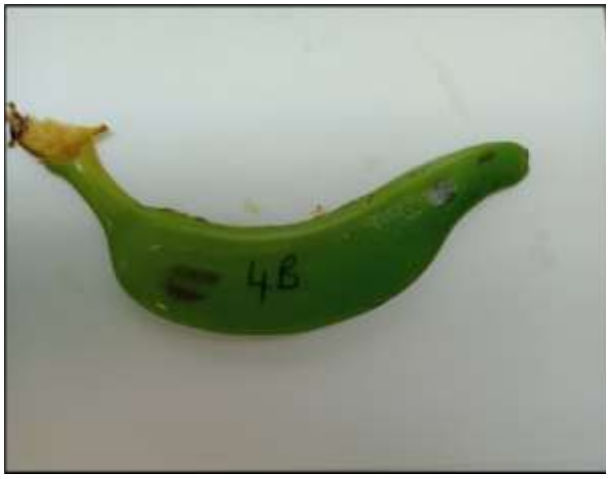


Figure 5. Minor discolouration of flesh at the flower end

Figure 6. Unfilled fruit with severe internal discolouration and formation of hollow cavity.

Figure 7. A banana hand with all cut fingers exhibiting internal discolouration

Table 5. Bacterial and fungal organisms associated with internal discolouration of fruit

Region	Samples	Distorted fingers/internal discolouration		
		Bacterial association	Fungal association	Cause not determined
Queensland				
Tully *(incl. Kennedy)*	2	*Dickeya chrysanthemi* (1) *		1
Innisfail (Gordonvale to Mission Beach)	16	*Klebsiella pneumoniae* ss *pneumoniae* (1) *Pseudomonas* sp. (1) *	*Fusarium* spp. (1) Miscellaneous fungi (1)	12
Atherton Tablelands	4		Miscellaneous fungi (1)	3
Far North (Mossman to Lakeland)	3			3
NSW	3	*Pantoea agglomerans* (1) * *P. dispersa* (1) *	Miscellaneous fungi (2)	1
Total	**28**	**5**	**5**	**20**

* Samples with Mokillo type symptoms.

Three samples were symptomatic of Mokillo from which several bacterial genera/species of Enterobacteriaceae family and *Pseudomonas* sp. have been recovered.

In other samples, internal discolouration symptoms are different from those above and with a higher incidence in hands or bunches. The recovery of bacteria (*Klebsiella* sp. and *Enterobacter* sp.) or fungal organisms has been infrequent, suggesting that there is no specific organism associated with these symptoms. A range of fungi have been associated with the symptoms (*Fusarium* spp., *Pestalotiopsis* sp., *Cladosporium* sp., *Musicillium theobromae*, *Curvularia* sp. and *Nigrospora* sp.), however the recovery has been inconsistent. Various opportunistic bacteria and fungi present in the banana production system can present under certain environmental conditions.

Due to the inconsistent recovery of bacteria or fungi associated with the internal discolouration, DNA extractions of tissue exhibiting a range of symptoms (mild to severe, as well as asymptomatic) was conducted and sent to AGRF for microbial profiling. The DNA extractions for fungal microbial profiling did not generate sufficient data and it is likely that the plant DNA interfered with the fungal amplification. Alternative methods could be used in future studies to determine if unculturable fungi are implicated.

The diversity profiling for bacteria generated excellent data. Bacteria from a total of 17 families were detected using both the primer sets V1-V3 and V3-V4. A high abundance of Cyanobacteriaceae (34-99%) was identified across all samples (including asymptomatic tissue) and in both primer sets. At the genera level, *Klebsiella* sp. was also present using both primer sets and ranged between 8-40%, together with *Enterobacter* sp. which had the highest detection using V1-V3 (8-20%), but only in two samples. Other bacteria genera were also identified including *Agrobacterium*, *Burkholderia, Dyella, Novosphingobium* and *Salinispora*, however, their abundance was low, ranging from 1-8% and in only 2 or 3 samples. Bacteria belonging to the families Pseudomonadaceae (< 0.01%), Rickettsiaceae (3-18%), as prevalent across all samples, this indicates these bacteria are not pathogenic, as the highest population was detected in the asymptomatic tissue. However, no previously identified bacterial pathogens were recovered from discoloured internal banana tissue.

Additional studies into the cause of the distortion and associated internal discolouration of fruit is required to understand how and when fruit become infected and to determine if symptoms are pest, disease or abiotic

initiated. Grower surveys of on-farm practices (bunch injections, bunch dusting, organic mulches and or change in pesticide use) will provide essential information and assist in resolving the issue.

Other fruit samples received include three with typical crown mould symptoms caused by *Fusarium* spp. from market agents. Seven samples were received with symptoms of fruit speckle from Tully (1), Lakeland Downs (2) and the Atherton Tablelands (4). Two fungal organisms (*Zasmidium musae* and *Cercospora* sp.) were consistently recovered from one sample from Lakeland Downs. In all other cases, no consistent fungal organisms were recovered, however, symptoms on one were suspected to be caused by flower thrips. Two samples from the Atherton Tablelands were received with water-soaked spots and a wet rot. Again, no fungal or bacterial organisms were associated with the spot symptoms, however the cause of the wet rot was attributed to the fungal organism *Rhizopus stolonifer,* as fruit were exposed to high field temperatures prior to harvest. Three additional samples were received from the wet tropical coast region with suspected symptoms of a bacterial soft rot. No fungal or bacterial organisms were recovered from one of the samples, however, *Dickeya* species were recovered from the other two samples. Three other samples received were considered as a genetic defect (1) or related to incorrect bell injection applications (2) as no fungal or bacterial organisms were recovered. Four samples from Innisfail and one received from NSW exhibited raised spots with longitudinal cracking, symptomatic of diamond spot. The causal organism (*Cercospora hayi)* does not produce identifying structures on plant material, therefore isolations were required to confirm if the pathogen is present. However, if symptoms are old, the recovery of the fungus is reduced, and in these cases *C. hayi* was not recovered.

Diseases associated with banana corm and pseudostem.

A range of corm and pseudostem samples (Table 6) were received for diagnostics and the identifications were either caused by bacterial or fungal organisms. The parentheses in Table 4 indicate the number of samples of the same cultivar or disease symptoms. The incidence of Panama disease (Race 1) on the Atherton Tablelands has increased in the last 2-3 years and is a major constraint to the commercial production of Lady Finger and Ducasse. Isolations and single spore cultures were conducted at the Mareeba Plant Pathology laboratory, before being sent to the Plant Biosecurity Laboratory (PBL) at ESP for both molecular and vegetative compatibility group (VCG) characterization of *Fusarium oxysporum* f.sp. *cubense*. Laboratory results concluded that three of the four samples from the Atherton Tablelands were confirmed with VCG0124, whereas one sample had a combination of two VCG's and was identified with VCG0124/5.

In addition to the Panama samples, a range of bacterial corm samples were also received. Historically, the organisms *Pectobacterium* and *Dickeya* have been reported as the main pathogens associated with bacterial corm rot (BCR) in north Queensland. In addition to *D. chrysanthemi,* two new species (D*. zeae* and *D. fangzhongdai)* have been found to cause pseudostem rot, corm rot and plant toppling, particularly in the Innisfail area. This finding showed the presence of more than one strain/pathovars of *D. chrysanthemi* in Australian banana growing area like previous BCR studies (Akeiw, 2001) and report of *Dickeya zeae* to cause severe banana soft rot disease in Guangdong Province of China, and the causative agent has been identified as a variant of *D. zeae*, formerly known as *Erwinia chrysanthemi* pv. *zeae* (Feng *et al*, 2019). A more detailed report on BCR can be found in Appendix 14.

In addition to the BCR associated bacteria, the environmental bacteria *Sphingobacterium thalpophilum (*syn *Flavobacterium* sp*.)* was recovered from NSW corm rot samples, however this organism is not regarded as primary or pathogenic. In typical corm rot symptoms, an obvious zone (black discoloration) is evident between healthy and infected tissues (Figure 8), this material has a less putrid smell compared to a sample with mixed infection of opportunistic or environmental bacteria. This was also reported by Akiew *et al*, 1998 in similar studies.

Table 6. Identification of causal organisms associated with corm and pseudostem rot of banana.

Location	Cultivar	Symptoms	Identification
Queensland			
Atherton Tablelands	Ducasse	Panama disease	Panama VCG0124 Race 1
	Lady Finger (5)	Panama disease (2) Panama disease (2) Root rot	Panama VCG0124 Race 1 Panama VCG0124/5 Race 1 Cultures not sent for VCG analysis
	Cavendish	Root rot and sudden death of tissue culture plants	Non-pathogenic *Fusarium oxysporum* recovered.
	Cavendish (2)	Plant roll-out	No bacteria or fungi recovered. Weevil borer damage evident.
	Cavendish	Death of cigar leaves	No bacteria or fungi recovered.
	Cavendish	Sheath rot, watery stem lesion	*Rahnella aquatilis*
Innisfail (Gordonvale to Mission Beach)	Cavendish (9)	Corm rot (4) Soft rot of corm (slight odour) Corm rot (no smell) Pseudostem soft rot Leaf and stem blight (tissue culture plants) Corm and pseudostem soft rot	No bacteria or fungi recovered *Dickeya zeae* *Dickeya fangzhongdai* *Pseudomonas* spp. *Acinetobacter baumani* and *Brucella sp.* *Dickeya zeae and D. fangzhongdai**
	Ducasse	Panama disease	Panama VCG0124 Race 1
New South Wales			
Duranbah	JV42.41 (1) High Noon (1)	Firm discolouration of corm	Panama VCG0124 Race 1
	Not disclosed	Firm discolouration of corm	Unidentified basidiomycete
Coffs Harbour	Unknown	Soft rot of corm with putrid smell	Environmental bacteria *(Sphingobacterium thalpophilum (*syn *Flavobacterium* sp.*)*

* Samples were also assessed for Banana Associated Wilt Phytoplasma (BWAP)

Samples from the Innisfail property that recovered *D. zeae* and *D fangzhongdai* were also excluded of Panama disease and BWAP.

Figure 8. Typical black margin at the outer edge of the bacterial infected zone.

Entomology diagnostics.

Several bunch pest samples were received for diagnostics at SJRF and include those listed below.

A new caterpillar, *Pyroderces* sp. commonly known as 'pink scavenger' (Figure 9 and 10) was identified in the Lakeland Downs area causing significant damage to banana fruit. Larvae were found to be feeding on the peel of fruit, resulting in an abrasion due to faeces remaining on the fruit.

Figure 9. Close up of pink scavenger adult.

Figure 10. Pink scavenger larva and feeding damage on banana fruit.

Three separate fruit samples from the wet tropical coast (Innisfail and Tully) were submitted with symptoms not unlike that of banana flower thrips. The identification was purely based on fruit symptoms as no adults, larvae or pupae of thrips were observed.

In addition to the bunch pests, samples of foliar pests were also received for identification. Field inspections of damage to cigar leaves on the Atherton Tablelands resulted in banana scab moth being the cause. This finding was unusual, as scab moth invariably causes damage to fruit rather than leaves. Other sites with similar damage were also reported, primarily on the cultivar Lady Finger. Molecular studies conducted are detailed in Appendix 15.

A total of seven samples were received with foliage damage caused by caterpillars (*Spodoptera litura*). These samples were submitted because of the Fall armyworm detection in 2020 and as growers became aware of this new incursion and had a heightened concern for caterpillar damage. All samples were from the wet tropical coast region.

A private consulting company conducting research trials at SJRF requested the identification of insects present on banana suckers, these were confirmed as the common banana aphid (*Pentalonia nigronervosa*).

Two additional samples of banana leaves were submitted and identified as damage caused by the swarming and leaf chewing beetle (*Rhyparida discopunctulata).*

Mite samples (2) were sent to a specialist for identification (Queensland Museum). One from glasshouse grown tissue culture plants was that of *Tetranychus ludeni* (vegetable spider mite) and the other was mites (*Proctolaelaps aurura)* commonly observed on banana weevil borer (BWB). These mites are commonly associated with rotting plant material, but they are also known to hitch hike on BWB.

Virology samples

Six domestic biosecurity samples were received: two banana samples from Rockhampton, one *Canna* sp. sample from Cairns, and a *Heliconia* sp. and *Alpinia* sp. sample from north Queensland. The banana samples were positive for BanMMV while the *Canna* sp. sample was infected with a potyvirus not known to infect banana. BBTV was not detected in either the *Heliconia* or *Alpinia* samples.

Four samples from a central Queensland property under investigation by the federal Department of Agriculture were indexed for endemic and exotic viruses. BanMMV was detected in one sample and bacilliform particles in another. One of the samples was positive for one of the five BSV species detected by the specific multiplex assay. Additional identification of this BSV species was not undertaken, however the sample has been retained for reference.

Four samples from a commercial property in Lakeland Downs exhibiting symptoms of distortion, chlorotic patches and leaf streaking were sent to ESP for virology diagnostics. Molecular and electron microscopy assessment did not detect any known banana viruses and symptoms were therefore attributed to an off-type in tissue culture plants.

Another diagnostic sample was received from north Queensland (Little Gem - a variant of Goldfinger), but no viruses were detected in this sample and the symptoms were also attributed to an off-type.

Forty-four samples were received from SJRF for virology assessment. Of 30 FLF-1/FHIA-18 samples, Banana streak OL virus (BSOLV) was detected in one FHIA-18 sample and Banana streak IM virus (BSIMV) was detected in FLF-1. BSOLV was detected in two samples of deformed fruit with black splotches from irradiated 'Goldfinger' plants. BSOLV was also detected in five symptomatic leaf and fruit samples of 'High Noon' plants (Figure 11). No virus was detected in five asymptomatic leaf and fruit samples of 'High Noon' plants tested for comparison. BSOLV was detected in a line of 'CIRAD-07' recently released from post-entry quarantine. No viruses were detected in one sample (unspecified Cavendish cultivar) and the symptoms were attributed to an off-type.

Two samples from a plant at Wamuran with Fusarium wilt Race 1 symptoms and suspect leaf streaking were received from ABGC BBTV inspectors, however, BBTV was not detected in either sample.

Forty-six *Musa acuminata* ssp*. malaccensis* samples were received from The University of Queensland ahead of export to research collaborators. No viruses were detected in 45 samples, however, CMV was detected in one.

Figure 11. BSOLV symptoms in fruit from ‘High Noon' plants.

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Appendix 19 – Fostering a cohesive plant protection RD&E program for the banana industry

Quarterly videoconferencing

Regular communication with project team members and other researchers working in banana plant protection underpinned the objective to foster a more cohesive RD&E program. One of the activities designed for this purpose was the instigation of a regular videoconferencing update on project activities to share research results, lessons learned and raise awareness of activities being undertaken in banana plant protection projects.

The quarterly videoconferences (QVC's) were held 3-4 times per year in a 1 hour webinar format that invited project team members from BA16001 and other projects to report on their activities and findings and answer questions from participants. Agenda items and presentations were canvassed amongst the banana RD&E network before each QVC, with a rotation of researchers reporting to try and ensure an equal opportunity for all participants.

Table 1. Record of QVCs conducted during BA16001

Date	Participation	Evaluation conducted
30/8/17	24	Yes
22/11/17	27	Yes
28/2/18	27	
24/5/18	29	Yes
27/9/18	21	
5/2/19	31	Yes
2/5/19	27	
29/8/19	17	
7/11/19	25	
12/2/20	21	
20/5/20	33	Yes
12/11/20	24	
3/2/21	29	
20/5/21	5 – Theme leaders	

The option to record the webinars and upload the file to the project SharePoint site meant that the content of all the QVCs was available for members of the banana R&D network to watch at their convenience if they could not participate on the day. Evaluation of the QVCs was undertaken at regular intervals to track progress against its objective of improving cohesion and communication within the network of R&D providers and improving knowledge of plant protection R&D activities. The evaluation results show that the QVCs were successful in achieving these objectives with:

- From 93-100% of respondents across sequential years indicating that the QVCs had contributed very strongly to bringing the project team together to share knowledge and information (Table XX).
- From 97-100% of respondents across sequential years indicating that participating in the QVCs improved their understanding of project activities (Table XX)
- A range of 45-83% of respondents across sequential years indicating that participating in the QVCs helped them achieve their project outcomes (Table XX)

Table 2. Evaluation results for the QVCs

As a result of participating in QVCs you have a better understanding of the activities being undertaken in the project (% of respondents)			
	May 2018 (n=19)	**Feb 2019 (n=20)**	**May 2020 (n=29)**
Strongly agree	63	35	48
Agree	32	65	52
Neutral	5	0	0
Disagree	0	0	0
Strongly disagree	0	0	0
To what degree do you think the QVCs have brought together the project team to share information and knowledge? (% of respondents)			
	May 2018 (n=19)	**Feb 2019 (n=21)**	**May 2020 (n=29)**
Excellent	63	24	24
Very good	37	48	59
Good	0	24	10
Fair	0	5	7
Poor	0	0	0
The information presented in the QVC has assisted you in achieving your project outcomes (5 of respondents)			
	May 2018 (n=19)	**Feb 2019 (n=20)**	**May 2020 (n=28)**
Strongly agree	21	0	24
Agree	26	45	59
Neutral	47	45	10
Disagree	0	10	7
Strongly disagree	0	0	0
Overall, how would you rate the QVCs? (% of respondents)			
	May 2018 (n=19)	**Feb 2019 (n=20)**	**May 2020 (n=30)**
Excellent	-	20	33
Very good	-	60	43
Good	-	20	20
Fair	-	0	0
Poor	-	0	3

Project SharePoint site

To facilitate access to key project documents, resources and materials the project developed an electronic repository that could be accessed by project team members and other key project stakeholders (by invitation). A SharePoint site was established to help manage project content across all project team members in all themes (including project members of BA16005) and the site was accessible from anywhere at any time irrespective of organisational affiliation.

The site was structured with a folder for each theme where team members (irrespective of which theme they are working on) could easily locate, share and collectively work on documents. The site contained a newsfeed section so that attention could be drawn to newly added documents or relevant industry information highlighted. A team contact list was established in the site so that everyone could access contact details, including the respective themes for each team member. A collective communications and extension activities spreadsheet was also uploaded to the site so that team members could progressively add details about their communication activities.

Each theme leader received one-on-one advice on using the site with the opportunity to provide feedback before being rolled out to the whole project team. Team members were given an overview of the site during the November 2017 video conference as well as receiving instructions via email on how to login and use the site.

Evaluation of the overall usage of the SharePoint site remained roughly static with 42 and 46% of respondents reporting that they had accessed the sites during the project Table XX.

Table 3. Evaluation of usage of the project SharePoint site

Have you accessed the project SharePoint site? (% of respondents)		
	Feb 2019 (n=20)	May 2020 (n=30)
Yes	42	46
No	58	54

Banana Scientific Symposia

The other key activity designed to achieve a more cohesive RD&E program was a biennial workshop for Australian banana researchers. These symposia were planned to provide a scientific forum for the exchange of ideas between R&D providers and other key stakeholders such as biosecurity agencies, funding agencies and industry organisation representatives. The symposia were also designed to encourage interaction and networking through facilitated problem solving and networking activities integrated into the program. Banana producers were not included in the workshops to avoid the need to pitch presentations and activities to both scientific and producer audiences.

The project plan proposed 2 workshops between the Australian Banana Industry Congress and the Banana Industry Roadshows organised by the National Banana Development and Extension project (BA16007/BA19004). Two Banana Scientific Symposia were held during the project in November 2018 and April 2021. The second symposium was originally planned for November 2020 but was delayed due to COVID-19 restrictions on travel and group gatherings. The 2021 symposium included on-line participation and presentation to help overcome the travel restrictions and assist remote participation, as well as facilitating the remote involvement of a keynote international speaker. Participation in both symposia was excellent with 55 attendees from 8 agencies/institutions in 2018, increasing to 82 participants (60 in person and 22 on-line) from 11 agencies/institutions in 2021.

Evaluation was undertaken for both events to measure progress in achieving the objectives of improved networking, communication, knowledge of R&D activities and collaboration, with results showing significant achievement of these. A detailed report for each symposium including evaluation, is presented below.

Banana Scientific Symposium 2018 Report

Introduction

The Australian banana industry is well supported by banana researchers from various government agencies, universities and service providers around Australia. Interaction, collaboration and the exchange of ideas between researchers and industry stakeholders is key to having a successful RD&E program to support the Australian banana industry. Theme 5 within the improved plant protection for the banana industry project (BA16001) has a focus on activities which foster a more cohesive RD&E program. To continue to foster this cohesive research environment the first Banana Scientific Symposium was held to bring together Australian banana researchers and industry stakeholders across all industry, government and university funded projects and research areas. The 2 day event (27th-28th November 2018) held in Cairns was strategically planned to offer the opportunity for researchers to share their work and learnings, facilitate interaction and networking, initiate potential future collaboration and encourage forward thinking.

