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FINAL REPORT

Supply chain monitoring and improvement to reduce banana quality loss

ENDFOODWASTE COOPERATIVE RESEARCH CENTRE

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Industry Partner Foreword

Pacific Coast Eco Bananas are a grower cooperative from north Queensland who pioneered the development and marketing of an Ecoganic® farming system to grow our signature red wax tipped bananas. Pacific Coast Eco Bananas exported bananas to the Asia Pacific Region from 2009 to 2014, by way of a direct communication relationship with Park N Shop in Hong Kong and using their preferred Australian exporting agent. Through this period the greatest challenge was supply chain chilling damage to fruit. The cost in sale credits was not the only problem. The presentation of grey and dull fruit prevented market growth. During the period 2014 to 2018 market opportunities in Hong Kong and Singapore were directed to export agents in the Sydney Markets. Eco Bananas were being consolidated with other produce that required transhipping at different temperatures significantly below the 13 degrees required for bananas.

The fact that after 10 years customers were still buying red tip Eco Bananas in Singapore and Hong Kong spoke volumes about the flavour and eating quality of the product. During 2018, the interest in ecologically grown bananas increased significantly. The need to solve supply chain problems of chilling and waste became critical, hence the initial discussions with the Queensland Government's Department of Primary Industries to help with the development of a scientific tool that could open visibility across the supply chain and consolidators processes.

The decision whether a banana becomes waste or is accepted in the marketplace is mostly based on appearance of the fruit skin. The banana skin is very delicate and small changes in either temperature, humidity and handling processes become very important factors to understand. Access to global work in banana ripening under perfect conditions is readily available. There was no scientific reference evidencing the effect of undesirable supply chain practices and conditions being experienced in Australia. There is never a shortage of information but sound documented knowledge was missing. Whilst supply chain issues have improved somewhat over the past 15 years the same issues still exist today. There is a general no acceptance of blame in the supply chain with rejected fruit/waste being at the growers cost.

There are many participants in the supply chain once fruit leaves the farm gate with the export supply chain adding even more participants. Eco Bananas recognised to reduce waste in the domestic and export banana sales as well as create a successful commercial export business, rigid scientific monitoring and research would be critical. Knowledge and tools to navigate how to make improvements to processes that were out of control of the business were key.

This research project conducted extensive trials and monitoring of variables such as growing requirements, packaging, transport and supply chain temperatures that determine whether Eco Bananas became waste at the process and pack stage, were sold at a premium or reduced price, or simply became waste as a result of supply chain weaknesses.

The project was successfully conducted by Queensland Department of Primary Industries. The development of a decision tool provides banana farmers with *knowledge* to identify the root causes of banana waste and or reduced returns of bananas in both the Australian banana domestic and export market.

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Dianne Sciacca

Managing Director Pacific Coast Eco Bananas

2nd April 2025

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Executive Summary

This project was a 4-year initiative to provide Australian banana growers and their supply chain partners with increased knowledge, skills, tools and confidence to successfully manage postharvest handling risks, reduce waste and deliver more predictable fruit quality. In 2020, an estimated 10% of banana consignments were rejected by the market due to fruit arriving over-ripe or with chilling injury, presumably because they were handled either too warm or cold. Working with Pacific Coast Eco Bananas (PCEB), a north Queensland banana grower cooperative who produce Ecoganic® and organic 'Williams' Cavendish fruit, the project:

- Monitored export and domestic handling conditions to identify opportunities for improving practices;
- Developed a decision support tool to quantify handling impacts on fruit quality and prioritise improvement strategies; and
- Increased general awareness and adoption of monitoring technologies and the decision support tool.

Using modern real-time autonomous reporting data loggers, the project team monitored 51 random Ecoganic® and organic banana consignments along domestic and export supply chains. The monitoring identified that packed fruit were seldom pre-cooled at farms to the recommended 13-14°C with 80% of consignments dispatched at >20°C. The warm handling temperatures were associated with consignment rejection due to fruit arriving in the domestic market with advanced peel colour. The monitoring revealed that export fruit received variable durations of ethylene gas-ripening of 1-3 days at 15-17°C. A quarter (25%) of domestic road freight loads and 69% of airfreight export shipments experienced temperatures <13°C for as little as 6 hours or up to 9 days. Export fruit were exposed to <13°C when part of mixed commodity consignments that required lower (e.g. 5°C) storage temperatures. Exposure to low temperatures led to rejection of four Ecoganic® banana consignments due to visible chilling injury.