Planning process & setting the agenda

Offering attendees of the Banana Scientific Symposium an interactive event which was more than just sharing PowerPoint presentations that really engaged attendees and encouraged networking drove the ideas around setting the location and format of the event. The venue and room in which the event was held (Trinity room at the Shangri-La) was carefully selected to facilitate a round table (cabaret) arrangement, big enough to facilitate activities which require attendees to move around the room but also small enough to keep the attendees together and not too spread out. The room also had natural lighting and although not an essential feature was preferred as it is anecdotally known to combat zoning out and sleepiness which may assist with concentration levels with complex science-based topics.

The first step in the planning process was to establish a comprehensive contact list of researchers and other interested stakeholders involved in Banana RD & E. This was achieved through the planning teams extensive contacts, completing an inventory of those involved in industry funded projects and with close liaison with Australian Banana Growers R & D Manager Rosie Godwin. Using this contact list the potential attendees were invited via e-mail to submit 150 word abstracts answering two main questions: What is the impact or objective of your specific research area for the banana industry? and how is your research aims to achieve this? From this process 27 researchers were selected to present their work with the aid of PowerPoint in a 15 minute time slot allowing an additional 5 minutes for questions (See agenda). To go beyond the typical 'stand and deliver' method employed at conference style events several other methods were employed to facilitate networking and discussion. These methods can be grouped into three areas:

- Facilitated networking
- Scenario planning activity
- Marketplace activity

Facilitated networking

Small networking techniques and activities were scatted throughout the 2-day agenda. Firstly when attendees arrived at the symposium they were given a lanyard with a name tag which on the reverse side listed a series of numbers, corresponding to the tables they were nominated to sit at. Throughout the event attendees shifted four times to different tables. After each 'table shift' a short 5 minute icebreaker style activity was conducted to facilitate networking amongst those at each table. These activities were as follows:

- Map of world travel – Each table was supplied with an A3 laminated world map and several coloured stars. Each person at the table was asked to nominate the most interesting place they had travelled to for work, then discuss why they had travelled to that location and what made it interesting. Each table then nominated the most interesting person's work travel and this was shared with all the attendees.
- Something in common – Each table was tasked with finding the most interesting thing they have in common (e.g. all have seen Panama disease firsthand). Each table then shared their most interesting thing in common with all the attendees.
- Chinese whispers via mime – Attendees at each table stand in a straight line with their backs to the presenter except the first person who faces the presenter. The presenter then shows a series of actions (e.g. pipette then place plate into plate reader, press start etc.). The first person in the line then taps the next person in their team on the shoulder and repeats the action. This person shows the next

person like Chinese whispers until the final person who then shows all the attendees. This activity emphasises the importance of clear and concise communication.

- Trivia Quiz – Throughout both days a series of questions based on the presentations are formulated and using Poll everywhere via and iPad on each table the questions are asked and each table works as a team. The poll everywhere program displays the leader board and results live and is nice light way to recap on some of the work presented at the symposium.

Scenario Planning

As the name suggests this activity which was conducted at the end of the first day posed potential scenario's to participants and required them to discuss potential theoretical solutions as a group to one of two industry doomsday style scenarios termed "Bananageddon". Half of the round tables (4) were given the "The green monster" scenario and the other half (3) were given the "A new plague on your house" scenario. These scenarios, the process and the steps for the activity are detailed in the table below. The scenario planning session ran for a total of one hour. Each table was given 45 minutes to discuss the scenario and asked to capture the key elements on A0 size sheets of paper. Once the groups had discussed their respective scenario a spokesperson from each table summarised and shared the key aspects of their discussion with all of the attendees.

Ideas' marketplace

Inspiration for this session was taken from the open space forum activity format. At the beginning of the symposium attendees were introduced to the concept of this session and encouraged to nominate topics that they want to explore, concepts they would like to develop or knowledge they would like to gain on a whiteboard at the back of the room. This was encouraged throughout the event and even prompted when there was a lot of questions and discussion following a presentation. This process resulted in 4 topic areas forming the marketplace:

- Land use for farms affected by Panama disease tropical race r (convened by Jim Pekin)
- Phytoplasma (convened by Andre Drenth)
- Foc inoculum management (convened by Jay Anderson)
- Fruit quality assessments – including sensory and consumer acceptance (convened by Katie Ferro and Soumi Paul Mukhopadhyay)

Each topic was assigned to a separate physical area within the venue and attendees could then choose which topic they would like to contribute to. Attendees could move between topics if they wanted to listen or contribute to multiple topics. This process culminated in each of the four convenors summarising the respective discussions to the rest of the attendees and also noting down key points and further actions/recommendations in a summary sheet which was distributed to the attendees following the event.

Background to both scenario's		
The year is 2024 and the Australian banana industry continues to provide the only source of fresh bananas for Australian consumers. The industry is still mostly based in the tropics of Queensland but the continuing spread of Fusarium wilt TR4 in the coastal wet tropics and tablelands regions has resulted in banana production starting in a range of non-traditional regions like the dry tropics (Ayr-Sarina), gulf catchments (Georgetown/Gilbert River) and Cape York Peninsula (Lakeland Downs, Hopevale/Starke). The growers in these new regions are a mix of new entrants to the banana industry and existing producers that have moved or expanded.		
Scenario 1: "The green monster"	**Process**	**Activity**
The Government of the day has embraced a series of recommendations to reduce production impacts on the environment, improve the health and safety of farm workers and maintain the safety of fresh produce for consumers by: – Banning/deregistering a range of pesticides used in bananas ▪ all neonicotinyl insecticides ▪ all organophosphate insecticides ▪ all dithiocarbamate fungicides ▪ chlorothalonil fungicide ▪ all nematicides ▪ most herbicides – paraquat, diquat, glyphosate, glufosinate-ammonium only allowed under strict conditions – Banning the aerial application of all pesticides – Regulating and licencing nitrogen and phosphorus inputs and sediment management practices for all catchments fronting the Great Barrier Reef	The group has been called in by the National Banana Growers Association and Horticulture Industry Research and Development to develop a research, development and extension plan to help the industry to adapt to the reality of a production system with fewer available nutrient and pesticide inputs, spread across a broader range of environments than ever before.	Each member of the group briefly discuss the implications for crop production from your professional perspective of these changes. As a group, identify and discuss: • the R&D work you believe is required to transition the industry from the current production system to a new low-input model • Make sure you consider how to integrate the R&D components to maximise impact and minimise duplication. • As a group, identify how to communicate/demonstrate the new production systems to facilitate adoption of the new research results

Scenario 2: "A new plague on your house"	Process	Activity
Some of the new banana production in the coastal dry tropics from Ayr to Sarina is starting to experience some concerning symptoms, an unfamiliar malady referred to as Banana Necrotic Canopy Syndrome (BNCS). Individual plants lose vigour, with the leaf canopy rapidly dying and the plant/stool following suit. Some plants recover but most do not and the timeframe from first symptoms to death of the stool can be as rapid as 4 months. Within blocks the spread of the conditions is quite rapid, starting as individual plants but becoming clumps of multiple plants within 12-18 months. Worryingly the BNCS has apparently moved as much as 5-10 km to previously unaffected farms within a region. Interestingly not all banana varieties seem to be equally affected with Ducasse bananas in backyards and along creek banks not showing any symptoms despite being relatively common.	The group has been called in by the National Banana Growers Association and Horticulture Industry Research and Development to develop a research, development and extension plan to identify the cause of this new problem and develop effective eradication or management practices.	As a group, identify and discuss: • The range of R&D work you believe is required to identify the cause, distribution and mechanism of spread for this new problem. • Consider how you would integrate the R&D components to maximise impact and minimise duplication • As a group, identify how to communicate/demonstrate your R&D plan and its results to banana growers in affected areas and elsewhere, the NBGA, government regulatory bodies and other key industry stakeholders

Evaluation

The Banana Scientific Symposium which was held in cairns on the 27th – 28th November 2018 was attended by 55 participants from 8 different RD&E providers – DAF, NTDPIR, NSW DPI, DAWR (NAQS), ABGC, QAAFI, UQ and JCU. With the objective of running this event being to facilitate interaction and networking, initiating collaboration and exchange of ideas a three-pronged approach was taken to evaluate the success of the Banana Scientific symposium. Qualitative and quantitative evaluation was conducted using three approaches:

- Real-time evaluation using Turningpoint™ – quantitative
- Network matrix assessment - quantitative
- Follow up Survey Monkey Survey – qualitative

Real-time evaluation using Turningpoint™ – Quantitative

Turningpoint™ which is an electronic polling system was used to ask attendees at the at the completion of the Banana scientific symposium a series of questions to both evaluate the impact of the event and also identify areas for improvement for the anticipated event to be held in 2020. Table 2 details all the questions which were asked and the respective percentages for the responses. Overall, from this survey attendees where very positive about the symposium with 98% indicating they had gained new contacts, and 100% said their knowledge of banana R&D activities benefited from attending the symposium. 98% indicated they would attend again and 100% said they would recommend the event to others. On a scale of 1-5 (1 being lowest and 5 being highest) 97% ranked the symposium a 4 or 5.

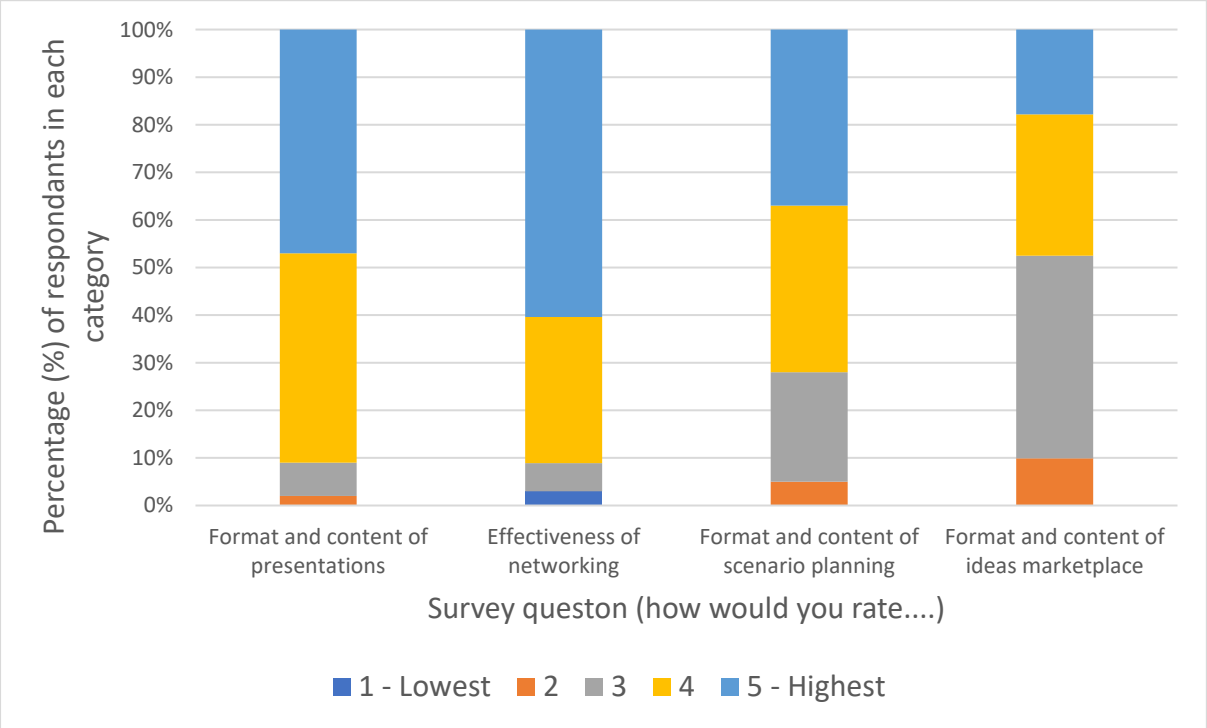
Although attendees weren't asked to compare the elements of the agenda the responses relating to the format and content of the presentations, effectiveness of the networking activities, format and content of the scenario planning, and the format and content of the ideas marketplace activity are compared in Figure 1. The format and content of the presentations and effectiveness of the networking received the most amount of 4 or 5 rankings (1 being lowest and 5 being highest). Not too far behind and overall very good ratings was the scenario planning where 72% of attendees rated it that session a 4 or 5/5. The Ideas market place session had 42% of attendees rate it a 4 or 5/5 however time was very limited for this session and comments from the qualitative feedback using survey monkey indicated that this was the downfall of this session and that they did like the session but wanted more time for discussion.

Table 4. Evaluation from the TurningPoint™ survey questions asked at the completion of the Banana Scientific Symposium

Evaluation question	Answer option	Percentage (%)
Have you gained new contacts from attending this symposium	Yes	98
	No	3
Have you identified any new research concepts you could contribute to from attending this symposium?	Yes	86
	No	14
Have you identified any communication or extension opportunities from attending this symposium?	Yes	56
	No	44
Has your knowledge of the banana R&D activities benefited from attending the symposium?	Yes	100
	No	0
How much has your knowledge of banana R&D activities benefited from attending the symposium?	1 – Lowest	2
	2	0
	3	26
	4	43
	5 - Highest	28
How would you rate the format and content of the presentations?	1 – Lowest	0
	2	2

	3	7
	4	44
	5 - Highest	47
How would you rate the effectiveness of the networking activities?	1 – Lowest	3
	2	0
	3	6
	4	31
	5 - Highest	61
How would you rate the format and content of the scenario planning?	1 – Lowest	0
	2	5
	3	23
	4	35
	5 - Highest	37
How would you rate the format and content of the Ideas Marketplace activity?	1 – Lowest	0
	2	10
	3	43
	4	30
	5 - Highest	18
How appropriate was the venue for the symposium activities?	1 – Lowest	0
	2	0
	3	10
	4	38
	5 - Highest	52
How appropriate was the catering?	1 – Lowest	0
	2	12
	3	19
	4	40
	5 - Highest	30
Would you attend this event again?	Yes	94
	No	6
Would you recommend attending this event to other people?	Yes	100
	No	0
How would you rate this event overall?	1 – Lowest	0
	2	0
	3	3
	4	41
	5 - Highest	56

Figure 1. Comparison of responses relating to the format and content of different elements of the agenda



Network matrix assessment – quantitative

Attendees were given a network evaluation form to complete at the beginning of the symposium which was then completed again at the end of the event which asked them to rate how well they knew each individual in attendance on a scale of 1-4 (1 – not really, 2 – well, 3 – quite well, 4 – very well). Figure 2 is an example excerpt of a completed network evaluation form. This exercise was designed to measure the level of networking by the attendees over the 2-day event.

Fifty of the participants who attended both days completed the network analysis tables. Figure 3 shows the number of ratings in each of the four categories at the beginning and end of the symposium. The overall number of relationships rated as 'not really' dropped by 56.7% and the number of 'very well' ratings increased by 18.6%. Across all the ratings 1417 resulted in no change however 703 (33.2%) indicated a positive change as a result of attending (Table 3). Nearly 50% of these changes (350) occur as shift from a rating of 1 (not really) to a 2 (well) which is expected given it was only a two day event.

Figure 2. Excerpt of a completed network evaluation form

Tuesday 27/11/18

Attendee	How well do you know your fellow participants?			
	Very well (I have worked with them previously)	**Quite well** (I have spoken with them previously)	**Well** (I know them well enough to say hello)	**Not really** (I don't really know them)
Attendee 1		✓		
Attendee 2			✓	
Attendee 3				✓

Wednesday 28/11/18

Attendee	How well do you know your fellow participants?

Figure 3. Comparison of ratings in each of the four categories at the beginning and end of the symposium

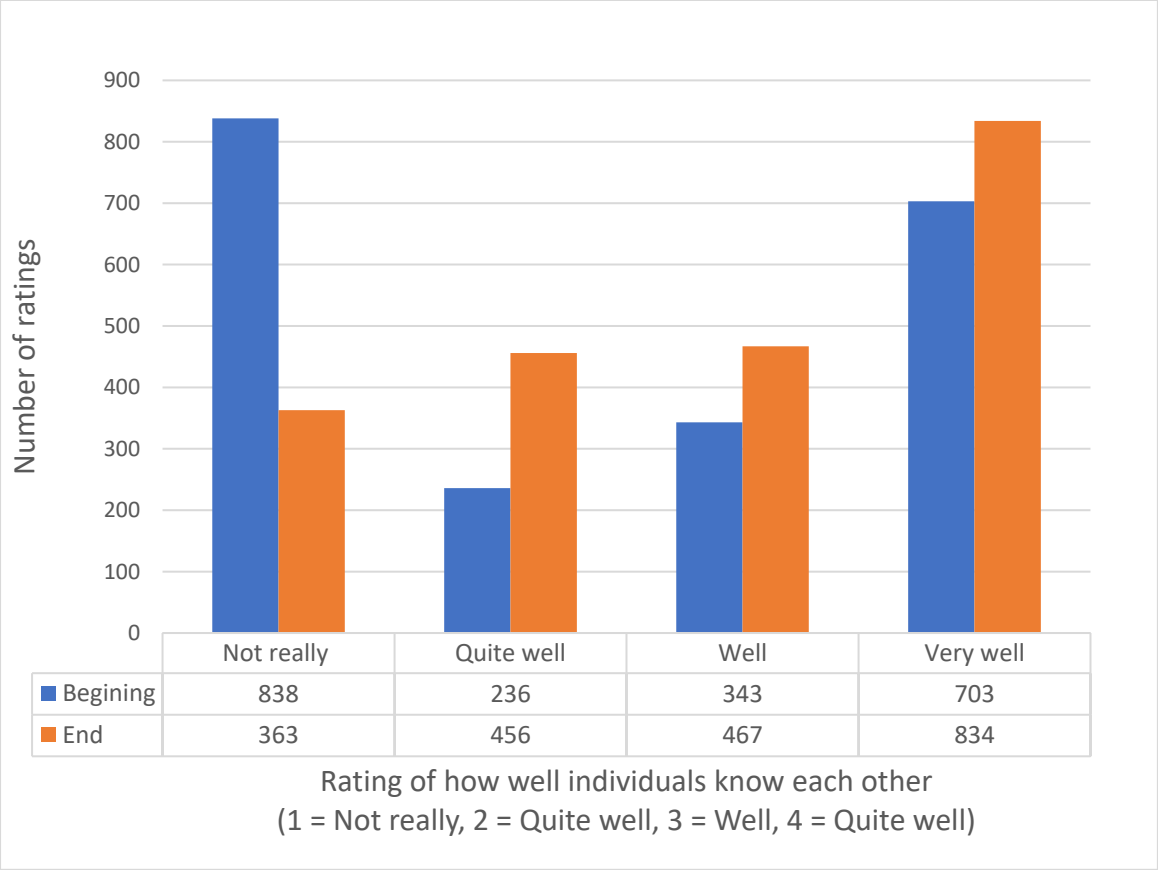


Table 5. Number of changes of ratings indicated by attendees comparing before and after ratings of each attendees' connections (rating scale 1 – not really 2 - well, 3 – quite well, 4 – very well)

Change	Number (Count)
No Change (0)	1417
+1	556
+2	136
+3	11
Total positive changes	703

Another way to view the data from this network analysis is by heatmaps colour coding to represent different values. The heatmaps in Figure 3 show the scores at the beginning of the workshop compared to after the workshop The attendees are ordered by institution and therefore it might be expected to see red (quite well) near the diagonal. The vertical axis is the person completing the form and the horizontal axis is the person being scored. The white horizontal rows are the people who did not return the evaluation form. There is a large amount of red squared indicating closer relationships in the bottom left-hand corner which are predominantly staff affiliated with DAF in north Queensland and ABGC. There are a few dark rows which correspond to DAWR (NAQS) and a newer NSW DPI project member who have not been well connected into banana RD&E previously. Comparing the two heatmaps there is notably less black (not really rating) and more yellow, red and blue ratings on the after heatmap compared to the before heatmap. Overall, this shows that there was an increase in the number of connections and improved connections overall within the group of attendees.

Network graphs are another way to visualise the connections between attendees of the Banana Scientific Symposium. These complex graphs show link between every participant in each of the rating categories (Figure 4). The size of the node (orange circles with attendees initial) is relative to the number of links relating to each of the participants. When comparing the rating 1 connections the before graph is very busy demonstrating that there were lots attendees who didn't know each other well. Compared to the after graph for the rating 1 and there were significantly fewer attendees who indicated that they still didn't know other attendees well following the event. The opposite pattern when comparing the before and after for ratings 2 and 3 is observed as attendees have noted that they have increased ratings from either 1 to 2, 1 to 3 or 2 to 3. Observing the size of the nodes there are some notable shifts for some participants. Soumi Mukhopadhyay (SMu), Sandy Perkins (SP) and Joanna Kristofferson (JK) were the least connected (largest nodes) at the beginning of event (Rating 1) however the size of their nodes decreased in the after graph of rating 1 demonstrating major shifts from ratings 1-2 both given out and given to these participants. At the other end of the scale the most connected person in the rating 4 graphs both before and after the symposium was Tony Pattison.

Figure 4. Visual heatmap representation of ratings given by the attendees to each respective attendee before and after the Banana Scientific Symposium.

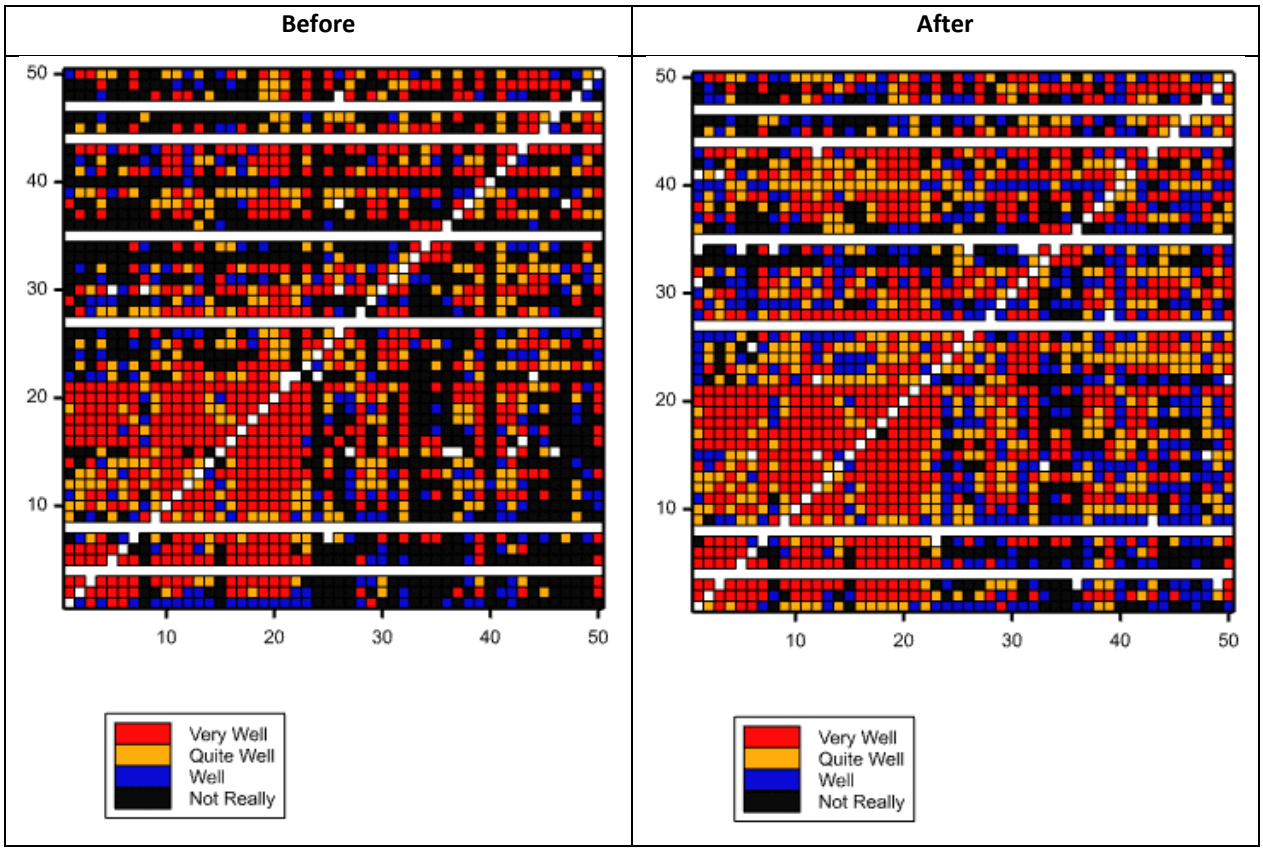
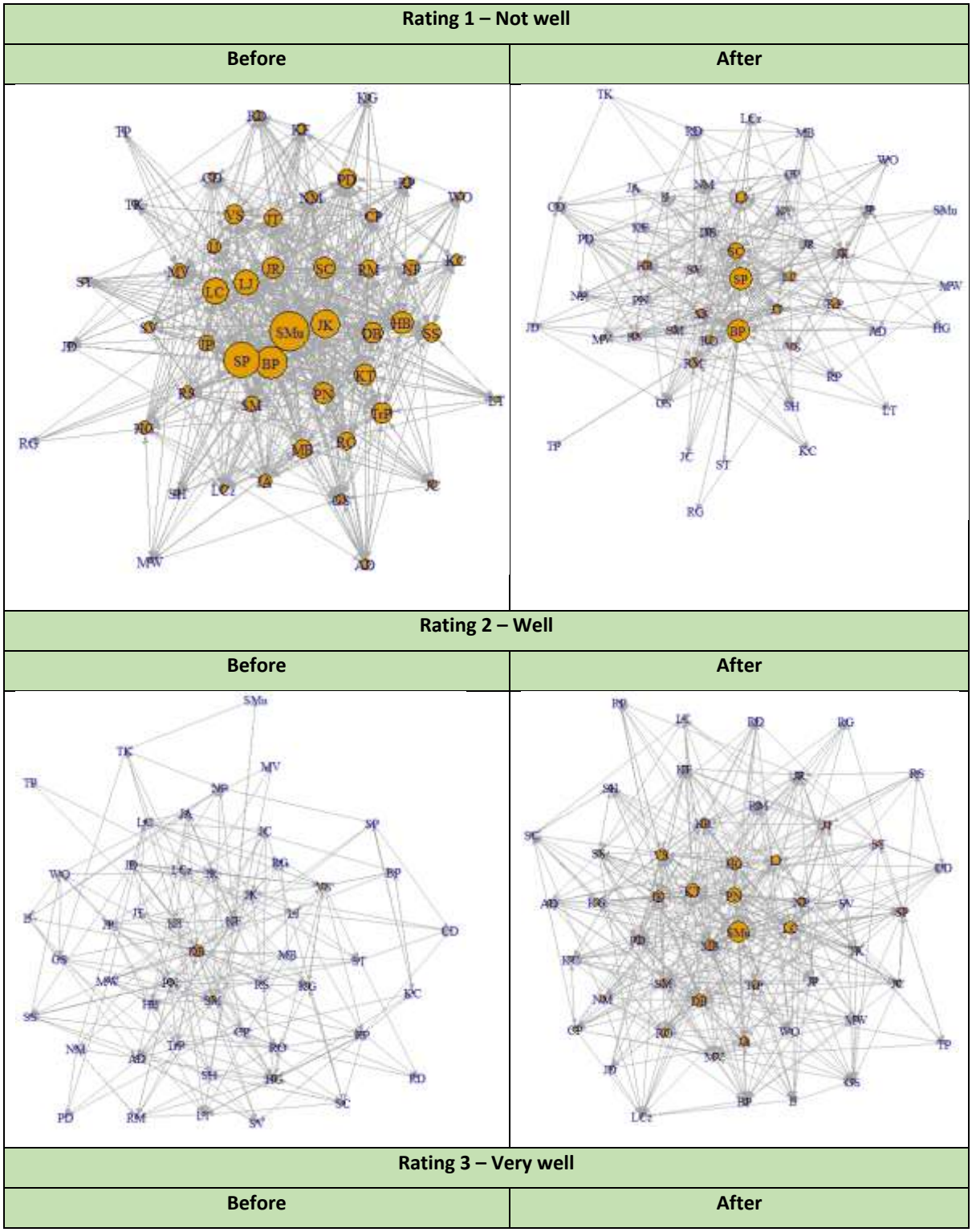
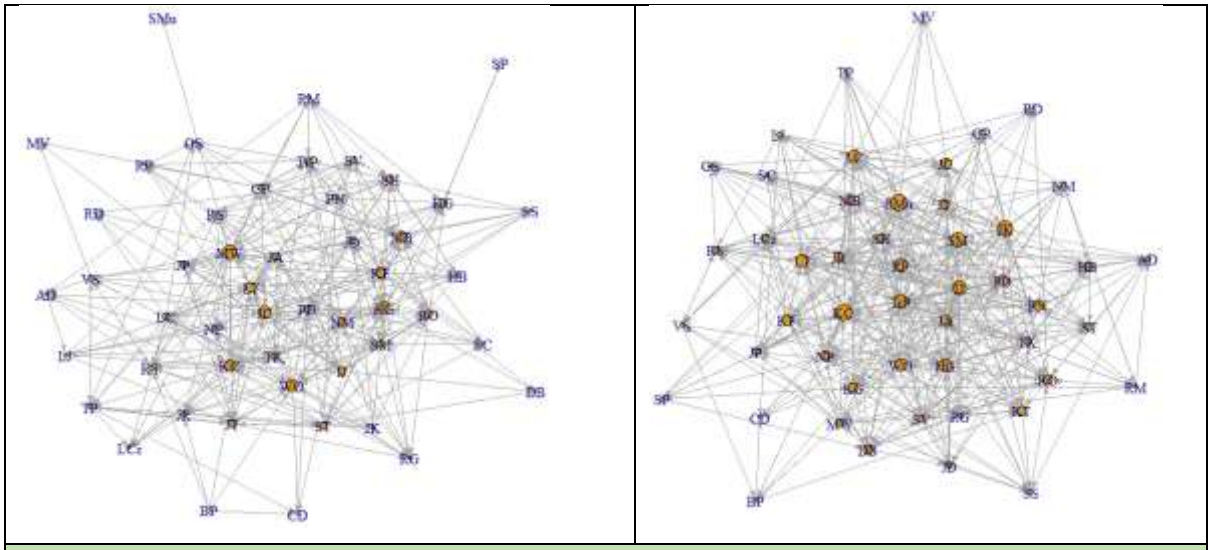
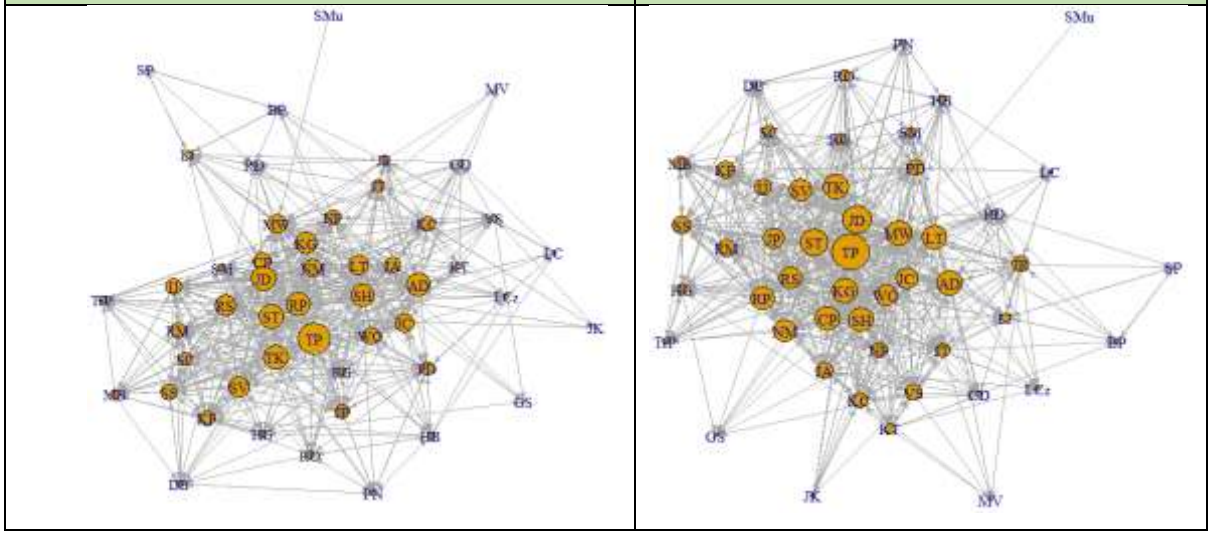


Figure 5. Network graphs showing connections in each rating category (1 – Not well, 2 – Well, 3 – Very well 4 – Quite well) before and after the Banana Scientific Symposium.





Rating 4 – Quite well	
Before	**After**



Follow up Survey Monkey Survey – qualitative

Data captured at the symposium was quantitative and in order to give attendees the opportunity to provide qualitative feedback short survey was sent to all attendees via Survey Monkey. The survey consisted of five open ended questions:

- What worked well?
- What needed more work?
- What was missing?
- What outputs (if any) would you like to receive from the symposium.
- Please let us know if you have any other suggestions, feedback, and/or comments about the symposium.

The voluntary feedback questions were completed by 14 of the attendees and their responses are detailed in Table 6. Overall, the comments, feedback and suggestions were very positive with many comments commending the organisation, format and nature of the facilitated networking activities. There was constructive feedback mostly around the time of the open space forum on the last day which unfortunately was unavoidable however will be taken into account for similar future events. As a result of the suggestions in response to the question surrounding what outputs attendees would like to receive attendees a table with all the attendees and their contact details and a collated copy of the abstracts were e-mailed to all attendees.

Table 6. Responses from the Survey Monkey feedback

What worked well?
• Table activities, format of Symposium, good mix of presentations, networking. • Changing tables and activities at beginning of sessions was a great initiative. Thought the use of technology to capture feedback was excellent - much easier & quicker than via paper. Plus being able to see results on screen was useful. Overall timing was really good. Enjoyed the content of the symposium and the moderator & workshop co-ordinators were terrific. • Bringing everyone together to share what they are working on. The networking opportunities. Breaking up the day with games and activities • ran on time went away with a good feeling good venue scenario exercise moving around tables learning about others- fun exercise including trivia sense of team/cooperation getting my cast off • The format was good, having all the researchers together in one place created a positive feeling that has been missing in banana R&D • The interactive activities before each session were great 'ice-breakers' and also a good way re-engage people after breaks etc. • Keeping people to time (mostly), mixing the tables worked really well. The games kept energy high, pretty good location. Positive attitude and clear information leading up to symposium • The ice breaker activities to start each session. Nominating which table we sat at to maximise mixing/networking. Excellent set of talks and a really positive, collegiate atmosphere. Inclusive, regardless of organisation or subspecialty. Meeting ran to time, with ample time for most activities. • People management engagement activities • The timing, food and team building activities were great. I also thought the sayings on the back of the table cards were a nice touch • The strict timing. The group activities which broke up the day and energised/inspired the group. I really thought it was a high quality symposium and was well organised and run • Table swapping method and table activities • Small number of participants that allowed the networking activities to work • The relatively short presentations and how they were grouped.
What needed more work?
• Some presentations were a bit too technical and a bit 'chicken chicken'. This is probably unavoidable for a scientific symposium. • Really liked the idea of the final workshop sessions. A real shame that we ran out of time • Not a lot. Everything seemed to run like clockwork. • More time for discussion I suppose but would have to cut down on number of speakers/or time allocated good to be prepared earlier and allow for overseas speakers as suggested in my email from earlier in the year - particularly seeking keynotes from them and perhaps some from the Australian team. Don't just confine it to what people are currently doing but include looking into the future/& review and synthesis presentations • Timing. Researchers need to learn to stick to time. We ran out of time in breaks because of this • It felt a little rushed at the end. • A way to not run out of time at the end - difficult because the discussion groups around the marketplace were really good. But - then it might mean sacrificing some of the time from the talks - a tricky one. • I would have liked more time for the final "open forum" activity, and perhaps more explanation at the start of the meeting so workshops could have been better understood ahead of time. • Distribution of invitations to wider groups • It would be good to have more guidance on what content to put into the presentations, particularly as this was the first time this happened it was hard to judge the amount of context to set with presentations and how to tie them together. • time allocated to last activity • I would have liked more time at the end for the final activity with discussions around 'hot topics' • Some of the presentations.

What was missing?
• Nil • Grower representation. I would have liked the opportunity to hear their ideas on or for R&D. Or heard their feedback or questions generated from the talks. It may have been good to offer a couple of spots to the local university to send along students. • As someone who doesn't have a lot of knowledge on genetics, some background information would have been appreciated for the presentations on these topics. However, I'm not sure how this would be achieved quickly and in the context of a 15-minute presentation • People complaining • Maybe a second social event. It was difficult to catch up with everyone during the symposium • A summary of the work from people who weren't presenting - any quick way of doing that? Just to know what the link of some people were to bananas • Talks from our NAQS colleagues. Maybe, grower representatives? • A message from grower's perspective to feedback to scientists are they doing well? Are they missing something? Would they like more effort in a certain area. • Information on what funding would be coming up in the future for banana related research. As much as encouraging collaboration is important without funding and an understanding of what research Hort Innovation wants done it may never come to be. Perhaps a presentation to start off the session by Hort Innovation and associated funding bodies about what the current projects are and what objectives and funding and priorities look like in the next one to three years. • Hort Innovations representative and other funding bodies reps, TR4 biosecurity monitoring presentations • nothing I can think of • Tony's fish and Richard's mobile • a prize for the best/ most promising presenter.
What outputs (if any) would you like to receive from the symposium.
• Abstracts, contact details of presenters so that they can be contacted for further information. • Abstracts, activity notes and access to presentations if possible. And attendee contacts. • Contact list of attendees (with a photo so we can put faces to names) with brief abstract or blurb of what they are working on. • we didn't get to see a report back to the meeting on the final activity due to time constraints for travellers perhaps a summation of vibes/survey monkey results • PDFs of presentations on Sharepoint or similar • Distribution of abstracts would be good and the notes from the discussion. I also like where conferences provide the names and contact email of the participants. Possibly this could be done with a 30 words or less what your banana work is? • Abstract and notes from the open forum (final activity). • Abstracts would be good. Perhaps a trickle of info back so the legacy is longer. 1 abstract per week? Action points in a fun way? • Summaries of the group activities and presenters abstract and contact details • Names, headshot and affiliation of all participants Abstracts of talks • Notes or summary of major talking points Areas of interest that featured in the meeting and some sort of overall analysis e.g. things we know a lot about from the talks, what gaps do we have in our current knowledge that need filling. • The abstracts and contact details of attendees.
Please let us know if you have any other suggestions, feedback, and/or comments about the symposium.
• Excellent event and would attend future symposiums. Great job Banana team! • The chairs weren't that great if you could feedback to the venue please. Can't think of much else at the moment. • Congratulations to you all for organising a very successful event. The symposium is a great idea and I look forward to (hopefully) attending the next one. Thank you!

- Nice job - pulled it off very well. Very much better of course than is typical of research-oriented staff. I didn't think the bar function downstairs worked wonderfully both in terms of seating and some aspects of food (no fish for Tony?/cold chips .....), bit noisy.
- I'm not a big fan of the icebreakers. I feel they take up valuable time
- I thought it was well run, with sufficient time for networking and social interaction during the breaks/at the dinner to assist in forming new relationships and discuss work in a less 'formal' way
- Great work! Except I have come home with more work.... ;-)
- This was the best meeting I have been to in a very long time. Bravo and thank you to the organisers.
- Overall very good
- As a presenter I prefer to have control of my presentation via a mouse and have the laptop in front of me while presenting so there is no need to look at the screen
- It was great- a lot of effort obviously went into organising it, and it paid off- a good combination of info sharing and facilitated networking
- I liked the networking activities. Perhaps some sort of grower representation or involvement to get them interested in what is happening in banana research?
- The symposium was well run with interesting speakers and topics.

Recommendations

The first banana scientific symposium was successful in achieving the outcome of offering attendees the opportunity to share their work and learnings, facilitating interaction and networking, initiating potential future collaboration and encouraging forward thinking. Within theme 5 of the improved plant protection for the banana industry project (BA16001) there is capacity to host the second banana scientific symposium in 2020. Recommendations to improve on the first banana scientific symposium have been derived from analysing of the evaluation, comments and suggestions from constructive feedback and the learning from organising and facilitating the event.

Attendees: Although invitations were extended, due to time conflicts there was little representation from funding organisations. Invitations could be sent further in advance to secure potential attendance by these representatives. Invitations were not extended to growers due to the nature of the content on the agenda being quite complex and also creating an open environment for researchers to freely discuss work in progress. The time of banana growers is very valuable to them given the nature of their farming operations and already conflicting commitments, therefore the benefit of their potential attendance should be carefully considered. However, at future events inviting a selection of grower representatives or SIAP members could be considered.

Location: Majority of banana researchers are located in either north Queensland or southeast Queensland therefore logistically to save on travel costs future symposiums should alternate between these locations. Holding the first symposium off-site in Cairns was beneficial as most north Queenslanders also stayed overnight in Cairns which accommodated more time for networking. There are other benefits beyond the additional time to holding these style events off site including: attendees being more focused, less distracted, less likely to attend part days etc. For these reasons for the 2020 symposium a venue within a couple of hours of Brisbane could be considered. As mentioned previously careful consideration for the conference room should be taken to ensure it is of appropriate size to facilitate the agenda, estimated number of attendees and preferentially have some natural light.

***Timing and agenda*:** The first banana symposium was a two day event with the second day finishing at 3pm to allow attendees to catch flights home that same day. Although this worked well, general feedback was that some activities were a little rushed (e.g. ideas marketplace) and that a longer event (e.g. 2 full days or 2.5 days). There was also a suggestion from attendees that an additional 'social' evening would have been beneficial and a slightly longer agenda would more easily facilitate this. Given there was such positive feedback with the event overall, and attendees could see the value in giving up their time to attend, it is likely that a slightly longer would be supported.