Parallel supply chain simulation trials quantified the impacts of different handling scenarios on fruit quality. This helped PCEB growers to prioritise interventions to reduce deviations from best practice that otherwise compromised fruit quality. Pre-cooling of packed Ecoganic® fruit to 14°C in 6 hours reduced rates of peel colour development by 22% relative to bananas that were gradually cooled to 14°C during 4 days of simulated road transport. A standard ethylene treatment with 100 parts per million of ethylene for 2 days at 16°C was optimal for coordinating rapid uniform fruit ripening. A critical exposure time of 24-48 hours to 10-12°C was sufficient to induce visible chilling injury in Ecoganic® fruit and risked consignment rejection. The project team also identified insulated packaging that could reduce the risk of fruit developing chilling injury. Modified atmosphere packaging was shown to extend the storage life of Ecoganic® fruit and reduced potential mould development during simulated seafreight.

The project team developed an interactive decision support tool that was based on mathematical modelling of trial data. The tool was validated in export supply chains to accurately predict the risk of chilling injury and the development of advanced peel colour. PCEB growers relied on the tool to guide handling strategies for successfully exporting entire pallets of Ecoganic® fruit to existing (i.e. Hong Kong) and emerging (i.e. Japan) markets in 2023. PCEB growers also gained hands-on experience and skills using modern remote monitoring technology to identify risks to product quality. By the end of the project, 50% of PCEB growers were independently deploying loggers into consignments and interpreting handling conditions data.

Taken overall, the project team assisted growers to remotely monitor export handling conditions and fruit quality, delivered a decision support tool to guide improved supply chain performance and shared project learnings to promote greater industry awareness and adoption. This supported PCEB to reduce banana fruit quality loss and waste along the supply chain from 10% of all consignments in 2020 to 0% for export shipments and 4% for domestic loads by 2023. This corresponded to a combined waste reduction of 286 tonnes and a saving of $762,960 in revenue loss in 2023. It was also associated with increased demand for PCEB bananas from a Japanese customer. This highlights the potential for further development of Australian banana exports into niche markets by focusing on monitoring and managing fruit quality. The project approach and benefits could also be extended towards improving Australia's domestic banana supply chain practices to reduce waste and deliver more predictable product quality.

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1. Introduction

1.1 Background

Australia produced 374,251 tonnes of fresh banana fruit in 2022/23, worth $583 million at farm gate (Hort Innovation Australia Ltd, 2024). Bananas were the third most valuable fruit crop in Australia behind table grapes and apples in 2022/23. The state of Queensland currently accounts for 94% of national production. The major growing regions are in north Queensland near Tully, Innisfail, Kennedy, the Atherton Tablelands and Lakeland (Australian Banana Growers' Council, 2024). The 'Williams' cultivar (*Musa* AAA; Cavendish subgroup) represents 97% of production (Australian Banana Growers' Council, 2024).

Almost all (i.e. >99.9%) Australian banana production is for the domestic market, with more than 5 million fruit consumed each day (Australian Banana Growers' Council, 2024). The fruit are a staple in Australian diets with ≥ 88% household penetration (Nielsen, 2024). Banana fruit are grown year-round and harvested at a green unripe state. The fruit are transported 2,000-5,000 km in refrigerated trucks from production regions in northern Australia to major metropolitan centres. Optimal transport temperatures for 'Williams' Cavendish bananas are 13-14°C (Duan et al., 2007). This slows down rates of fruit metabolic activity associated with ripening and deterioration but avoids the risk of under-peel chilling injury that occurs at storage temperatures below 13°C. Chilling injury is a physiological disorder that is visible as a dull grey-brown discolouration of the banana peel. The extent of injury is a function of chilling temperature and exposure time (Kader et al., 2002). Banana fruit are typically treated with ethylene gas under controlled temperatures of 13-18°C to trigger uniform ripening and then distributed to retail stores (Kader et al., 2002).

An average of 62 tonnes of Australian bananas, or less than 0.1% of production, were exported during the past 5 years (Hort Innovation Australia Ltd, 2024). Principal export markets included Hong Kong, USA, Singapore, New Zealand and Japan. Banana exports are often opportunistic and/or managed by domestic market consolidators filling temporary demand (Dianne Sciacca, personal communication, 2022). Green or pre-ripened fruit are typically exported as part of a mixed commodity airfreight consignment from major cities such as Sydney, Melbourne or Brisbane. Over the past 5 years, there have also been several banana consignments sea-freighted from Australia to Japan (Daiji Takashima, personal communication, 2023).