In terms of the agenda, the mix of presentations, short networking activities and longer strategic style activities (e.g. scenario planning and ideas marketplace) was very popular among the attendees. The agenda of the 2020 event should lend itself to a similar format of using a mix of activities in amongst the presentations to

facilitate networking and foster future, forward thinking. New and innovative methods of facilitating networking and sharing learnings should be explored and implemented into the agenda where appropriate. The novel timing method which was used to keep presenters to time (clock ticking noises and gongs) kept most presenters to time, however reminding presenters of the importance of keeping to their allocated time would still remain important.

Evaluation: Implementing an evaluation plan from the onset would again be an important attribute for the 2020 symposium. Not only to determine the level of success of the event but similar to these recommendations determine areas what worked well as well as what improvements can be made for similar future events. If a similar process for the network matrix assessment was to occur some minor changes to the data capture table could be made to increase the level of accuracy of the data captured. Similarly, methods should be considered to capture qualitative feedback at the event itself.

2018

Banana Scientific Symposium

27 & 28 November
Cairns

Day 1 – Tuesday 27 November 2018

9.00 am — Program starts

Welcome, overview of the symposium — *Stewart Lindsay*

Strengthening the banana industry diagnostic capacity — *Andre Drenth*

Banana blood disease – a pathogen on the move — *Jane Ray*

PCR based diagnostics of fusarium wilt of bananas targeting secreted in Xylem genes — *Lilia C. Carvalhais*

Morning tea

Development of new diagnostic antibodies for banana bunchy top virus — *Megan Vance*

Diagnostics – Eyes to the future — *Kathy Grice*

Novel viruses detected during quarantine screening of banana germplasm — *Kathy Crew & Visnja Steele*

Molecular markers for resistance, localisation studies using GFP-transformed Foc and SIX gene analysis – studies to inform on ground control of Fusarium wilt — *Jay Anderson*

Providing evidence that banana tissue culture plantlets are free from Fusarium Wilt — *Sharon Hamill*

Access to banana varieties with improved pest, disease and agronomic traits — *Jeff Daniells*

Lunch

Goldfinger and Mutagenesis, where to from here? — *Massimo Bianco & Katelyn Ferro*

Subtropical banana variety evaluation trial — *Matt Weinert*

Understanding the cause of fruit quality downgrades on farm and post ripening in the subtropical banana industry — *Matt Weinert*

Afternoon tea

What sensory attributes are important for Australian Cavendish bananas? — *Soumi Paul Mukhopadhyay*

Containing and managing banana bunchy top virus — *John Thomas*

Banana bunchy top virus in non-banana hosts in French Polynesia — *Kathy Crew*

Discussion/workshop session

5.00 pm — Program finish

Day 2 – Wednesday 28 November 2018

8.00 am - Program starts

Reflection and summary of day 1 — *Stewart Lindsay*

Banana plant and soil microbiomes — *Paul Dennis*

Soil abiotic characteristics driving suppression of Panama disease — *Ryan Orr*

Application of soil qPCR assay to monitor TR4 levels in Northern Territory trials — *Lucy Tran-Nguyen*

Nitrogen application rate alters microbial functional dynamics and suppressiveness of banana soil to Fusarium wilt — *Hazel Gaza*

Banana production corresponding to changes in ground cover and nitrogen application rates — *Tony Pattison*

Morning tea

Understanding Tropical Race 4 in a bunching plant — *Elizabeth Czislowski*

Alternative hosts of Panama disease — *Wayne O'Neill*

Alternative hosts of Panama disease in the Northern Territory — *Sharl Mintoff*

Plant-parasitic nematodes in banana production areas of Australia — *Jenny Cobon*

Lucid key - a selection tool for rotation crop selection for nematode management — *Kathy Thomson*

Banana bunch protection and emerging entomological issues — *Richard Piper*

Mapping banana productivity — *Trevor Parker*

On the right track — Tackling bagging machine damage to ground cover — *Dale Bennett*

Lunch

Discussion/workshop session

3.00 pm - Program finish

Banana Scientific Symposium 2021 – Summary and evaluation results

Introduction

The Australian banana industry is well supported by banana researchers from a range of public agencies and institutions although many of these providers are geographically separated and often working in separate research projects. Within BA16001 a key focus for Theme 5 was to promote a collaborative and cohesive RD&E program through a program of activities to improve networking, communication and collaboration within the Australian banana RD&E community. The objective for this was to improve RD&E outcomes for the Australian banana industry through a more interconnected and cooperative program in plant protection.

One of the major activities conducted for this purpose was the biennial Banana Scientific Symposium (BSS), an event to bring together Australian banana researchers, funding agencies and key industry stakeholders to share their work, facilitate interaction and networking and encourage collaboration and consideration of future RD&E needs for the banana industry. The second BSS was held as a two day event in Brisbane on 20th – 21st April 2021, delayed from the original October 2020 timing due to restrictions associated with COVID-19.

Planning and developing the agenda and activities

Building on the success of the first BSS, the BSS 2021 continued to refine the processes and activities deployed in 2018 to ensure an interactive event that shared work activities and results to improve knowledge of plant protection RD&E while engaging and encouraging attendees in networking and collaborative problem solving.

Underpinning this process was the room layout which provided for "cabaret" style seating with 7-8 people per table. The project team used a coded lanyard system to allocate attendees to tables with the intention of mixing institutions and work groups at each table, with the makeup of each table group changing from day 1 to day 2. The foundation of the symposium agenda was 10 minute presentations on research topics grouped in sessions based on the themes:

- Integrated pest and disease management
- Diagnostics and virus research
- Variety and consumer research
- Panama disease research
- Banana microbiomes and management of Fusarium wilt – a programmed approach
- Other banana research

Each session was chaired by a member of the organising project team to introduce the sessions and their speakers as well as manage timing and questions.

A range of facilitated networking and collaborative problem-solving activities based around the table groups complemented the program of presentations, either in the breaks between sessions or as full afternoon sessions. Staging the facilitated group sessions in the afternoon was designed to overcome fatigue and the slump in participant attention in the periods after lunch.

COVID-19 restrictions on domestic travel for some locations meant that the capacity to present and listen to other presentations on-line was also included in BSS2021. To enable the smooth functioning of on-line presentations the project team contracted a professional audio-visual business, and this was a significant contribution to the successful integration into the programme. This capacity also allowed the BSS2021 to include an on-line keynote international speaker for the first time, presenting to both the in-person and on-line participants in an evening session on day 1.

An evaluation plan was developed in concert with the development of the activities program and agenda. It was designed to test the achievement of the stated objectives for BSS2021. Evaluation activities at the event were paper based and included assessing networking impacts, changes in knowledge of research activities and outcomes, daily reflections of key learnings as well as assessment of participant satisfaction. An on-line survey of all participants was conducted soon after the symposium to collect addition data and feedback.

Overlaying all of these activities was the need to implement COVID safe practices to protect participants and comply with Queensland Government health regulations.

10-minute presentations

Presentations were derived through an invitation to all prospective participants to submit a 150 word abstract of their work, answering 2 main questions:

- What is the impact or objective of your specific research area for the banana industry?
- How is your research aiming to achieve this?

From this process 36 abstracts were submitted for consideration and selected for presentation at the symposium. This represented an increase of 33% from the numbers submitted in 2018 (27), and the abstracts (with the authors' permission) were collated and presented in a booklet to all participants. Each session was followed by question and answer panel of all the presenters managed by the session chairperson.

The programme also included an international keynote speaker for the first time. Dr Phillipe Tixier of CIRAD (France) joined the symposium via MS Teams in an evening session on Tuesday 20th April (5.30 – 6.30 pm). Dr Tixier presented an overview of CIRAD's work in integrated pest and disease RD&E in bananas titled *"Agroecological Banana Cropping Systems: the case of the French West Indies – a 25 years retrospective"* followed by a facilitated question and answer period.

Facilitated networking activities

As stated previously the mixing of staff from different institutions and project teams on each day at the table groups was implemented to introduce researchers that may not necessarily interact in their normal professional circles. A series of simple, fun "ice breaker" activities were used during the symposium to maximise the interaction at the table and in the broader group of attendees. These activities were:

- *"Who's your Homies?"* – this quick and simple activity was conducted at the start of the first day and was designed to help table group members get to know each other better. It asked each table group to decide on a name for their group by selecting 3 words from 3 lists provided by the organising team, and arranging them in any order, which each table then shared with the whole audience. This activity was also run with the on-line participants as an on-line group.
- "*What's your Homies' theme song?"* – this activity followed on from the initial group "ice breaker" during a break between sessions in the late morning of the first day. Table groups were asked to spend 5 minutes in discussion and decide on a theme song that represented their group, considering common interests and activities of group members. A spokesperson from each table then shared their theme song with the whole symposium with a narrative around the group name, the theme song and the rationale behind its choice. This activity was also run with the on-line participants as an on-line group.
- *"Find your pair"* – this activity ran over both days of the symposium and was designed to improve interaction and networking by participants attending the venue. Each participant was issued with a lanyard with a single word printed on the back of the name tag that is commonly associated with another word eg salt and pepper, nuts and bolts. Working within rules that stipulated what questions could be asked and information revealed, participants had to find the other person within the whole group that had their matching word. When participants identified their pair, they recorded both their names and submitted into a draw for small prize.
- *"Who am I?"* – this activity was conducted just prior to lunch on the second day and was designed to test how much participants had got to know their fellow attendees. A series of interesting and obscure facts about a single participant were presented to the symposium and the other participants had to guess who the identity of the mystery symposium member.

Collaborative group activities

Two larger group activities were conducted in the BSS2021 programme in the afternoon sessions of each day. The objective for these activities was to improve networking and collaboration through group-based problem solving focusing on "real world" professional and banana industry issues.

- *"The Solution Room"* – the afternoon session on the first day was titled "The Solution Room" and was designed to provide peer-supported advice for priority issues identified by the members of the table-based groups. In the table groups of 6 people, members spent a short amount of time (3 mins) to think of a challenge/issue/question they were facing in their work. Taking turns in 7-minute cycles each group

member presents their problem to the other members to discuss and "brainstorm" solutions. At the completion of the activity, one spokesperson for each table group shared a summary/overview of the issues addressed.

- *"Life's a Pitch"* – the afternoon session on the second day was titled "Life's a Pitch" and was designed to encourage collaboration, problem solving and communication with multi-disciplinary groups of 6-7 people. Groups were presented with a list of banana industry priority issues identified during the industry consultation activity undertaken by the national banana extension and development project in 2020/21. Having selected an issue each group then spent 40 minutes working up innovative project/research concepts to address their selected issue. Each group then pitched their concept in front of the full symposium group to a panel of 3 research managers (Nick Macleod – DAF, Irene Kernot – ACIAR, Rosie Godwin – ABGC), who voted for the 3 best concept pitches. Adding to the interactivity the panel responded to each "pitch" by asking clarifying questions or commenting about issues such as collaboration, methodology, funding, industry impact.

<u>*Evaluation*</u>

Assessment of the success of BSS2021 in achieving its stated objectives using a range of quantitative and qualitative questions and activities was undertaken during and at the completion of the event, and through a follow-up electronic survey of participants. Participation in the event was excellent with 82 participants (59 in-person and 23 on-line) from 10 different organisations – DAF, NT DITT, NSW DPI, QAAFI, UQ, ABGC, ACIAR, Horticulture Innovation, SCU and USC – representing a 49% increase in participant numbers (55), and a 25% increase in participating organisations (8) from the 2018 symposium.

Evaluation of participant networking

A network matrix assessment was conducted with all attendees as was conducted in 2018 with attendees given a network evaluation form to fill in at the beginning of the event, and then complete at the end. The assessment asked participants to rank how well they knew each individual in attendance on a scale of 1-4 (1 – not really, 2 – quite well, 3 – well, 4 – very well). This evaluation technique was designed to measure the change in familiarity for each participant with all their fellow participants as a result of attending the BSS2021 and participating in organised and informal networking. Fifty-three participants completed the network matrix assessment at the completion of the BSS2021.

Figure 6. Comparison of the number of ratings of how well individuals know each other at the start and completion of the BSS2021

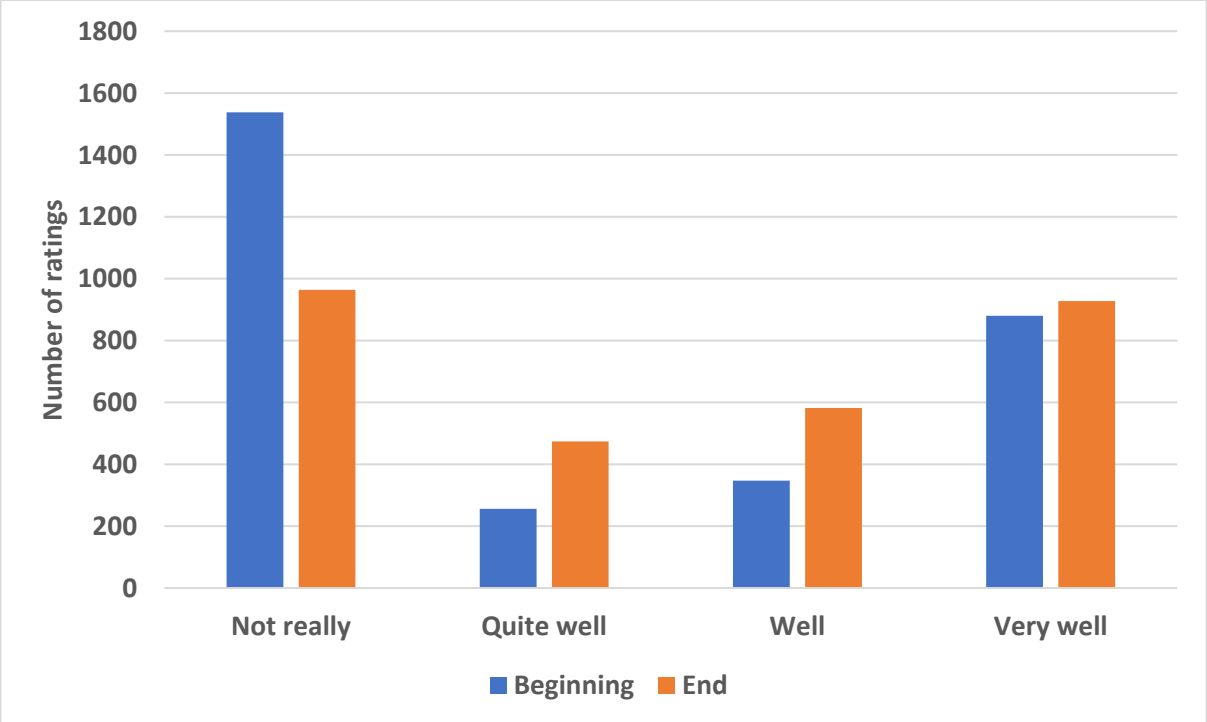
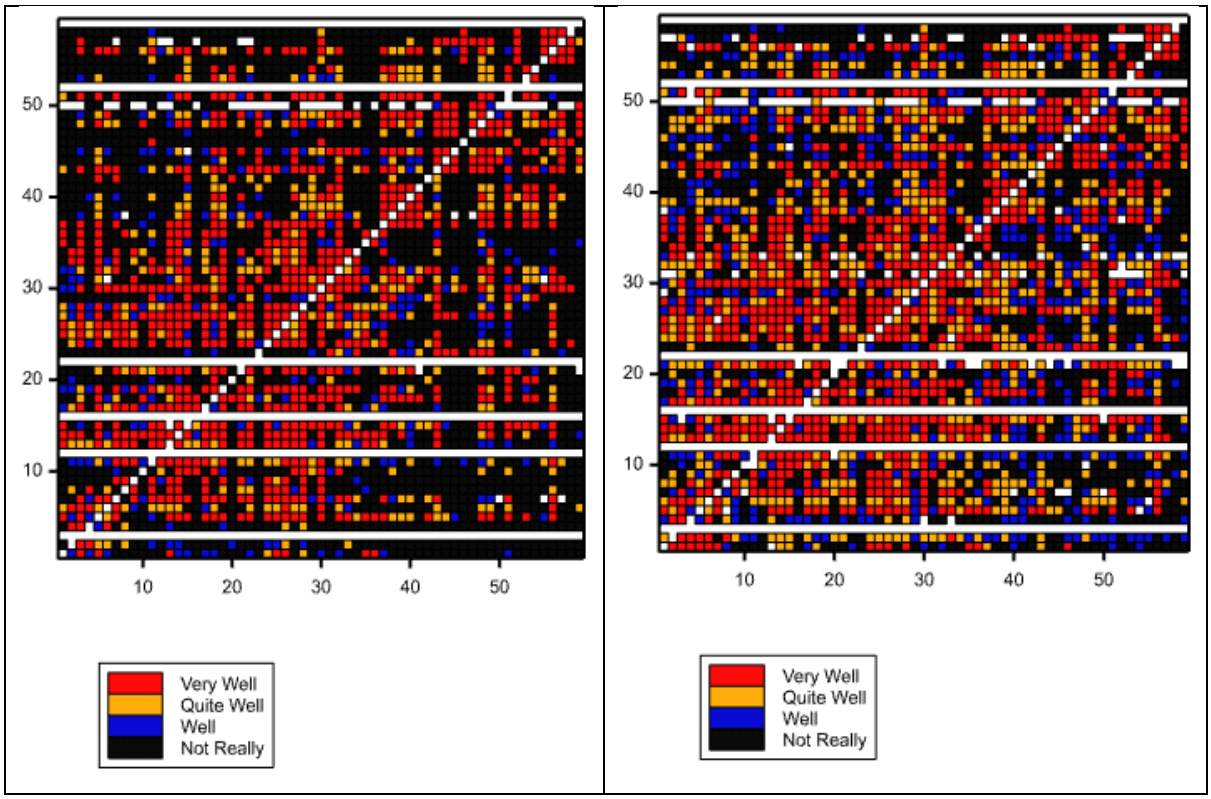


Figure 6 shows the number of ratings in each category at the beginning and end of the symposium. The total number of “Not really” ratings reduced by 37% (1538 to 964) between the beginning and end of the symposium, with consequent increases of 85%, 68% and 5.5% in the ratings of “Quite well”, “Well” and “Very well” respectively. These data reflect the improvements in networking and familiarity achieved across the participant group as a result of the BSS2021. This is corroborated by the response in the general evaluation question that showed 100% of participants had made new contacts by attending the symposium (Table 7).

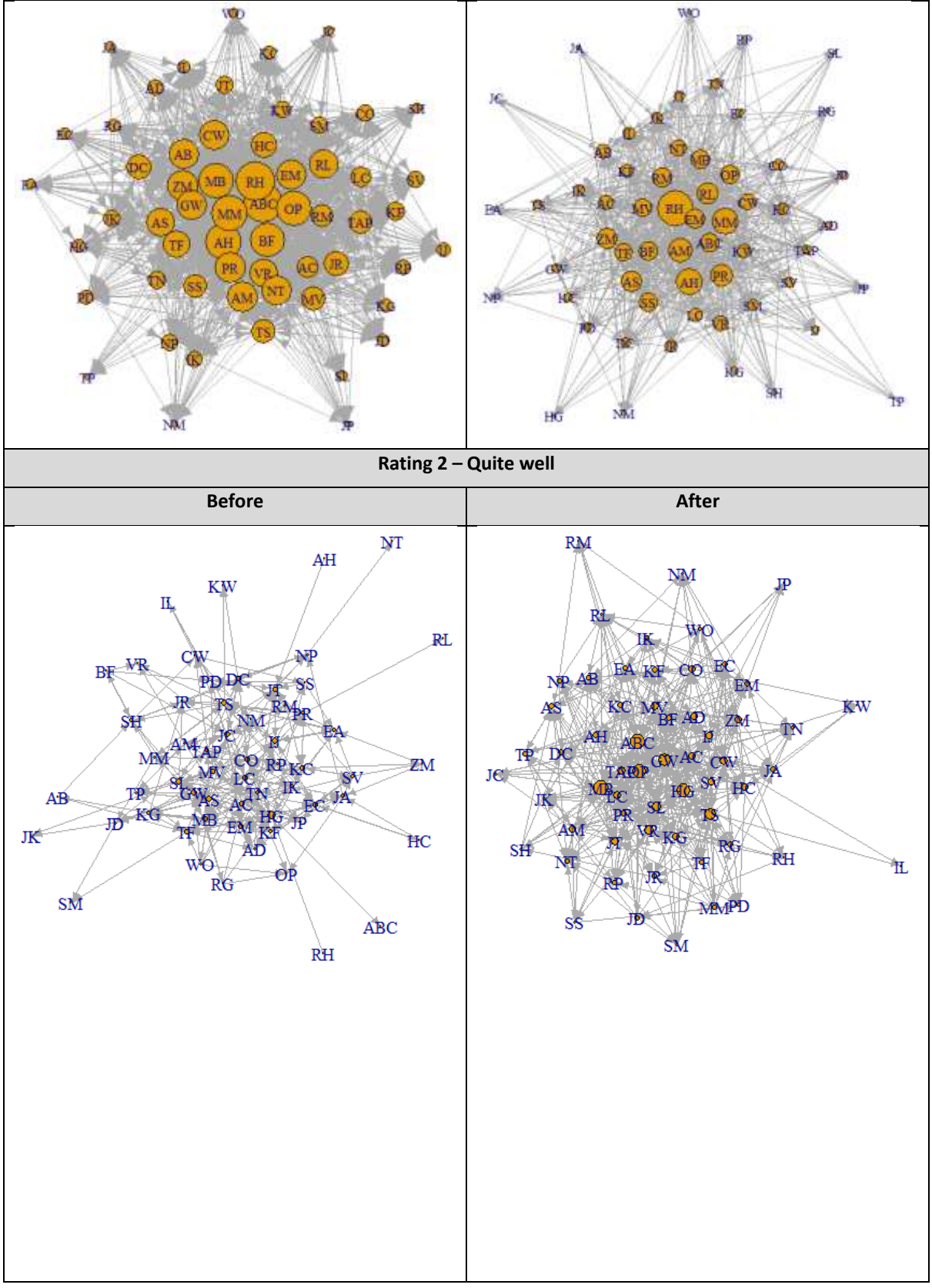
A simple way of viewing the data graphically is using heatmaps. The heatmaps in Figure 7 show the scores at the beginning (left) and after the symposium (right). The vertical access is the person completing the form and the horizontal access is the person being scored. The participants are ordered by affiliated institution therefore it might be expected to see more groups of red squares (highest rating) along the diagonal. The white horizontal rows are people that did not return the evaluation form. There are visually fewer black squares (rating = “Not really”) in the graph on the right representing the post event assessment compared to the pre-event assessment on the left, particularly the top left and bottom right regions of the graphs. This demonstrates an improved level of networking between different organisations.

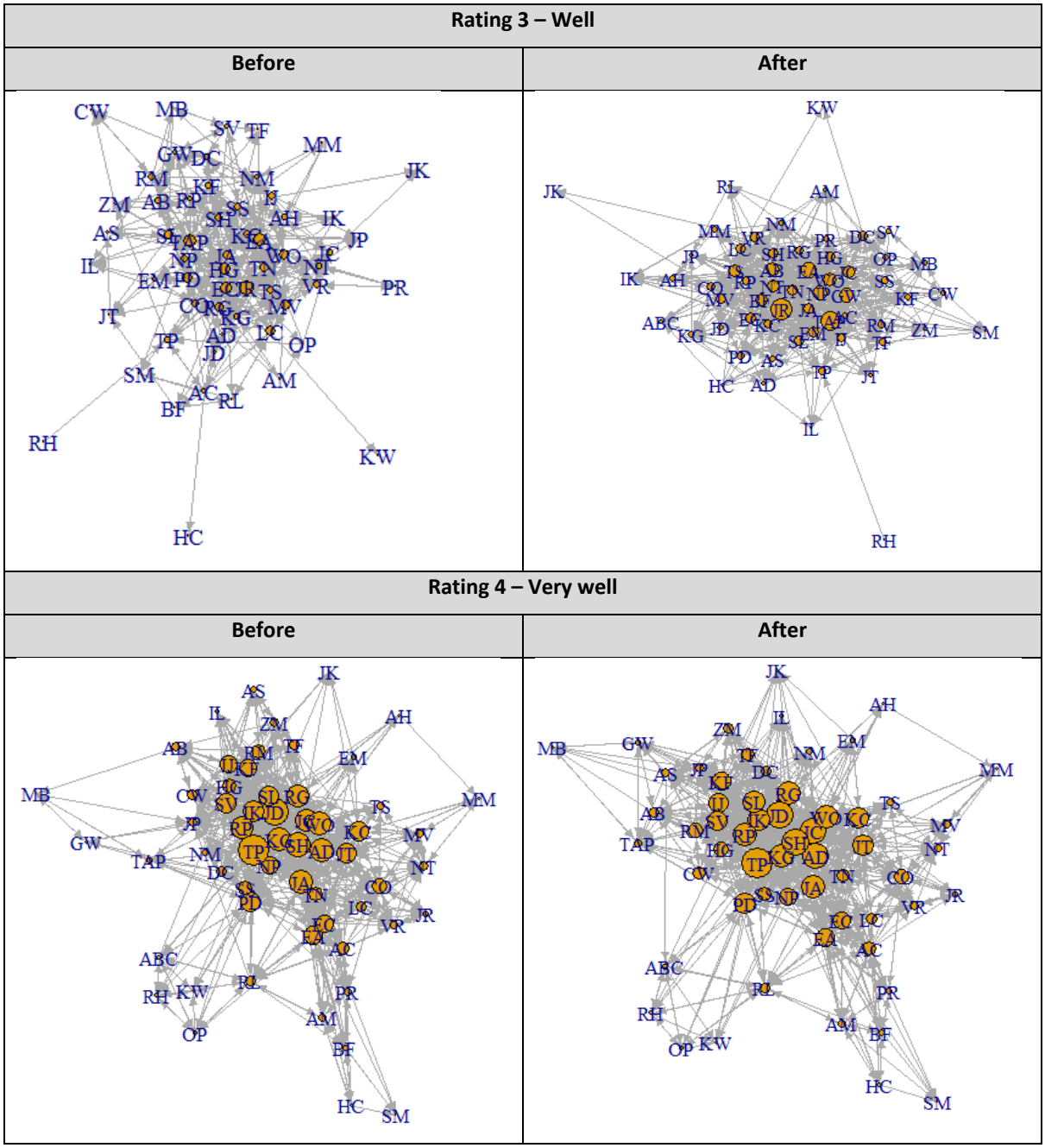
Figure 7. A graphical representation of changes in familiarity ratings between the beginning and end of the BSS2021 using heatmaps



Network graphs are another method of visually representing the strength of linkages between individuals attending the BSS2021 (Figure 8). These complex graphs show links between each participant for each rating category, and the size of the node (orange circle with participants’ initials) is relative to the number of links to each of the other participants. Comparing the network graph for rating 1 connections between the beginning and the end of the symposium, there is a significant reduction in the size of the nodes and the complexity, reflecting an improvement in networking amongst the participants that resulted in less rating 1 being awarded at the end of event. There was a significant increase in the complexity of linkages and size of nodes for ratings 2 and 3 at the end of the symposium, reflecting the improved familiarity as a result of the interactions at the event. Overall, the rating 4 network graph changed only slightly, with an additional 48 of these ratings being awarded at the end of the symposium.

Figure 8. Network graphs indicating changes each familiarity rating between the beginning and end of the symposium





Evaluation of impacts on knowledge and attitudes

A paper-based survey was used at the completion of the event to assess impacts on the knowledge and attitudes of participants with regard to banana plant protection R&D activities, and opportunities for improved collaboration. In the 2018 symposium this assessment was conducted using the Turningpoint™ electronic polling system, however at the BSS2021 the COVID-safe plan and increased numbers of participants made this impractical. Participants were asked to respond to questions around changes in their knowledge of R&D activities, identification of new collaboration opportunities and project ideas as well as questions about the value of individual elements and activities and an overall rating of the symposium. Questions about the value and impact of the international presenter were overlooked in the assessment at the event, resulting in additional questions being posed on-line to participants after the event. The questions posed in this questionnaire and the results are presented in Table 1.

In summary, the survey results show that every participant's knowledge of banana plant protection R&D improved by attending the symposium (100% positive response), with 97% of respondents rating the impact as a 4 or 5 (1 – lowest, 5 – highest). Improvements in networking identified in the network matrix assessment

were corroborated by the 100% positive response to the question about gaining new contacts. This improved networking and knowledge contributed to positive responses to questions about identifying new research concepts they could contribute to (82% - yes, 18% - no). The inclusion of an international presenter was highly valued with 100% of respondents positive on the inclusion in the program and for future events. Phillipe Tixier's topic and presentation were well received with 100% of respondents rating it a 4 or 5 (1 – lowest, 5 – highest), and 75% indicating that the presentation helped them identify/consider new research approaches or concepts.

Assessment of the different elements of the program showed a positive response to networking activities (95% - rating 4 or 5), format and content of presentations (98% - rating 4 or 5), and facilitated group activities (The Solutions Room – 82% rating 4 or 5; Life's a Pitch – 73% rating 4 or 5). Overall, respondents ranked the event positively (100% - rating 4 or 5) and indicated they would attend again (100% - rating 4 or 5) and recommend the symposium to others to attend (100% - rating 4 or 5).

Table 7. Evaluation from the survey questionnaire at the completion of the symposium

Evaluation question	Answer option	Percentage (%)
Have you gained new contacts from attending this symposium? (n=42)	Yes	100
	No	0
Have you identified any new research concepts you could contribute to from attending this symposium? (n=45)	Yes	82
	No	18
Have you identified any communication or extension opportunities from attending the symposium? (n=47)	Yes	64
	No	36
Has your knowledge of banana R&D activities benefitted from attending the symposium? (n=47)	Yes	100
	No	0
How much has your knowledge of banana R&D activities benefitted from attending the symposium? (n=47)	1 – Lowest	0
	2	0
	3	2
	4	57
	5 – Highest	40
How would you rate the format and content of the presentations? (n=47)	1 – Lowest	0
	2	0
	3	2
	4	38
	5 – Highest	60
Was the inclusion of an international presenter a valuable addition to the program? (n=14)	Yes	100
	No	0
How valuable did you find the presentation from Phillipe Tixier (CIRAD)? (n=12)	1 – Lowest	0
	2	0
	3	0
	4	67
	5 – Highest	33

Did listening to Phillipe Tixier's presentation help you identify/consider any new research approaches or concepts? (n=12)	Yes	75
	No	25
Would you like to see an international presenter included in future symposiums? (n=14)	Yes	100
	No	0
How would you rate the value of the networking activities? (n=42)	1 – Lowest	0
	2	0
	3	5
	4	43
	5 – Highest	52
How would you rate the value of "The Solutions Room" activity? (n=39)	1 – Lowest	0
	2	0
	3	18
	4	44
	5 – Highest	38
How would you rate the value of the "Life's a Pitch" activity? (n=37)	1 – Lowest	0
	2	3
	3	24
	4	41
	5 – Highest	32
How appropriate was the venue for the symposium activities? (n=42)	1 – Lowest	2
	2	0
	3	5
	4	24
	5 – Highest	69
How appropriate was the catering? (n=41)	1 – Lowest	0
	2	0
	3	40
	4	37
	5 – Highest	54
Would you attend this event again? (n=46)	1 – Lowest	0
	2	0
	3	0
	4	15
	5 – Highest	85

Would you recommend attending this event to other people? (n=47)	1 – Lowest	0
	2	0
	3	0
	4	11
	5 – Highest	89
How would you rate this event overall? (n=47)	1 – Lowest	0
	2	0
	3	0
	4	19
	5 – Highest	81

The survey questionnaire also offered the opportunity for respondents to provide suggestions and comments on the event. The responses to this question are presented in Table 8.

Table 8. Suggestions and comments provided in the survey questionnaire at the completion of the symposium

Suggestions and/or comments
• Bit tired going into the last activity and taking it sufficiently seriously enough; 2018 (related activity) I seemed to have more energy for - bit flat at the end; What info do we have for access to? Just Philippe's?; list of contacts?; what was made available last time?; what happened to BA16001 reviewers?; location lead to fluidity of participants in and out of sessions; not to be missed event!!
• Well run "event" and provided a great opportunity to mingle and share information on our work
• Well done!; excellent coordination & daily management
• No proper food for dinner (Tuesday night)
• 10 min talks plus later question panel & themes worked well; networking activities not as good as previous event; air con cold!!; excellent organisation
• Congratulations to organising team; it's very difficult to keep everyone engaged throughout the whole symposium but I think this was achieved very well; the scientific content was generally very well presented
• Everything was great!; Thanks for organising this and making it face to face instead of another run-of-mill online thing
• Like the previous symposium, this was a fantastic opportunity to reconnect with the banana scientific community and to make new connections; a great selection of presentations and wonderful guest speaker
• Excellent symposium; great networking activities - it's never easy to encourage participation from attendees; good use/integration of remote speakers
• "Excellent" - very professional, educative and entertaining
• I think 2 days is a good timeframe; excellent spread of presentations and video links worked well for those not able to attend in person; excellent job done by the whole extension team; excellent idea to have an international guest speaker
• Overall, excellent; next symposium could take a broad look at banana production systems including supply chain systems and the sociological aspects of grower adoption of learnings
• Not a reflection of the event - I probably won't be with the industry when the next one is on
• Really great to hear some hot off the press work; there was actually some useful discussions in amongst the crazy of the "Life's a Pitch"; catering was good but maybe some more fruit; bananas at smoko; in a post-COVID world, swapping tables between sessions
• Would be great if we could get an email list if people want to contact others - not everyone presented at symposium so contacts aren't in the booklet; needs bananas in the catering; was great to get an idea of what was going on in the research space; would be great to include more extension also?; so researchers are aware of the activities/how we do extension - "Life's a Pitch" kind of did that but if

there is an opportunity to put forward the kind of information that extension officers can share in bananas (it may already exist, I don't know?) • Learnt a lot about the field; met lots of people; well managed - kept to time guidelines/plan; venue a bit cold (was warmer outside); networking activities engaged me and others • Brilliant work team; need better coffee options - almond latte • Well done team for a really informative and enjoyable 2 days • Good with shorter talks; good grouping of presentations • Great work extension team!; great to hear what is going on in banana research, the progress and new ideas; also great opportunity for new researchers to be part of the banana research community rather than work in isolation in their labs; a lot of interaction between the young people, which will carry on beyond the meetings and their research and their post-doc careers • This was my first conference ever and it was so fun and interesting!; I liked that networking and socialising was encouraged, but that the activities weren't too intense/put us on the spot • Great but even more networking would be even better; more get to know people time • Great symposium; the organisers have been doing a fantastic job to get this symposium so successful; thank you • Good work team :); Thanks for organising • The program was structured perfectly; Presentations were the ideal length; breaks and networking activities were organised to occur at the right times to avoid disengagement; There is nothing I would recommend to improve the event • Thanks for putting on such an important symposium; My knowledge has improved significantly and hopefully this will in turn benefit future trials as well as my own banana farming practices

A facilitated reflection activity was also conducted at the start of day 2, with participants asked to take 5 minutes to reflect on the presentations and activities from the first day and record their responses to the following questions on the reflection template provided:

- Name 1 new idea or concept that you learnt on Day 1
- Name 1 presentation that really caught your interest
- Have you met any new colleagues that may be influential in your work?

The facilitator then asked participants to share their reflections with the whole group. The reflections recorded on the template sheets are presented in Table 9. Of particular note was the range of topics engaging participants during the first day, with Dr Phillipe Tixier's presentation mentioned by 35% and 31% of respondents to the first 2 questions. The value of the networking associated with the symposium was reinforced by responses to questions 3 about meeting new colleagues with 88% responding positively, 9% saying they knew most people but still benefitted from renewing these relationships while 3% indicated they had not met any new colleagues that might influence their work.

Table 9. Responses recorded during the reflection activity conducted at the start of Day 2

Responses – Name 1 new idea or concept that you learnt on Day 1 (n=34)
• Novel isometric virus • Time management - starting with the big things at the start of the day and working down to the small things (Problem solving activity); also the variety of diseases and pests that affect bananas was unknown to me and this was a good scope • Top down, bottom up concept of reducing soilborne pathogens talked about by Philippe Tixier • Microbiome techniques - I spoke to Olwen at lunch Tuesday and learned a lot about the influence of endophytes • Betel nut and Taro are alternative hosts for the phytoplasma issue • Moving from agroecology to agroforestry in the evolution of banana plantations - Philippe Tixier • I've learned about the use of nematodes to control pests and found it really interesting • Use of EPN to combat weevil borer • Agroecology & the use of NGS to study food webs • The disease cycle and how different external and internal factors combine

- Use of EPN for control of BWB and other banana pests - was familiar with their use in other crops, but not banana
- Planting trees between bananas for soil improvement
- Testing use of trees in banana intercropping - how to make that work
- Planting trees with bananas reduces impact of black Sigatoka; Banana Blood disease is new to me!
- Curious about the link between interplanting trees in banana plantations & its effect on BS in the Antilles
- DDGWAS - genome wide associated ??; resistance gene in B genome for BBTV
- That molecular science is very difficult to understand when you don't understand it
- Use of EPN and endophytic microorganisms to manage insect pests and diseases
- Philippe Tixier's presentation with the inter row plantings of various species and also trees; would be interesting to see how they would go with Fusarium
- Phytoplasma can be mistaken with bacteria, or other way round; simple tests can take a lot to develop; similarities being faced by researchers
- Ways of understanding dispersal of new/under researched diseases
- Use of trees in banana plantations to increase soil health and diversity
- Possibility of new options around diagnostics; TR4 resistant Cavendish that have market appeal
- Organisms involved or being sought in Crown rot; progress in EPN research to control BWB; epidemiology of Banana Blood disease
- EPN's to control BWB
- cover crops influencing nematode population through effect on omnivores
- progress on new varieties; consumer panels; agroecology and transdisciplinary work
- better understanding of the process of variety evaluation & commercialisation (additional & lengthy steps & challenges); concept that more funding is required to meet community expectations regarding sustainability
- the plant breeding project aimed at obtaining resistance to BBTV was very interesting
- How resistant varieties are selected etc; how the consumer/pre-commercialisation studies work; nematode vs weevil
- Banana (?) talk by Philippe, the use of intercropping to improve crop health - great concept
- better understanding of competitive ELISA for BBTV Mab epitope mapping
- Banana blood disease is something I hadn't heard of before/ or knew it was similar to Moko
- BBTV immunity - it is interesting to see that possible immunity does exist in the B genome - possibility to harness this in the future

Responses – Name 1 presentation that really caught your interest (n=35)

- The entomopathogenic work - promising results (in the lab)
- Tasty and TR4 resistant - it was interesting to see the processes used on the farm to consumer side of things
- Nematodes - Jenny Cobon
- Current diagnostics for banana blood disease & Moko - Dr Vivian Rincon-Florez - especially a better understanding of *Ralstonia*
- How well Ashley's presentation went – pre-commercialisation trial results
- Use of EPN to control weevils - Shanara Veivers
- The presentation of John Thomas with trying to find resistance to BBTV in wild germplasm
- Philippe Tixier - integrated farming - next level implementation
- John Thomas - BBTV resistance
- Shanara's talk; the role of the soil health in disease control
- Philippe Tixier - the gradual introduction of biological diversity into banana crops to help improve soil health & provide shelter for beneficial insects etc. A success story built on a combination of trial and error and systematic approaches + functional
- Philippe Tixier - can I go? I'm learning French; Wayne's sniffer dogs today - sign me & Aurora up!
- BBTV resistance is out there - good news
- Jane Ray - new disease to me & the process of understanding how it is transmitted was interesting
- Parasitic nematodes to manage BWB; in this day and age the use of biological control is coming more pertinent; having said that there were an array of presentations that were of interest

- Phytoplasma; guest speaker's talk - Philippe Tixier
- Development of new diagnostic antibodies for BBTV
- Philippe Tixier - intercropping, layered ecosystems
- Dr Philippe Tixier - CIRAD - agroecosystems across banana and other production systems
- Unfortunately missed John Thomas' presentation (had to dash off to a lecture) but interested to know that *M. balbisiana* resistant to BBTV
- Development of ELISA tests are a lot more complicated than seems for simple tests from Megan Vance; Nandita - taxonomic problems; Philippe - parallels with NQ work
- Enjoyed Philippe Tixier presentation about extension experiences overseas, especially with a more biological control focus & the potential to incorporate tree crops into banana farming
- Philippe Tixier's presentation; Lilia Carvalhais
- Session 3 - Jeff, Ashley, Katie; Banana blood disease - Jane
- Epidemiology of Banana Blood disease - Jane Ray; Tasty & TR4 Resistant assessment of fruit - Katelyn Ferro
- New banana Picorna-like virus
- Lilia Carvalhais - phytoplasmas
- Philippe Tixier
- Picorna-like virus - useful to understand the implications of detection of new/emergent viruses in the process
- International guest speaker - Philippe Tixier
- Bunchy top virus & Blood disease & Moko - especially the development of diagnostics antibodies
- Philippe Tixier's presentation
- Jane Ray's talk - epidemiology of banana blood disease
- The crown; resistance to BBTV
- Goldfinger research - it will very interesting to see how they perform in the subtropics at our new trial site

Have you met any new colleagues that may be influential in your work? (n=33)