Pacific Coast Eco Bananas (PCEB) are a cooperative of six banana growers near Innisfail in north Queensland. Collectively, they produce over 400 hectares of Ecoganic® 'Williams' Cavendish fruit using a certified non-chemical farming system (Pacific Coast Eco Bananas, 2024). Ecoganic® bananas are distinguished by a red paraffin wax covering that is applied to the tip of fruit after harvest (Figure 1). Two PCEB growers also produce certified organic and/or conventional 'Williams' fruit. The organic fruit tips are dipped in green paraffin wax. While most Ecoganic® and organic bananas are produced for the Australian domestic market, small volumes have been exported each week by market consolidators via airfreight to high-end retailers in Singapore and Hong Kong since 2009.

Figure 1. Photograph of ripe Ecoganic® 'Williams' Cavendish banana fruit with distinctive red wax covering.

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An estimated 10% of PCEB banana consignments are rejected by the domestic and export market each year because the fruit arrive over-ripe or with chilling injury, presumably as they are transported too warm or cold (Dianne Sciacca, personal communication, 2020). This potentially represents up to 572 tonnes in physical waste and $1.75 million in revenue loss per annum. It also reflects a significant waste of inputs and energy that has gone into growing and transporting the fruit to market. Between 10% and 30% of bananas produced in north Queensland are generally discarded at the farm because they do not meet strict retail quality specifications (White et al., 2011). On average, an additional 5-8% of fruit consignments are rejected on arrival in the market by retailers because they develop quality defects along the supply chain (Kitchener, 2014).

1.2 Gaps in current knowledge

Accurate monitoring of fresh produce temperatures during postharvest handling is an important traceability requirement to allow corrective actions if conditions breach set limits. It is also an essential element of continual improvement in product dispatch, transport and arrival procedures. There is currently no monitoring of domestic and export Ecoganic® banana consignment temperatures which limits the capacity of PCEB growers and their supply chain partners to identify, assess and manage handling risks that may otherwise compromise fruit quality. Our experience with monitoring mango export consignments is that temperatures can commonly deviate above or below the optimum range and reduce fruit quality (Ainsworth et al., 2018).

Quantifying product history (e.g. production conditions, harvest maturity) and the impacts of variable handling conditions on fresh produce quality can also inform best practice strategies. It is currently not well understood how Ecoganic® bananas respond to inevitable variations in supply chain handling temperatures. This information could be applied to develop mathematical models for predicting banana arrival quality, waste levels and shelf life, as demonstrated for other horticultural commodities (Tijskens and Polderdijk, 1996; Hertog et al., 2014). These decision support tools can inform more efficient stock rotation and support a shift towards first-expired, first-out logistics that reduces the potential for physical and economic waste (Jedermann et al., 2014).

1.3 Project objectives

The general intent of this project was to provide banana growers and their supply chain partners with increased knowledge, skills, tools and confidence to successfully manage postharvest handling risks, reduce waste and deliver more predictable fruit quality. The project had three core activities:

1. Monitoring export and domestic consignments to quantify handling temperatures and time to market, identify the cause of fruit quality loss and highlight improvement opportunities;
2. Developing a decision support tool that predicts fruit arrival quality, waste and shelf life based on how bananas respond to variations in supply chain temperature and duration; and
3. Encouraging adoption of consignment monitoring technology, improved postharvest practices and the decision support tool to reduce waste by PCP chains and the broader Australian banana industry.

This 4-year project commenced in March 2020. The project team consisted of supply chain RD&E specialists from the Queensland Department of Primary Industries (DPI) plus commercial banana growers from the PCEB cooperative.

2. Methodology

The underlying philosophy of the project was to utilise co-innovation and participatory learning approaches to ensure commercial relevance and maximum impact. While the project team worked in-depth with a co-investing banana business, generic experiences, learnings and recommendations were shared with the broader industry through webinars, conference presentations, articles and

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case study factsheets to increase awareness and adoption of improved practices that reduce fruit quality loss and waste along the supply chain. The project commenced soon after declaration of the covid-19 pandemic. The associated disruption to supply chains and increased airfreight rates greatly reduced demand and frequency of PCEB exports. This led the project team to focus more on domestic supply chain monitoring and improvement until viable export pathways slowly returned. The project consisted of three programs: 1) Monitoring, 2) Decision support tool, 3) Adoption of improved practices.