- Not new colleagues; guest speaker Phillipe Tixier
- Hazel Gaza - although I have spoken with her over Zoom it was nice to get the opportunity to see in person and talk to her out of a meeting context
- Yes - everyone; have enjoyed making connections with people from DAF, DPI etc
- Olwen - consider more of the influence/impact of non-pathogens
- Brendan Fu - interest of synchronisation of flowering in banana
- No
- Yes - the biometrician (Carole Wright)
- Phillipe Tixier - expand on the work we are currently researching; Carole Wright - always good to know a biometrician
- Yes - Carole Wright; always good to have a biometrician
- Not yet - I think Dr Paul's work (Paul Dennis?) catch my interest to do something with him in the future
- Have discussed potential new work areas with old colleagues as well as new acquaintances
- I feel that everyone is influential; We are all in the banana area; Concepts and ideas can be shared across departments
- Meet some new colleagues - yes; not sure how influential but did learn some new techniques
- Everyone
- There are lots of people that I can draw on
- Yes
- Yes
- Made linkages with ESP and UQ to develop and collaborate for molecular diagnostics
- Yes
- Zac McKeever gave no-nonsense insights into banana production problems and what works for growers and how to pitch science ideas
- Would be great to look more into Phillipe's work and experiences to learn from
- Yes - possibly future collaboration with others (Andrew Hayes in particular)

- Yes lots - Elizabeth Aitken, Jay Anderson, Andre Drenth, Suren Samuelian, Tony Pattison, Elizabeth Czislowski, Wayne O'Neill
- I work and know most of the people working in the various research areas but I continue to benefit from their association and collaboration
- Yes
- Yes
- Potentially
- Yes - have already discussed the potential of collaborating on some work with people I've met for the first time at the symposium
- Sharon Hamill - microbes and tissue culture
- Yes many - networking was a highlight
- No - but I did get good value from reconnecting with existing colleagues
- Yes
- Two new additions to the ABGC staff may be interesting to work with as a grower; great to catch up with the regulars being so isolated in NNSW

Discussion

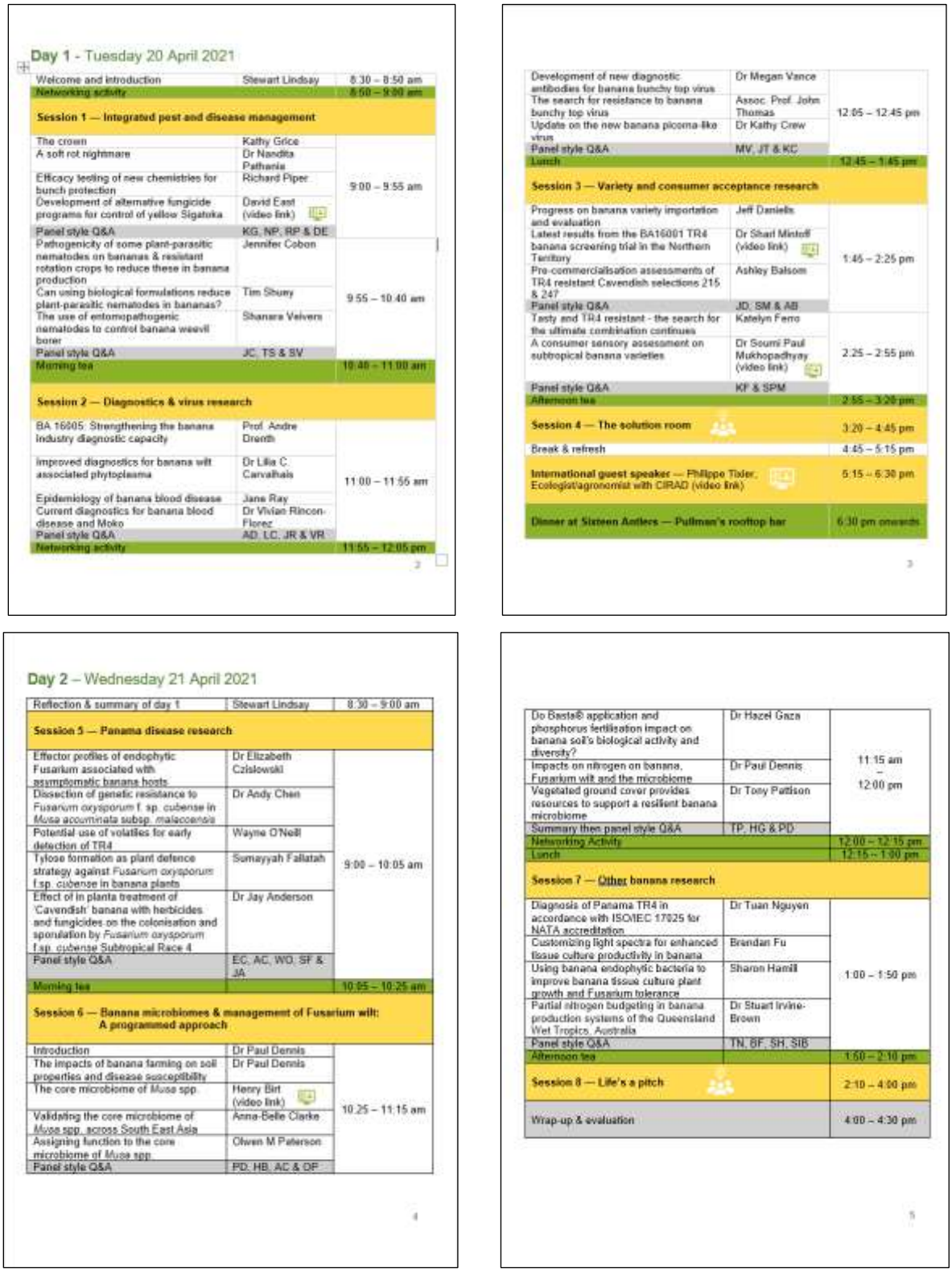
The BSS 2021 built on the success of the first symposium and successfully contributed to promoting a collaborative and cohesive RD&E program within the Australian banana RD&E community. In spite of restrictions on travel due to COVID19 management requirements, the symposium was held in Brisbane in April 2021 with an increased number of participants and participating organisations. The programme developed by the organising project team integrated opportunities to share information on current R&D activities with facilitated networking and collaborative group activities. Interstate travel restrictions were overcome by enabling remote viewing presentations from NT and WA. An on-line presentation from an international presenter was arranged and very positively received by the symposium participants.

Recommendations for the second symposium identified from the 2018 event evaluation and feedback were incorporated into the planning and development of the BSS2021 program. Key examples of this were:

- Alternating the location of the symposium from Cairns to Brisbane, which allowed a larger contingent of university staff and students to participate
- Including an international keynote presenter
- Allowing more time for the symposium, especially the collaborative group activities

Evaluation of the event showed that the participants valued the symposium very highly for the opportunity to meet and engage with the broader banana R&D community, and to develop an improved understanding of the breadth and nature of the plant protection R&D being undertaken in bananas. The general suggestions and comments from both the 2018 and 2021 symposia indicate that these events are highly valued by the participants and have succeeded in improving the networking and cooperation with the banana R&D community.

Figure 9. Full agenda for the Banana Scientific Symposium 2021



Day 1 - Tuesday 20 April 2021

Welcome and introduction	Stewart Lindsay	8:30 – 8:50 am
Networking activity		8:50 – 9:00 am
Session 1 — Integrated pest and disease management		
The crown	Kathy Grice	9:00 – 9:55 am
A soft rot nightmare	Dr Nandita Pathania	
Efficacy testing of new chemistries for bunch protection	Richard Piper	
Development of alternative fungicide programs for control of yellow Sigatoka	David East (video link)	
Panel style Q&A	KG, NP, RP & DE	
Pathogenicity of some plant-parasitic nematodes on bananas & resistant rotation crops to reduce these in banana production	Jennifer Cobon	9:55 – 10:40 am
Can using biological formulations reduce plant-parasitic nematodes in bananas?	Tim Shuey	
The use of entomopathogenic nematodes to control banana weevil borer	Shanara Velvers	
Panel style Q&A	JC, TS & SV	
Morning tea		10:40 – 11:00 am
Session 2 — Diagnostics & virus research		
BA 16005: Strengthening the banana industry diagnostic capacity	Prof. Andre Drenth	11:00 – 11:55 am
Improved diagnostics for banana wilt associated phytoplasma	Dr Lilia C. Carvalhais	
Epidemiology of banana blood disease	Jane Ray	
Current diagnostics for banana blood disease and Moko	Dr Vivian Rincon-Florez	
Panel style Q&A	AD, LC, JR & VR	
Networking activity		11:55 – 12:05 pm

Development of new diagnostic antibodies for banana bunchy top virus	Dr Megan Vance	12:05 – 12:45 pm
The search for resistance to banana bunchy top virus	Assoc. Prof. John Thomas	
Update on the new banana picorna-like virus	Dr Kathy Crew	
Panel style Q&A	MV, JT & KC	
Lunch		12:45 – 1:45 pm
Session 3 — Variety and consumer acceptance research		
Progress on banana variety importation and evaluation	Jeff Daniells	1:45 – 2:25 pm
Latest results from the BA16001 TR4 banana screening trial in the Northern Territory	Dr Shari Minloff (video link)	
Pre-commercialisation assessments of TR4 resistant Cavendish selections 215 & 247	Ashley Balsom	
Panel style Q&A	JD, SM & AB	
Tasty and TR4 resistant - the search for the ultimate combination continues	Katelyn Ferro	2:25 – 2:55 pm
A consumer sensory assessment on subtropical banana varieties	Dr Soumi Paul Mukhopadhyay (video link)	
Panel style Q&A	KF & SPM	
Afternoon tea		2:55 – 3:20 pm
Session 4 — The solution room		3:20 – 4:45 pm
Break & refresh		4:45 – 5:15 pm
International guest speaker — Philippe Tixier, Ecologist/agronomist with CIRAD (video link)		5:15 – 6:30 pm
Dinner at Sixteen Antlers — Pullman's rooftop bar		6:30 pm onwards

Day 2 – Wednesday 21 April 2021

Reflection & summary of day 1	Stewart Lindsay	8:30 – 9:00 am
Session 5 — Panama disease research		
Effector profiles of endophytic Fusarium associated with asymptomatic banana hosts	Dr Elizabeth Czislowski	9:00 – 10:05 am
Dissection of genetic resistance to *Fusarium oxysporum* f. sp. *cubense* in *Musa acuminata* subsp. *malaccensis*	Dr Andy Chen	
Potential use of volatiles for early detection of TR4	Wayne O'Neill	
Tylose formation as plant defence strategy against *Fusarium oxysporum* f.sp. *cubense* in banana plants	Sumayyah Fallatah	
Effect of in planta treatment of 'Cavendish' banana with herbicides and fungicides on the colonisation and sporulation by *Fusarium oxysporum* f.sp. *cubense* Subtropical Race 4	Dr Jay Anderson	
Panel style Q&A	EC, AC, WO, SF & JA	
Morning tea		10:05 – 10:25 am
Session 6 — Banana microbiomes & management of Fusarium wilt: A programmed approach		
Introduction	Dr Paul Dennis	10:25 – 11:15 am
The impacts of banana farming on soil properties and disease susceptibility	Dr Paul Dennis	
The core microbiome of *Musa* spp.	Henry Birt (video link)	
Validating the core microbiome of *Musa* spp. across South East Asia	Anna-Belle Clarke	
Assigning function to the core microbiome of *Musa* spp.	Olwen M Paterson	
Panel style Q&A	PD, HB, AC & OP	

Do Basta® application and phosphorus fertilisation impact on banana soil's biological activity and diversity?	Dr Hazel Gaza	11:15 am – 12:00 pm
Impacts on nitrogen on banana, Fusarium wilt and the microbiome	Dr Paul Dennis	
Vegetated ground cover provides resources to support a resilient banana microbiome	Dr Tony Pattison	
Summary then panel style Q&A	TP, HG & PD	
Networking Activity		12:00 – 12:15 pm
Lunch		12:15 – 1:00 pm
Session 7 — Other banana research		
Diagnosis of Panama TR4 in accordance with ISO/IEC 17025 for NATA accreditation	Dr Tuan Nguyen	1:00 – 1:50 pm
Customizing light spectra for enhanced tissue culture productivity in banana	Brendan Fu	
Using banana endophytic bacteria to improve banana tissue culture plant growth and Fusarium tolerance	Sharon Hamill	
Partial nitrogen budgeting in banana production systems of the Queensland Wet Tropics, Australia	Dr Stuart Irvine-Brown	
Panel style Q&A	TN, BF, SH, SIB	
Afternoon tea		1:50 – 2:10 pm
Session 8 — Life's a pitch		2:10 – 4:00 pm
Wrap-up & evaluation		4:00 – 4:30 pm

Appendix 20 – List of extension and communication outputs from BA16001

Extension/communication outputs - Producer/industry service provider audience

Primary audience	Activity	Name	Date	Location	Topic/information presented	No. of participants/ target reach
Growers	Conference poster	K Thomson et al	23/05/19	ABIC 2019	Lucid key - a selection tool for rotation crop selection for nematode management	373
Growers	Conference poster	J Cobon et al	23/05/19	ABIC 2019	Plant-parasitic nematodes in banana production areas of Australia	373
Growers	Conference poster	S Hamill et al	23/05/19	ABIC 2019	Safeguarding the Australian Banana Industry!	373
Growers	Conference poster	S Hamill et al	23/05/19	ABIC 2019	Clean tissue cultures from Fusarium infected banana suckers	373
Growers	Conference poster	D East & L Vawdrey	23/05/19	ABIC 2019	Innovation control of yellow Sigatoka	373
Growers	Conference poster	J Daniells	23/05/19	ABIC 2019	Progress on agronomic evaluation of new varieties at South Johnstone	373
Growers	Conference poster	S Mintoff et al	23/05/19	ABIC 2019	Identification of banana varieties with resistance or tolerance to Fusarium wilt Tropical Race 4	373
Growers	Conference poster	N Pathania et al	23/05/19	ABIC 2019	Internal discolouration of banana fruits - disease or disorder	373
Growers	Conference poster	R Piper et al	23/05/19	ABIC 2019	The effect of bunch cover colour on banana rust thrips damage and fruit quality	373
Growers	Conference poster	R Piper & D Farrell	12-14/05/21	ABIC 2021	Bunch pest control - Assessing novel insecticides for bell injection	470
Growers	Conference poster	D East & D Farrell	12-14/05/21	ABIC 2021	Development of alternative fungicide programs for control of yellow Sigatoka	470
Growers	Conference Poster	A Balsom, K Ferro & J Daniells	12-14/05/21	ABIC 2021	Pre-commercialisation assessments of the TR4 resistant Cavendish, GCTCV's 215 & 247	470
Growers	Conference poster	K Ferro, A Balsom & J Daniells	12-14/05/21	ABIC 2021	Tasty and TR4 resistant - the search for the ultimate combination continues	470

Growers	Conference poster	J Daniells, K Ferro & A Balsom	12-14/05/21	ABIC 2021	Progress on agronomic evaluation of new varieties at South Johnstone	470
Growers	Conference poster	S Mintoff et al	12-14/05/21	ABIC 2021	Progress with TR4 varietal screening in the Northern Territory	470
Growers	Conference poster	S Veivers et al	12-14/05/21	ABIC 2021	Can entomopathogenic nematodes (EPNs) control banana weevil borer (Cosmpolites sordidus)?	470
Growers	Conference poster	J Cobon et al	12-14/05/21	ABIC 2021	Resistant rotation crops to reduce plant-parasitic nematodes in banana	470
Growers	Conference poster	T Shuey et al	12-14/05/21	ABIC 2021	Can using biological formulations reduce plant-parasitic nematodes in bananas?	470
Growers	Conference poster	N Pathania et al	12-14/05/21	ABIC 2021	Innovative technique to reduce early suckering	470
Growers	Conference presentation	K Thomson	23/05/19	ABIC 2019	Rotation crops - a key to nematode management (3 min talk)	373
Growers	Conference presentation	S Hamill	23/05/19	ABIC 2019	Clean tissue cultures from Fusarium infected banana suckers (3 min talk)	373
Growers	Conference presentation	K Crew	23/05/18	ABIC 2019	Risks are real from Bunchy Top! (3 min talk)	373
Growers	Conference presentation	J Daniells et al	13/05/21	ABIC 2021	Mining for Gold - Beneath the surface of Goldfinger and beyond...	470
Growers	Conference presentation	K Crew	13/05/21	ABIC 2021	A new banana virus detected in quarantine germplasm screening (3 min Speed talk)	470

Growers	Field walk	M Weinert	22/05/19	ABIC 2019	Pre-congress tour - Farm walk at Duranbah trial site	25
Growers	Field walk	M Weinert et al	5/07/19	Duranbah	Subtropical growers	20
Growers	Field walk	J Daniells et al	21/06/19	South Johnstone	BA16001 Banana Variety Assessment Trial, South Johnstone	55
Growers	Field walk	J Daniells, S Lindsay, T Kukulies	6/03/20	South Johnstone	SJ variety trial field walk	17
Growers	Field walk	J Daniells	30/07/21	South Johnstone	SJ variety trial 2 field walk	50
Growers	Field walk	N Pathania	30/07/21	South Johnstone	Tissue culture modification to reduce sucker numbers	50
Growers	Field walk	S Lindsay et al	5/09/19	BA16007 NextGen grower group activity	NT CPRF Banana Variety Trial visit (including live stream to Tweed Vallet BGA FB page)	16 + on-line
Growers	Magazine article	Stewart Lindsay	1/12/17	Australian Bananas, Issue 51	Overview of Australias search for pest and disease resistant varieties	1200
Growers	Magazine article	Stewart Lindsay	1/12/17	Australian Bananas, Issue 51	Introduction to New Improve Plant Protection Program - project summary	1200
Growers	Magazine article	David Peasley	26/11/17	Tweed daily News online	Best bet varieties, https://m.tweeddailynews.com.au/news/appetite-for-banana-future-is-growing/3274111/?ref=hs	
Growers	Magazine article	Jeff Daniells	1/12/17	Australian Bananas, Issue 51	Fusarium wilt Race 1 varietal screenign results	1200
Growers	Magazine article	Jeff Daniells	1/12/17	Australian Bananas, Issue 51	Prospects for the niche market variety - "Pisang Gajih Merah"	1200
Growers	Magazine article	Tegan Kukulies	1/12/17	Australian Bananas, Issue 51	Carnarvon east coast research tour	1200
Growers	Magazine article	Sharl Mintoff	17/04/18	Australian Bananas, Issue 52	Path to most resistance	1200
Growers	Magazine article	Matt Weinert	17/04/18	Australian Bananas, Issue 52	On trial: Work continues at Duranbah	1200
Growers	Magazine article	Rosie Godwin	17/04/18	Australian Bananas, Issue 52	Taiwanese research visit	1200
Growers	Magazine article	Stewart Lindsay	17/04/18	Australian Bananas, Issue 52	National plant protection program moving ahead	1200

Growers	Magazine article	Jenny Cobon	30/08/18	Australian Bananas, Issue 53	Plant parasitic nematodes impacting Australian banana production	1200
Growers	Magazine article	Everyone	1/12/18	Australian Bananas, Issue 54	Sharing the science of bananas	1200
Growers	Magazine article	Jeff Daniells	1/12/18	Australian Bananas, Issue 54	New variety evaluation goes in at South Johnstone	1200
Growers	Magazine article	Matt Weinert	1/12/18	Australian Bananas, Issue 54	Taking on Turkey: ProMusa 2018	1200
Growers	Magazine article	Matt Weinert	1/12/18	Australian Bananas, Issue 55	Tweed grower takes on trial site	1200
Growers	Magazine article	M Weinert	1/08/19	Australian Bananas, Issue 56	Duranbah Field Day	1200
Growers	Magazine article	J Daniells	1/08/19	Australian Bananas, Issue 56	New Varieties on Show	1200
Growers	Magazine article	S Mintoff et al	1/08/19	Australian Bananas, Issue 56	NT Banana Variety Trial for Resistance to TR4 Complete	1200
Growers	Magazine article	J Daniells	1/04/20	Australian Bananas, Issue 58	Plant crop variety results South Johnstone	1200
Growers	Magazine article	T Kukulies	1/04/20	Australian Bananas, Issue 58	South Johnstone Field Walk	1200
Growers	Magazine article	T Flanagan	1/08/20	Australian Bananas, Issue 59	Duranbah Closure	1200
Growers	Magazine article	S Lindsay	1/08/20	Australian Bananas, Issue 59	National plant protection project kicking major banana variety goals at the halfway mark	1200
Growers	Magazine article	S Mintoff	1/08/20	Australian Bananas, Issue 59	Plant crop results from the latest TR4 screening trial in the NT	1200
Growers	Magazine article	S Lindsay	1/12/20	Australian Bananas, Issue 60	Integrated pest and disease management a key focus for national plant protection program	1200
Growers	Magazine article	K Ferro, J Daniells & A Balsom	1/12/20	Australian Bananas, Issue 60	Pre-commercialisation trials testing new varieties from paddock to plate	1200

Growers	Magazine article	K Ferro, J Daniells & A Balsom	12/04/21	Australian Bananas, Issue 61	First ratoon variety results at South Johnstone	1200
Growers	Magazine article	T Pattison	12/04/21	Australian Bananas, Issue 61	Rotation crops for banana growers to reduce nematodes	1200
Growers	Magazine article	T Flanagan	16/08/21	Australian Bananas, Issue 62	Slab a sign of things to come	1200
Growers	Magazine article	S Lindsay	16/08/21	Australian Bananas, Issue 62	Science symposium	1200
Growers	Magazine article	S Mintoff et al	16/08/21	Australian Bananas, Issue 62	First ratoon results from the TR4 variety screening trial in the Northern Territory - The main trial	1200
Growers	Magazine article	K Ferro et al	16/08/21	Australian Bananas, Issue 62	Best of the best - DAF's Goldfinger mutagenesis trial enters it's third phase	1200
Growers	Magazine article	R Piper	16/08/21	Australian Bananas, Issue 62	Biological control of banana rust thrips	1200
Growers	Magazine article	K Ferro et al	1/12/21	Australian Bananas, Issue 63	An update on the variety trials in the Northern Territory	1200
Growers	Magazine article	S Mintoff et al	1/12/21	Australian Bananas, Issue 63	First ratoon results from the TR4 variety screening trial in the Northern Territory - Part 2: The sub-trial	1200
Growers	Magazine article	T Kukulies	1/12/21	Australian Bananas, Issue 63	De-leafing critical for controlling leaf spot	1200
Growers	Magazine article	K Crew	1/12/21	Australian Bananas, Issue 63	New banana virus discovered in quarantine	1200
Growers	Presentation	S Lindsay	13/06/19	CCBGA monthly meeting	BA16001 program update	20
Growers	Presentation	S Lindsay	12/12/19	CCBGA monthly meeting	Africa TR4 strategy workshop/Mozambique & South African banana production visits	22
Growers	Presentation	J Daniells	3/10/19	Banana R&D Speed Dating Night, Innisfail	Variety Evaluation Trials	40
Growers	Presentation	S Lindsay	3/10/19	Banana R&D Speed Dating Night, Innisfail	Variety development activities	40
Growers	Presentation	R Piper	3/10/19	Banana R&D Speed Dating Night, Innisfail	Bunch pest management	40

Growers	Presentation	D East	3/10/19	Banana R&D Speed Dating Night, Innisfail	Yellow Sigatoka management	40
Growers	Presentation	P Trevorrow & N Pathania	3/10/19	Banana R&D Speed Dating Night, Innisfail	Bacterial corm rot	40
Growers	Radio interview	Matt Weinert	18/11/17	ABC NSW North Coast rural report	Best bet varieties, recorded at the Murwillumbah Show on 04/11/17	Unknown
Growers	Radio interview	Matt Weinert	20/03/18	NNSW	BA16001 subtropical varieties and BA16007	120
Growers	Radio interview	J Daniells	18/05/20	ABC Far North Rural Report	Interview concerning “Plant crop variety results South Johnstone” 18 May 2020	Unknown
Growers	Roadshow presentation	Stewart Lindsay	24/07/18	Murwillumbah	Variety is the spice of life - an overview of banana variety importation and development	21
Growers	Roadshow presentation	Stewart Lindsay	26/07/18	Coffs Harbour	Variety is the spice of life - an overview of banana variety importation and development	21
Growers	Roadshow presentation	Stewart Lindsay	9/08/18	Tully	Variety is the spice of life - an overview of banana variety importation and development	17
Growers	Roadshow presentation	Stewart Lindsay	10/08/18	Innisfail	Variety is the spice of life - an overview of banana variety importation and development	31
Growers	Roadshow presentation	Stewart Lindsay	17/08/18	Tablelands	Variety is the spice of life - an overview of banana variety importation and development	24
Growers	Roadshow presentation	Stewart Lindsay	30/08/18	Carnarvon WA	Variety is the spice of life - an overview of banana variety importation and development	21
Growers	Roadshow presentation	Jeff Daniells	24/07/18	Murwillumbah	Results from the variety/mutagenesis trials	21
Growers	Roadshow presentation	Jeff Daniells	26/07/18	Coffs Harbour	Results from the variety/mutagenesis trials	21
Growers	Roadshow presentation	Jeff Daniells	30/08/18	Carnarvon WA	Results from the variety/mutagenesis trials	21
Growers	Roadshow presentation	Matt Weinert	24/07/18	Murwillumbah	Update on the Duranbah trial	21
Growers	Roadshow presentation	Matt Weinert	26/07/18	Coffs Harbour	Update on the Duranbah trial	21
Growers	Roadshow presentation	Matt Weinert	30/08/18	Carnarvon WA	Update on the Duranbah trial	21

Growers	Roadshow presentation	Jenny Cobon	24/07/18	Murwillumbah	Plant-parasitic nematodes in bananas in the subtropics	21
Growers	Roadshow presentation	Jenny Cobon	26/07/18	Coffs Harbour	Plant-parasitic nematodes in bananas in the subtropics	21
Growers	Roadshow presentation	Jenny Cobon	30/08/18	Carnarvon WA	Plant-parasitic nematodes in bananas in the subtropics	21
Growers	Roadshow presentation	Sharl Mintoff	9/08/18	Tully	Banana variety screening to identify resistance to Fusarium oxysporum f. sp. cubense Tropical Race 4	17
Growers	Roadshow presentation	Sharl Mintoff	10/08/18	Innisfail	Banana variety screening to identify resistance to Fusarium oxysporum f. sp. cubense Tropical Race 4	31
Growers	Roadshow presentation	Sharl Mintoff	17/08/18	Tablelands	Banana variety screening to identify resistance to Fusarium oxysporum f. sp. cubense Tropical Race 4	24
Growers	Roadshow presentation	Richard Piper	24/07/18	Murwillumbah	Bunch pest management	21
Growers	Roadshow presentation	Richard Piper	26/07/18	Coffs Harbour	Bunch pest management	21
Growers	Roadshow presentation	Richard Piper	9/08/18	Tully	Bunch pest management	17
Growers	Roadshow presentation	Richard Piper	10/08/18	Innisfail	Bunch pest management	31
Growers	Roadshow presentation	Richard Piper	17/08/18	Tablelands	Bunch pest management	24
Growers	Roadshow presentation	Jeff Daniells	9/08/18	Tully	Interactive display - Banana variety display and taste session	17
Growers	Roadshow presentation	Jeff Daniells	10/08/18	Innisfail	Interactive display - Banana variety display and taste session	31
Growers	Roadshow presentation	Jeff Daniells	17/08/18	Tablelands	Interactive display - Banana variety display and taste session	24
Growers	Roadshow presentation	Jenny Cobon	24/07/18	Murwillumbah	Interactive display - plant parasitic nematodes of bananas	21
Growers	Roadshow presentation	Jenny Cobon	26/07/18	Coffs Harbour	Interactive display - plant parasitic nematodes of bananas	21

Growers	Roadshow presentation	S Lindsay	5/11/20	Innisfail	Update on banana variety importation and development	26
Growers	Roadshow presentation	S Mintoff	5/11/20	Innisfail	Banana variety screening for TR4 resistance in the NT	26
Growers	Roadshow presentation	J Daniells	5/11/20	Innisfail	South Johnstone agronomic trials	26
Growers	Roadshow presentation	K Ferro	5/11/20	Innisfail	On-farm commercialisation trials of TR4 resistant Cavendish cultivars	26
Growers	Roadshow presentation	R Piper	5/11/20	Innisfail	Banana rust thrips	26
Growers	Roadshow presentation	S Lindsay	6/11/20	Tully	Update on banana variety importation and development	16
Growers	Roadshow presentation	S Mintoff	6/11/20	Tully	Banana variety screening for TR4 resistance in the NT	16
Growers	Roadshow presentation	J Daniells	6/11/20	Tully	South Johnstone agronomic trials	16
Growers	Roadshow presentation	K Ferro	6/11/20	Tully	On-farm commercialisation trials of TR4 resistant Cavendish cultivars	16
Growers	Roadshow presentation	R Piper	6/11/20	Tully	Banana rust thrips	16
Growers	Roadshow presentation	S Lindsay	19/11/20	Murwillumbah	Update on banana variety importation and development	10
Growers	Roadshow presentation	S Mintoff	19/11/20	Murwillumbah	Banana variety screening for TR4 resistance in the NT	10
Growers	Roadshow presentation	J Daniells	19/11/20	Murwillumbah	South Johnstone agronomic trials	10
Growers	Roadshow presentation	K Ferro	19/11/20	Murwillumbah	On-farm commercialisation trials of TR4 resistant Cavendish cultivars	10
Growers	Roadshow presentation	R Piper	19/11/20	Murwillumbah	Banana rust thrips	10
Growers	Roadshow presentation	S Lindsay	20/11/20	Coffs Harbour	Update on banana variety importation and development	10

Growers	Roadshow presentation	S Mintoff	20/11/20	Coffs Harbour	Banana variety screening for TR4 resistance in the NT	10
Growers	Roadshow presentation	J Daniells	20/11/20	Coffs Harbour	South Johnstone agronomic trials	10
Growers	Roadshow presentation	K Ferro	20/11/20	Coffs Harbour	On-farm commercialisation trials of TR4 resistant Cavendish cultivars	10
Growers	Roadshow presentation	R Piper	20/11/20	Coffs Harbour	Banana rust thrips	10
Growers	Roadshow presentation	S Lindsay	27/11/20	Mareeba	Update on banana variety importation and development	21
Growers	Roadshow presentation	S Mintoff	27/11/20	Mareeba	Banana variety screening for TR4 resistance in the NT	21
Growers	Roadshow presentation	J Daniells	27/11/20	Mareeba	South Johnstone agronomic trials	21
Growers	Roadshow presentation	K Ferro	27/11/20	Mareeba	On-farm commercialisation trials of TR4 resistant Cavendish cultivars	21
Growers	Roadshow presentation	R Piper	27/11/20	Mareeba	Banana rust thrips	21
Growers	website	J Daniells	1/09/19	Better Bananas website	Agronomic Evaluation of New Varieties, South Johnstone - update	
Growers	Workshop	Stewart Lindsay	26/05/17	Innisfail	IPDM priority setting workshop - NextGen growers' group	6
Growers	Workshop	Stewart Lindsay	19/01/18	Tully	IPDM priority setting workshop - banana growers	13
Growers	Workshop	S Lindsay & R Piper	5/11/20	Innisfail	Managing banana rust thrips	26
Growers	Workshop	S Lindsay & R Piper	6/11/20	Tully	Managing banana rust thrips	16
Growers	Workshop	S Lindsay, T Flanagan & R Piper	19/11/20	Murwillumbah	Managing banana rust thrips & other insect pests	10

Growers	Workshop	S Lindsay, T Flanagan & R Piper	20/11/20	Coffs Harbour	Managing banana rust thrips & other insect pests	10
Growers	Workshop	S Lindsay & R Piper	27/11/20	Mareeba	Managing banana rust thrips	21
Consultants & agronomists	Presentation	D East	18/07/19	BAGMan discussion group meeting, SJ	Report on screening trials for new chemistry for Yellow Sigatoka	18
Consultants & agronomists	Presentation	R Piper	19/11/19	BAGMan discussion group meeting, SJ	Mite management	15
Consultants & agronomists	Workshop	Stewart Lindsay	10/05/17	Innisfail	IPDM priority setting workshop - banana agribusiness group	25
Industry	e-bulletin	Stewart Lindsay	1/08/17	Panama TR4 Program Update, Aug/Sept 2017	Search for Panama disease resistant banana continues	400
Industry	Field walk	J Daniells	28/05/18	ABIC 2019 - post-conf visit, international delegates	SJ Banana Variety Trial Inspection	5
Industry	Field walk	S Mintoff	30/05/19	ABIC 2019 - post-conf visit, international delegates	NT Banana Variety Screening Trial visit	4
Industry	Field walk	S Mintoff	11/11/19	Visit by Fyffe's representatives	NT Banana Variety Screening Trial visit	2
Industry & community	Presentation & discussion	M Weinert	14/09/19	Wollongbar	Bananas about Bananas - Wollongbar 125th Anniversary masterclass	20
Industry & community	Radio interview	Stewart Lindsay	27/09/17		Accessing and screening banana varieties for Foc TR4 resistance	Qld Country Hour audience
Supply chain businesses	Field walk	D East	28/02/20	Visit by Colin Campbell Chemicals & SDS Biotech K.K. Representatives	Yellow Sigatoka Fungicide Evaluation Field Trial	3

Extension/communication outputs - science community audience

Primary audience	Activity	Name	Date	Activity	Location	Topic/information presented	No. of participants/ target reach
Australian scientists	Presentation	K Grice	19/04/21	Presentation	Banana Scientific Symposium, 2021	The Crown	82
Australian scientists	Presentation	N Pathania	19/04/21	Presentation	Banana Scientific Symposium, 2021	A soft rot nightmare	82
Australian scientists	Presentation	R Piper	19/04/21	Presentation	Banana Scientific Symposium, 2021	Efficacy testing of new chemistries for bunch protection	82
Australian scientists	Presentation	D East	19/04/21	Presentation	Banana Scientific Symposium, 2021	Development of alternative fungicide programs for control of yellow Sigatoka	82
Australian scientists	Presentation	J Cobon	19/04/21	Presentation	Banana Scientific Symposium, 2021	Pathogenicity of some plant parasitic nematodes on bananas and resistant rotation crops to reduce these in banana production	82
Australian scientists	Presentation	T Shuey	19/04/21	Presentation	Banana Scientific Symposium, 2021	Can using biological formulations reduce plant parasitic nematodes in bananas?	82
Australian scientists	Presentation	K Crew	19/04/21	Presentation	Banana Scientific Symposium, 2021	Update on the new banana picorna-like virus	82
Australian scientists	Presentation	J Daniells	19/04/21	Presentation	Banana Scientific Symposium, 2021	Progress on banana variety importation and evaluation	82
Australian scientists	Presentation	S Mintoff	19/04/21	Presentation	Banana Scientific Symposium, 2021	Latest results from the BA16001 TR4 banana screening trial in the Northern Territory	82
Australian scientists	Presentation	A Balsom	19/04/21	Presentation	Banana Scientific Symposium, 2021	Pre-commercialisation assessments of TR4 resistant Cavendish selections 215 and 247	82
Australian scientists	Presentation	K Ferro	19/04/21	Presentation	Banana Scientific Symposium, 2021	Tasty and TR4 resistant - the search for the ultimate combination continues	82
Australian scientists	Presentation	S Mukhopadhyay	19/04/21	Presentation	Banana Scientific Symposium, 2021	A consumer sensory assessment on subtropical banana varieties	82

Australian scientists	Presentation	S Hamill	19/04/21	Presentation	Banana Scientific Symposium, 2021	Using banana endophytic bacteria to improve banana tissue culture plant growth and Fusarium tolerance	82
Australian scientists	Presentation	J Daniells	27/11/18	Presentation	Banana Scientific Symposium, 2018	Access to banana varieties with improved pest, disease and agronomic attributes	55
Australian scientists	Presentation	M Weinert, D Peasley & J Daniells	27/11/18	Presentation	Banana Scientific Symposium, 2018	Subtropical banana variety evaluation trial	55
Australian scientists	Presentation	S Mukhopadhyay, M Weinert & M Hickey	27/11/18	Presentation	Banana Scientific Symposium, 2018	What sensory attributes are important for Australian Cavendish bananas?	55
Australian scientists	Presentation	S Mintoff	27/11/18	Presentation	Banana Scientific Symposium, 2018	Another banana varietal screening trial for TR4 resistance in the Northern Territory	55
Australian scientists	Presentation	S Hamill	27/11/18	Presentation	Banana Scientific Symposium, 2018	Providing evidence that banana tissue culture plantlets are free from Fusarium wilt	55
Australian scientists	Presentation	K Crew	27/11/18	Presentation	Banana Scientific Symposium, 2018	Novel viruses detected during quarantine screening of banana germplasm	55
Australian scientists	Presentation	K Crew	27/11/18	Presentation	Banana Scientific Symposium, 2018	Banana bunchy top virus in non-banana hosts in French Polynesia	55
Australian scientists	Presentation & discussion	J Cobon	27/11/18	Presentation	Banana Scientific Symposium, 2018	Plant-parasitic nematodes in banana production areas of Australia	55
Australian scientists	Presentation & discussion	K Thomson	27/11/18	Presentation	Banana Scientific Symposium, 2018	Lucid key - a selection tool for rotation crop selection for nematode management	55
Australian scientists	Presentation & discussion	R Piper	27/11/18	Presentation	Banana Scientific Symposium, 2018	Banana bunch protection and emerging entomological issues	55
International scientists	Conference presentation	S Lindsay	20/10/20	Conference presentation	Online workshop series hosted by the International Tropical Fruits Network as part of the Virtual workshop series on "Safeguarding the Banana Industry from	Fusarium wilt TR4 in Australia - Status, containment measures and research initiatives	55

					Fusarium Wilt: Research Updates and Opportunities in Asia Pacific		
International scientists	Conference presentation	S Mintoff	3/11/20	Conference presentation	Online workshop series hosted by the International Tropical Fruits Network as part of the Virtual workshop series on "Safeguarding the Banana Industry from Fusarium Wilt: Research Updates and Opportunities in Asia Pacific	Screening for TR4 resistance: Banana variety field trials in the Northern Territory of Australia	82
International scientists	Conference presentation	M Weinert, D Peasley & A Drenth	12/08/2018	Conference presentation	XI International Symposium on Banana: ISHS-ProMusa Symposium on Growing and Marketing Banana under Subtropical Conditions, Istanbul, Turkey	Banana diversity in the Australian subtropics - meeting the challenge	Unknown
International scientists	Conference presentation	M Weinert, D Peasley, M Smith & A Drenth	12/08/18	Conference presentation	XI International Symposium on Banana: ISHS-ProMusa Symposium on Growing and Marketing Banana under Subtropical Conditions, Istanbul, Turkey	A simple cold tolerance test for banana cultivars	Unknown
International & Australian scientists	Conference presentation	Sharon Hamill and Emily Rames	14/12/16	Conference presentation	International Symposia on tropical and temperate Horticulture, Cairns Dec 2016	An effective indexing method for banana tissue culture provides long-term freedom from bacterial contamination	500
International & Australian scientists	Conference presentation	Sharon Hamill	14/12/16	Conference presentation	International Symposia on tropical and temperate Horticulture, Cairns Dec 2016	Rapid progression of disease in susceptible and resistant banana cultivars inoculated with *Fusarium oxysporum* f. sp. *Cubense* Race 1 and Subtropical Race 4 in tissue culture	500
International scientists	Journal article	S Mintoff et al	1/08/21	Peer-reviewed journal	Journal of Fungi 2021, 7 627: http//doi.org/10.3390/jof7080627	Banana cultivar field screening for resistance to *Fusarium oxysporum* f.sp. *cubense* Tropical race 4 in the Northern Territory	Unknown

International scientists	Journal article	C De Clerck, K Crew et al	2017	Peer-reviewed journal	Annals of Applied Biology 2017, 171: 15-27	Lessons learned from the virus indexing of *Musa* germplasm: insights from a multiyear collaboration	Unknown
International scientists	Journal article	TH Ngo, R Webb, K Crew et al	2020	Peer-reviewed journal	Journal of General Virology 2020, 101: 1305-1312	Identification of putative viroplasms within banana cells infected by banana streak MY virus	Unknown
International & Australian scientists	Journal article	S Hamill and E Rames	7/11/18	Conference paper	Acta Horticulturae, 1205, pp741-747	An effective indexing method for banana tissue culture provides long-term freedom from bacterial contamination	Unknown
International & Australian scientists	Journal article	S Hamill	7/11/18	Conference paper	Acta Horticulturae, 1205, pp749-756	Rapid progression of disease in susceptible and resistant banana cultivars inoculated with *Fusarium oxysporum* f. sp. *cubense* Race 1 and Subtropical Race 4 in tissue culture	Unknown
International scientists	Journal article	J Daniells & S Lindsay	2018	Conference paper	Acta Horticulturae, 1196, pp203-209	TR4 as a driver of agroecological approaches in banana production	Unknown
RD&E providers	Conference poster	Jenny Cobon	5/09/18	Conference poster	ASDS Conference 2018	Plant-parasitic nematodes in banana production areas of Australia	150
RD&E providers	Conference poster	N Pathania et al	25/11/19	Conference poster	22nd APPS Conference, Melbourne	Internal discolouration of banana fruits - disease or disorder?	400
RD&E providers	Conference poster	R.Piper & K Ferro	6/12/19	Conference Poster	Australian Entomological Society Conference, Brisbane	The effect of bunch cover colour on banana rust thrips damage	223
RD&E providers	Conference presentation	Donna Chambers	27/09/17	Conference presentation	Science Protecting Plant Health Conference, Brisbane	The effect of groundcovers on survival of Banana rust thrips *Chaetanaphothrips signipennis* (Bagnall) (Thysanoptera: Thripidae)	40+
RD&E providers	Conference presentation	Kathy Crew	22/02/18	Conference presentation	13th Australasian Plant Virology Workshop, New Zealand	Novel ampeloviruses from banana in south-east Asia	70
RD&E providers	Conference presentation	S Hamill	11/11/19	Conference presentation	TropAg 2019	Developments in Banana Tissue Culture in Australia	800
RD&E providers	Conference presentation	S Lindsay	12/11/19	Conference presentation	TropAg 2019	The RD&E Response to Queensland's Panama Disease TR4 Incursion	800
RD&E providers	Conference presentation	K Crew	22/11/19	Conference presentation	International Conference - Controlling Banana Diseases in Mozambique	Banana Bunchy Top Disease Management in Australia	150

RD&E providers	Conference presentation	K Crew	3/03/20	Conference presentation	Brisbane	Developing diagnostic assays for novel viruses detected in banana germplasm screening	80
RD&E providers	Newsletter	T Pattison	21/02/20	Newsletter	Australasian Plant Pathology Society monthly newsletter	Pathogen of the month - Feb 2020 - *Radopholus similis*	431
RD&E providers	Presentation & discussion	K Crew et al	1/03/20	Presentation	Annual Diagnosticians Workshop, March 2020, Brisbane	Developing diagnostic assays for novel viruses detected in banana germplasm	80
RD&E providers	Workshop	Kathy Crew	20/03/18	Workshop	NPBDN Annual Diagnosticians Workshop, Adelaide	Diagnostic Residential Report - High-level training in bioinformatics analysis of NGS data	120
Government	Seminars	Kathy Crew	28/11/17	Seminars	DAF Forestry & Biosciences Forum, Brisbane	Virus research protecting the banana industry	50
Government	Workshop	Jenny Cobon	17/04/18	Workshop	DAF Queensland, H&FS Management Team meeting, ESP Brisbane	What is wrong with these roots?	65

Appendix 21 – BA16001 research and development published on Better Bananas website (Period 1 July 2018 to 3 March 2022)

During this same period the website has had 13,829 users. Australian users make up 43.5% totalling 5,963.