2.1 Monitoring export and domestic supply chains

The objectives of the supply chain monitoring activity were to:

1. Quantify transport, ripening and storage conditions (e.g. temperature, time) and fruit performance (e.g. outturn quality, shelf life) during commercial shipment of Ecoganic® and organic 'Williams' Cavendish bananas; and
2. Demonstrate the benefits of regular consignment monitoring by identifying opportunities for improvement in handling practices to enhance supply chain performance and minimise fruit quality loss.

The project team initially mapped six principal supply chains (i.e. north Queensland to Adelaide, Brisbane, Melbourne, Sydney, Hong Kong, Singapore) that were identified as a priority for monitoring by PCEB growers based on their experience and perceived risk of fruit quality loss and claims. The characteristics (e.g. length, steps, chain partners, facilities, processes) of these supply chains were documented by surveying PCEB staff. PCEB fruit quality loss and baseline waste levels along these supply chains were estimated based on historical market rejection reports and data where available. Specific fruit quality defects and/or reasons for wastage were categorised and linked to handling steps in the supply chain.

Multiple commercial consignments of Ecoganic® and organic bananas from the summer and winter crop were remotely monitored to the five key export and domestic markets each year. The summer and winter crop were selected to capture the greatest risk of encountering warm and cold ambient temperatures that result in fruit arriving over-ripe or with chilling injury. In the final year of the project, an export consignment was also monitored to Japan. The project team used modern real-time autonomous reporting data loggers to track banana consignments from farm to retail. These portable devices consist of calibrated sensors for recording air and fruit pulp temperatures plus relative humidity and location. The loggers transmit this data to an online portal via the mobile network where users can view the route to market and history of handling and transport conditions. This allows users to identify where and when breaches in best practice occurred and to potentially intervene in near real-time. Initially, several loggers were included in single consignments to map temperature gradients within loads. This was scaled back to one logger per consignment to monitor average conditions more cost-effectively.

Fruit arrival quality (e.g. firmness, peel colour and defects) and shelf life assessment parameters were established in consultation with growers and marketers. Fresh produce surveyors in Hong Kong, Singapore and Japan were identified and trained up in banana quality assessment procedures to provide independent and reliable feedback on fruit quality and potential waste. Library or reference fruit samples from the same harvest batch were retained and held in the DPI laboratory in Cairns, Queensland under simulated export conditions. Following arrival in-market, fruit were held at 20°C and 65% relative humidity to emulate retail display conditions. The date at which individual fruit reached end of shelf life (e.g. oversoft, yellow peel colour with brown flecks) was recorded. Supply chain characteristics and fruit performance was compared against international best practice (Duan et al., 2007) to identify the potential to improve handling procedures. The impacts of implementing improvements were compared against initial chain performance. The consignment monitoring data was also used informed the design of supply chain simulation trials as described below in the decision support tools program.

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2.2 Developing a decision support tool

The objectives of the decision support tool activity were to:

1. Characterise Ecoganic®, organic and conventional 'Williams' Cavendish fruit quality and shelf life responses to different export and domestic supply chain handling scenarios (e.g. time x temperature);
2. Analyse and summarise the fruit response data to support development of best practice guidelines to enable growers and supply chain partners to adjust handling conditions to ensure optimum quality for consumers; and
3. Develop, verify and validate mathematical models, where applicable, that predict remaining shelf life and/or risk of quality defects such as chilling injury under commercial harvest, handling and supply chain conditions.

A series of 36 postharvest storage trials that quantified Ecoganic® 'Williams' fruit responses to different handling scenarios were completed at the DPI laboratory in Cairns. Briefly, fruit bunches were harvested at commercial maturity from PCEB farms and packed into boxes as per commercial practice. The fruit were transported to the laboratory and exposed to different temperatures and ethylene treatments in controlled environment rooms for varying durations that simulated the range of road, air and seafreight handling scenarios encountered in the monitoring program. The experiments were conducted with the summer and winter crop given their potential differences in postharvest response to different handling conditions (Marriott and Palmer, 1980). Fruit were also sourced from different crop ratoons to capture any crop-to-crop/season-to-season variability. Fruit quality and handling data were collected from harvest. Shelf life was assessed at 20°C and 65% relative humidity. While a range of fruit quality parameters were measured, the focus was quantifying risk of chilling injury and the end of shelf life. Model development involved determining the best fit for postharvest time temperature units (degree hours > 0°C) and shelf life data. The modelling relied on time x temperature matrices and a supply chain module approach. The storage experiments were refined and repeated based on results from the monitoring program over the life of the project to build more accurate models. Model robustness was verified by conducting comparative storage time x temperature experiments with organic and conventional 'Williams' fruit. Model accuracy was validated in the final year of the project by tracking and assessing several PCEB export consignments to Hong Kong and Japan.

2.3 Adopting improved practices to reduce waste

The objectives of the education and training activity were to:

1. Develop improved handling practices for Ecoganic® 'Williams' Cavendish bananas that reduce the risk of fruit waste based on supply chain and product quality monitoring and simulations;
2. Deliver and promote information products (e.g. factsheets, articles, webinars) to the broader banana industry; and
3. Build capacity of businesses along export and domestic supply chains to deploy monitoring technologies, interpret data efficiently and act on opportunities to improve handing conditions and fruit quality.

The project team worked closely with PCEB growers to demonstrate the benefits of a monitoring and decision support tool approach to identify opportunities for improving supply chain handling practices and reducing banana fruit waste. An experiential learning approach was used to provide the PCEB growers with hands on experience in trialling consignment monitoring technologies and the decision support tool. This helped the growers and their supply chain partners to identify, assess and manage postharvest handling risks. The consignment monitoring and simulation trial work also supported the development and implementation of supply chain improvement strategies that were designed to reduce fruit quality loss and waste. Benefit cost analysis was undertaken to determine commercial impacts and value of these project interventions. Non-confidential supply chain

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manuals and best practice guidelines were developed and delivered to PCEB and were then extended to the broader banana industry in the final year of the project. A series of industry-facing magazine articles, factsheets, webinars and conference presentations were also delivered to showcase project achievements and recommendations. Rates of adoption of consignment monitoring technologies plus the decision support tool and implementation of improved handling practices by PCEB growers were measured through interviews, comparison against best practice, and a reduction in fruit quality loss and waste.

3. Results and Discussion

3.1 Monitoring export and domestic supply chains

3.1.1 Supply chain mapping

The project team studied the movement of fruit from farm to retail, characterising each handling step (Figure 2). PCEB farms harvest mature-green Ecoganic® and organic fruit bunches in the morning. The bunches are transported to nearby pack sheds where they are de-handed into clusters of 3-5 fruit each, rinsed in a water bath, graded for quality and air-dried. Red or green food grade paraffin wax is applied to the distal tip of Ecoganic® or organic fruit, respectively. The fruit are generally packed into 15 kg capacity cardboard boxes on the same day as harvest. Fruit boxes are palletised and placed into a cold room operating at about 14°C at 5 out of the 6 growers for up to 24 hours. The remaining grower did not have a cold room at the pack shed and typically transported palletised fruit to another cooperative grower for cooling. Whilst not the focus of the current project, 15-20% of fruit were sometimes discarded at grading for failing to meet quality specifications set by the market (Frank Sciacca, personal communication, 2021).

Palletised consignments were transported to a local refrigerated storage depot in Innisfail for consolidation. The consignments were then road-freighted in refrigerated trucks to domestic wholesale markets or retail distribution centres in Brisbane, Sydney and Melbourne. The fruit were gas-ripened with approximately 100 parts per million ethylene by the retailers or a third-party ripener and maintained under controlled temperatures until reaching a desired peel colour prior to distribution to retail stores. Fruit boxes destined for the export market were collected by consolidators and exporters at the wholesale markets upon attaining 50% yellow peel colour. The boxes were built into mixed or multiple commodity airfreight pallets and exported by airplane to Hong Kong or Singapore. The fruit were then distributed by the importer to wholesalers and high-end retail customers. While PCEB growers worked with Perfection Fresh Australia to market domestic consignments, they had limited visibility and control over fruit exports. The project team identified five consolidators/exporters at the Sydney Produce Market who were managing weekly Ecoganic® and organic banana orders from international customers. The exporters sampled domestic grade fruit from ripeners or the market floor independently of PCEB.