PAGE	All page views	Australian users' page views	Avg. time on page - ALL	Avg. time on page – Australian users
BANANA VARIETY RESEARCH				
Banana variety research	367	136	2:44	1:48
Panama TR4 variety screening trial NT (June 2016)	134	43	1:41	1:10
Panama TR4 variety screening trial NT (December 2018)	185	119	4:07	4:10
Panama TR4 variety screening trial (Dec 2018) Main trial results	15	8	2:43	0:54
Developing new resistant varieties – CJ19 mutagenesis trial	42	21	1:33	1:37
Developing new resistant varieties – Dwarf Nathan mutagenesis trial	717	577	5:59	6:31
Developing new resistant varieties Goldfinger mutagenesis trial	546	350	3:45	3:31
Developing new resistant varieties GCTCV119 mutagenesis trial	41	14	1:17	1:11
Agronomic evaluation of new varieties South Johnstone screening trial (Sept 2018)	324	250	2:53	3:04
South Johnstone agronomic evaluations (plant crop)	48	35	5:24	5:01
Agronomic evaluation of new varieties South Johnstone Plant crop (Sept 2018)	16	10	5:39	3:23
Agronomic evaluation of new varieties South Johnstone First ratoon (Sept 2018)	30	11	1:16	0:24
South Johnstone field walk	-	20	-	2:00
Panama R1 variety screening trial, Duranbah NSW	140	119	3:39	4:05

PAGE	All page views	Australian users' page views	Avg. time on page - ALL	Avg. time on page – Australian users
BUNCH PESTS				
Bunch pests	55	54	1:28	1:29
Banana bunch cover trial	297	203	2:41	2:47
Effects of using different coloured bunch covers on banana rust thrips damage	70	41	5:09	6:27
Banana rust thrips	281	151	2:18	2:42
Banana rust thrips – General information	66	49	3:50	4:16
Banana rust thrips – monitoring and control	81	55	3:29	2:41
Images of Banana rust thrips and damage caused to fruit	61	14	2:37	3:07
TOTAL PAGEVIEWS	**3516**	**2280**		
VIDEO CONTENT HOSTED ON YOUTUBE				
Update on banana variety importation and development (2020 roadshow presentation)	4 views			
Banana variety screening for Panama disease TR4 resistance in the Northern Territory	181 views			
South Johnstone agronomic trials	39 views			
Pre commercialisation roadshow presentation	39 views			
New banana variety trial at the South Johnstone Research Station, Jeff Daniells	637 views			
TOTAL VIDEO VIEWS	**900 views**			

Appendix 22 – Evaluation results – grower interviews on commercial planting of Rahan Meristem Cavendish varieties

Grower 1

- Participated in Yara tour to Israel in 2015; visited Rahan Meristem, saw photos and data on these varieties; did not see the varieties in the field but other tour members went on to visit Central America where they saw Gal.
- The project trial at South Johnstone was the first time he saw these varieties in person, and it convinced him he wanted to trial them on his own farm; he said the trial at South Johnstone was very important for the industry to see varieties perform under Australian conditions.
- He grows around 220 acres (88 hectares) – 31 acres currently planted to Rahan Meristem varieties
- Planted 8000 plants in December 2020 to trial them – 2000 each of Jaffa, Gal, Adi 9001, Adi 9168
- Planted another 20 acres of Gal in 2021 (approximately 12,000 plants), with a plan to plant another 20 acres of Adi 9168 in 2022 (approximately 12,000 plants)
- His normal crop program is to replant after 7 crop cycles/6 years; he is not accelerating his replanting strategy to change to the new varieties
- His stated he felt the biggest limitations to the broader industry planting more of these varieties is the lack of availability of plants and confidence in their performance under commercial practice and local conditions
- Observations on the varieties in the plant crop:
  - Jaffa – big plant, similar or taller than Williams; large bunch with 2-3 more hands compared to Williams; bunch pruning (false hand plus 2 more hands) could have been less because of the improved fruit length compared to Williams; uniform fruit length from top to bottom of bunch, with well-spaced hands (better than Williams); plants leaning a bit – big bunch and no bunch support may explain it; possible it may have some resistance/tolerance to yellow Sigatoka leaf spot as there is a noticeable reduction in the Jaffa rows compared to adjacent Williams rows
  - Gal – good uniform fruit length on the bunch; a shorter plant than Williams; packout in the shed is running at 1.1-1.3 cartons per bunch compared to 1.0 cartons per bunch for Williams (10-30% yield increase)
  - Adi 9168 – very dwarf stature; uncomfortable to harvest in the plant crop because plants are so short; bunch size is good with very uniform fruit length on the bunch; some twisting in some hands; good carton to bunch packout ratio (1.1-1.3 cartons per bunch = 10-30% yield increase); some bunches are weighing 30 kg in plant crop
  - Adi 9001 – short stature plant compared to Williams but not exhibiting the dwarf characters of Adi 9168; appears to have more off-types in the planting than the other varieties

Grower 2

- He has planted 9,600 plants of the Rahan Meristem varieties – 4,500 Gal and 2,250 each of Adi 9168 and Adi 9001
- He did not participate in the Yara tour to Israel in 2015 and has not seen the varieties elsewhere overseas
- Being able to see the plants in the field at South Johnstone were a positive influence on his decision to trial them commercially; he stated that the South Johnstone trial has been very important for the industry to see these varieties growing under NQ conditions
- Need now to observe these varieties under commercial conditions for multiple crop cycles; want to know what the ratoons look like
- He stated that pre-commercialisation trials are very important step for informing growers, to help make the decisions to trial new varieties

- In his opinion, if the industry finds a suitable TR4 resistant variety, the availability of planting material will be the limiting factor; supply of planting material is the limiting factor to more growers planting the Rahan Meristem varieties
- The biggest issue with using tissue culture plants is not TC as a technology but the inconsistent quality and service from the TC nursery industry

Grower 3

- Has about 2,200 plants of each of the 4 Rahan Meristem selections; planted in November 2020
- He did not participate in the Yara tour to Israel in 2015 and has not seen the varieties elsewhere overseas
- He is trialling these varieties to see their performance under commercial farm conditions
- He didn't see the plants at the South Johnstone trial; decided to trial them after talking to Mission Beach Tissue Culture nursery (exclusive supplier for the varieties in Australia); put information together on their performance from overseas and in Australia
- He stated that he is strongly supportive of pre-commercialisation trials and has expressed strong interest in trialling Asia Pacific #3 and Asia Pacific #1TTT

Grower 4

- Planted approximately 10 acres (approx. 7000 plants) in late 2020 consisting of all 4 varieties; the first ratoon crop is currently starting to bunch
- He saw the Adi 9001 and Gal varieties overseas first in Ecuador, Costa Rica and Israel; have only seen the Jaffa and dwarf type (Adi 9168) in the field at South Johnstone
- He saw benefit in seeing the selections in the research trials, however for him this didn't influence his decision to plant them mainly because he had seen them overseas; however, it did convince his father to plant them
- He did see value in the South Johnstone trial demonstrating the varieties for those that didn't get the opportunity to see them overseas
- He said that he thought the bunches more square (uniform fruit length in hands across the bunch) and hoped this would increase packout rates and reduce waste levels
- He was very supportive of the pre-commercialisation trials and said it was a really important step in variety development; growers need to see the varieties in a commercial setting; he said on-farm trials were an efficient way of evaluating the varieties and growers have the benefit of being able to get a return on the fruit

Appendix 23 – Evaluation results from extension activities

Evaluation data collected at a range of extension events conducted by the project BA19004 and containing content and presentations generated by BA16001.

Theme 1 – Negotiate access to and trial banana varieties with improved pest and disease resistance

July 2021 Banana variety trial field walk, South Johnstone

Responses to evaluation questions (n=32)

"Do you feel that you are now better informed about the variety screening work as a result of attending today's field walk?"	
Rating scale	**% of respondents**
1 – Not at all	0
2 – A little bit	3
3 – Somewhat	27
4 – Quite a lot	55
5 – A lot	15

"As a result of attending today would you consider trialling new varieties?"	
Response	**% of respondents**
Yes	45
No	23
Maybe	32

"How would you rate today's event overall?"	
Rating scale	**% of respondents**
1 – No value	0
2	0
3	0
4	0
5	4
6	4
7	11
8	46
9	14
10 – Extremely valuable	21

2020 Banana industry Roadshows

Responses to evaluation questions (n=28)

***"How would you rate your change in knowledge of banana variety research and development?"* (n=68)**		
Rating scale	**% of respondents**	
	Before event	**After event**
1 – none	6	1
2 – Limited	45	0
3 – Okay	37	49
4 – Great, I know most	9	43
5 – Completely across all activities	3	7

***"How satisfied are you with the approach to developing and importing new banana varieties into Australia?"* (n=65)**	
Rating scale	**% of respondents**
1 – Very dissatisfied	0
2 – Somewhat dissatisfied	9
3 – Neither satisfied nor dissatisfied	20
4 – Satisfied	60
5 – Very satisfied	11

***"Overall, how would you rate today?"* (n=62)**	
Rating scale	**% of respondents**
1 – Lowest	2
2	0
3	0
4	0
5	11
6	11
7	32
8	23
9 – Highest	21

March 2020 Banana variety trial field walk – NextGen growers group, Banana Variety Subcommittee members, pre-commercialisation trial cooperators

Responses to evaluation questions (n=14)

"Do you agree with the planned approach to accessing and importing new banana varieties into Australia?"	
Rating scale	**% of respondents**
1 – Not at all	0
2 – A little bit	0
3 – Somewhat	7
4 – Quite a lot	43
5 – Very Much	50

"Do you feel that you are now better informed about the variety screening work as a result of attending today's field walk?"	
Rating scale	**% of respondents**
1 – Not at all	0
2 – A little bit	3
3 – Somewhat	27
4 – Quite a lot	55
5 – A lot	15

"Rating of your knowledge of project activities to evaluate banana varieties?"	
Rating scale	**% of respondents**
1 – None	0
2 – A little bit	14
3 – Some	14
4 – Quite a lot	43
5 – A lot	29

"Rating of your knowledge of the results of project activities to evaluate banana varieties?"	
Rating scale	**% of respondents**
1 – None	0
2 – A little bit	14
3 – Some	21
4 – Quite a lot	50
5 – A lot	14

"Have you made changes as a result of project activities?"	
Response	**% of respondents**
Yes	57
No	43

"How would you rate today's event overall?"	
Rating scale	**% of respondents**
1 – No value	0
2	0
3	0
4	0
5	0
6	7
7	36
8	14
9 – Extremely valuable	43

"Would you like to continue to be informed about results?"	
Response	**% of respondents**
Yes	100
No	0

October 2019 Banana speed dating a researcher night

Responses to evaluation questions (n=28)

"How much has your knowledge of variety R&D changed as a result of attending this event?"	
Rating scale	**% of respondents**
1 – Not at all	0
2	9
3	18
4	55
5 – Quite a lot	18

"On a scale of 1-9, how would you rate this event?"	
Rating scale	**% of respondents**
1 – Lowest	0
2	0
3	0

4	0
5	0
6	4
7	15
8	39
9 – Highest	43

September 2019 NextGen rower group NT visit

Responses to evaluation questions (n=16)

"How much did this trip help improve your understanding of the investment in variety screening and development?"	
Rating scale	**% of respondents**
1 – Lowest	0
2	0
3	0
4	10
5 – Highest	90

"Would you be interested in contributing to the development and/or evaluation of new varieties?"	
Response	**% of respondents**
Yes	100
No	0

"Overall, how would you rate this visit?"	
Rating scale	**% of respondents**
1 – Poor	0
2 – Fair	0
3 – Good	0
4 – Very good	20
5 – Excellent	80

June 2019 Banana variety trial field walk

Responses to evaluation questions (n=38)

"As a result of today, with regards to the overall project Improved Plant Protection for the Banana Industry, do you?	
Rating scale	**% of respondents**
1 – Still not know much about it	0
2 – Have a limited understanding	8

3 – Have a good understanding	74
4 – Have a very good understanding	18

"How much do you know about the trials to evaluate alternative banana varieties for improved disease or pest resistance?"	
Rating scale	**% of respondents**
1 – A little bit	5
2 – Some	50
3 – Quite a bit	34
4 – A lot	11

"Overall, how would you rate today's field walk?"	
Rating scale	**% of respondents**
1 – No value	0
2	0
3	0
4	0
5	0
6	0
7	16
8	42
9	26
10 – Extremely valuable	16

September 2017 NextGen rower group NT visit

Responses to evaluation questions (n=13)

"How much did this trip help in understanding the investment in variety screening and development?"	
Rating scale	**% of respondents**
1 – Not at all	14
2	0
3	29
4	29
5 – Quite a lot	29

"Overall, how would you rate this visit?"	
Rating scale	**% of respondents**
1 – Poor	0

2 – Fair	0
3 – Good	0
4 – Very good	14
5 – Excellent	86

Theme 4 – Investigate cost-effective and sustainable integrated pest and disease management (IPDM) options

February 2021 Banana agribusiness managers group meeting

Responses to evaluation questions (n=14)

"By participating in BAGMan meetings are you better informed on banana pest & disease R&D?"	
Rating scale	**% of respondents**
1 – Strongly disagree	0
2	0
3	0
4	50
5 – Strongly agree	50

"How useful are BAGMan meetings to keep up to date with the latest banana R&D?"	
Rating scale	**% of respondents**
1 – Not very useful	0
2	0
3	0
4	43
5 – Very useful	57

2020 Banana industry Roadshows

Responses to evaluation questions

"How satisfied are you with your current level of banana rust thrips control?" **(n=54)**	
Rating scale	**% of respondents**
1 – Not satisfied	6
2 – Somewhat dissatisfied	13
3 – Satisfied	37
4 – Very Satisfied	33
5 – Extremely satisfied	11
*Most growers were satisfied with their level of control but were not happy with the way they had to attain it (unforgiving timelines, heavy reliance on chemicals with WHS and environmental considerations)	

"How useful did you find this banana rust thrips workshop discussion?" **(n=60)**	
Rating scale	**% of respondents**
1 – Not very useful	3
2	3
3	10
4	25
5 – Very useful	58

"Would you consider changing any practices as a result of participating in the banana rust thrips workshop?" **(n=49)**	
Response	**% of respondents**
Yes	27
No	53
Maybe	20

"Overall, how would you rate today?" **(n=62)**	
Rating scale	**% of respondents**
1 – Lowest	2
2	0
3	0
4	0
5	11
6	11
7	32
8	23
9 – Highest	21

October 2019 Banana speed dating a researcher night

Responses to evaluation questions (n=28)

"How much has your knowledge of bunch pest R&D changed as a result of attending this event?"	
Rating scale	**% of respondents**
1 – Not at all	0
2	19
3	29
4	33
5 – Quite a lot	19

"How much has your knowledge of leaf spot R&D changed as a result of attending this event?"	
Rating scale	**% of respondents**
1 – Not at all	9
2	9
3	37
4	41
5 – Quite a lot	5

"How much has your knowledge of bacterial corm rot R&D changed as a result of attending this event?"	
Rating scale	**% of respondents**
1 – Not at all	0
2	10
3	24
4	57
5 – Quite a lot	10

"On a scale of 1-9, how would you rate this event?"	
Rating scale	**% of respondents**
1 – Lowest	0
2	0
3	0
4	0
5	0
6	4
7	15
8	39
9 – Highest	43

Appendix 24 – BA16001 IP register

Delivery Partner Name:	**Department of Agriculture and Fisheries**
Hort Innovation Project Number and Code:	**BA16001**
Hort Innovation Project Name:	**Improved plant protection in the banana industry**

PRE- EXISITNG IP (Background IP and Third-Party IP) brought into Project							
No	**Name of IP, if any**	**Type of Output**	**Usage**	**Nature of IP**	**Conditions of use**	**Confidentiality**	**Risks identified in relation to the IP**
1	BA14014 improved (	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; varieties il
2	BA14014 improved T	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c
3	FHIA banana germp	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c
4	EMBRAPA banana	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c
5	EPAGRI banana ge	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c
6	CIRAD banana germ	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c
7	TBRI banana germp	Plant Variety	Commercialisation	Confidential Information	Exclusive Licence	Confidential	Failure of PBR to be granted; failure of c

If Type of Output is designated as "other" provide	please provide details here.
Proprietor/Owner/Licensor of IP listed above:	**If the IP listed above is associated with another Hort Innovation Project insert the Hort Innovation Project number here or if not**
Horticulture Innovation, Department of Agriculture and Fisheries, FHIA, EMBRAPA, EPAGRI, CIRAD, TBRI	BA14014 (No 1&2 only)

PROJECT IP That is intellectual property developed during the Project							
No	**Name of IP, if any**	**Type of Output**	**Usage**	**Nature of IP**	**Conditions of use**	**Confidentiality**	**Risks identified in relation to the IP**
1	Macropropagation c	Other	Dissemination	Choose an item.	Creative Commons	Choose an item.	N/A
2	Communication mat	Article	Dissemination	Copyrights	Creative Commons	Choose an item.	N/A
3	Consumer sensory	Report	Dissemination	Copyrights	Creative Commons	Choose an item.	N/A
4	Plant variety researc	Report	Commercialisation	Confidential Information	Choose an item.	Choose an item.	N/A
5	Ag chemical evaluat	Report	Commercialisation	Confidential Information	Non-Exclusive Licence	Confidential	N/A
6		Choose an item.	Choose an item.	Choose an item.	Choose an item.	Choose an item.	

If Type of Output is designated as "other" provide details here:	A modification was made of the standard macropropagation cutting technique used in the banana tissue culturing process to reduce the number of suckers developing on the plants in their first crop cycle; this technique has been publicly demonstrated to growers and TC nursery industry stakeholders; it is intended that the technique be freely available to all potential users for the benefit of the banana industry.

1. NOTES (to be annotated/linked to IP item referenced in the tables above

Item	Notes
Pre-existing IP – entry 2	Restriction on use – negotiation of commercialisation with TBRI as contributor of prior IP (standard GCTCV 215)
Pre-existing IP – entry 3	Restriction on use – exclusive licence granted to DAF in Australia for research purposes only for a selected range of FHIA varieties; commercialisation to be managed through separate commercialisation agreements with FHIA
Pre-existing IP – entry 4	Restriction on use – exclusive licence granted to DAF in Australia for research purposes only for a selected range of EMBRAPA varieties; germplasm must be planted on DAF facilities or sites supervised by DAF; commercialisation to be managed through separate commercialisation agreements with EMBRAPA
Pre-existing IP – entry 5	Restriction on use – exclusive licence granted to DAF in Australia for research purposes only for a selected range of EPAGRI varieties; germplasm must be planted on DAF facilities; commercialisation to be managed through separate commercialisation agreements with EPAGRI
Pre-existing IP – entry 6	Restriction on use – exclusive licence granted to DAF in Australia for research purposes only for a selected range of CIRAD varieties; germplasm must be planted on DAF facilities or sites supervised by DAF; commercialisation to be managed through separate commercialisation agreements with CIRAD
Pre-existing IP – entry 7	Restriction on use – exclusive licence granted to DAF in Australia for research purposes only for a selected range of TBRI varieties; germplasm must be planted on DAF facilities or sites supervised by DAF; commercialisation to be managed through separate commercialisation agreements with TBRI and the Taiwanese Council of Agriculture