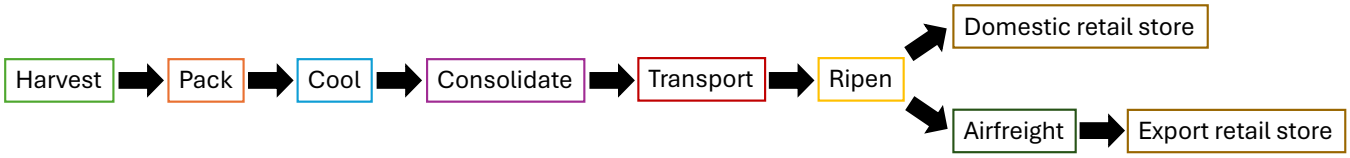

Figure 2. Diagram showing key steps along Ecoganic® and organic banana domestic and export supply chains.

3.1.2 Fruit quality loss and waste

As a baseline measure, it was estimated that 10% of domestic and export Ecoganic® consignments were rejected by the market in 2021 because of poor arrival quality (Dianne Sciacca, personal communication, 2021). By analysing feedback from the market,

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PCEB determined the relative expression of different quality defects in the rejected domestic consignments (Figure 3). Up to 39% of the rejected consignments arrived with excessive physical damage, including peel abrasion from transport vibration and chilling injury from low temperature exposure. About a fifth (i.e. 21%) of consignment rejections were because fruit arrived with advanced peel colour possibly from being picked too mature or transported too warm. An additional 12% of consignments were rejected because the fruit arrived above (>15°C) or below (<13°C) retail receival temperature specifications (e.g. ALDI, 2021) and were at risk of uneven ripening or developing chilling injury, respectively. Estimates by the Australian Food Cold Chain Council (Brodribb et al., 2020) suggest the poor temperature management in supply chains is responsible for $2.96 billion of fruit and vegetable waste each year. Our quality loss data support this observation. Waste levels at the farm (i.e. 15-20%) and along the supply chain (i.e. 10%) were generally consistent with previous reports for Australian bananas where a cumulative 15-38% of all fruit produced can be discarded before reaching the consumer because they fail to meet market specifications (White et al., 2011; Kitchener, 2014).

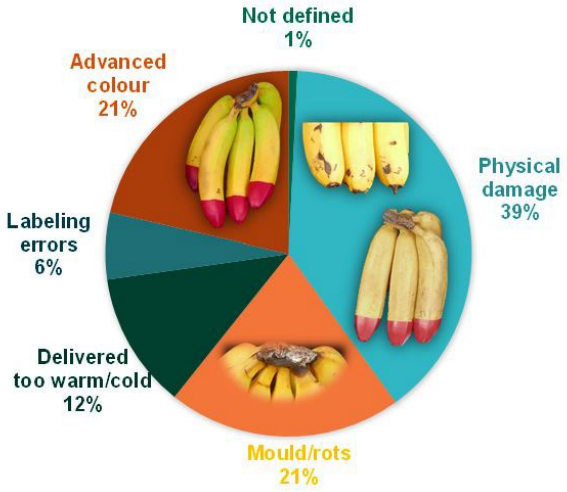

Figure 3. Relative proportion of quality defects in rejected domestic Ecoganic® banana consignments during 2021.

3.1.3 Supply chain monitoring

From 2020 to 2023, 35 domestic road freight and 16 airfreight export consignments of Ecoganic® and organic fruit from four PCEB growers were randomly selected and tracked along the supply chain using autonomous reporting data loggers. The temperature of a representative consignment is shown in Figure 4. The monitoring identified the following three critical control points in the supply chain where the risk of fruit quality loss was associated with variable temperature management and ripening practices:

- Inadequate pre-cooling at farms and the north Queensland transport depot to 13-14°C;
- Variable duration of ethylene gas-ripening of 1-3 days; and
- Low (<13°C) or high (>18°C) post-ripening storage and distribution temperatures.

About 80% of the monitored consignments were dispatched from farms at >20°C and it generally took 2-4 days of cold storage plus refrigerated transport before fruit reached the recommended 13-14°C. The warm handling temperatures were associated with rejection of one consignment due to fruit arriving in the domestic market with advanced peel colour. Temperatures in the middle of pallets were often 1-3°C warmer than fruit on the outside layers during the initial leg of the supply chain. This reflected poor

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refrigerated air circulation into the core layers of pallets and the buildup of heat from the respiring fruit. This increases the risk of premature and uneven ripening plus variable fruit quality for consumers.

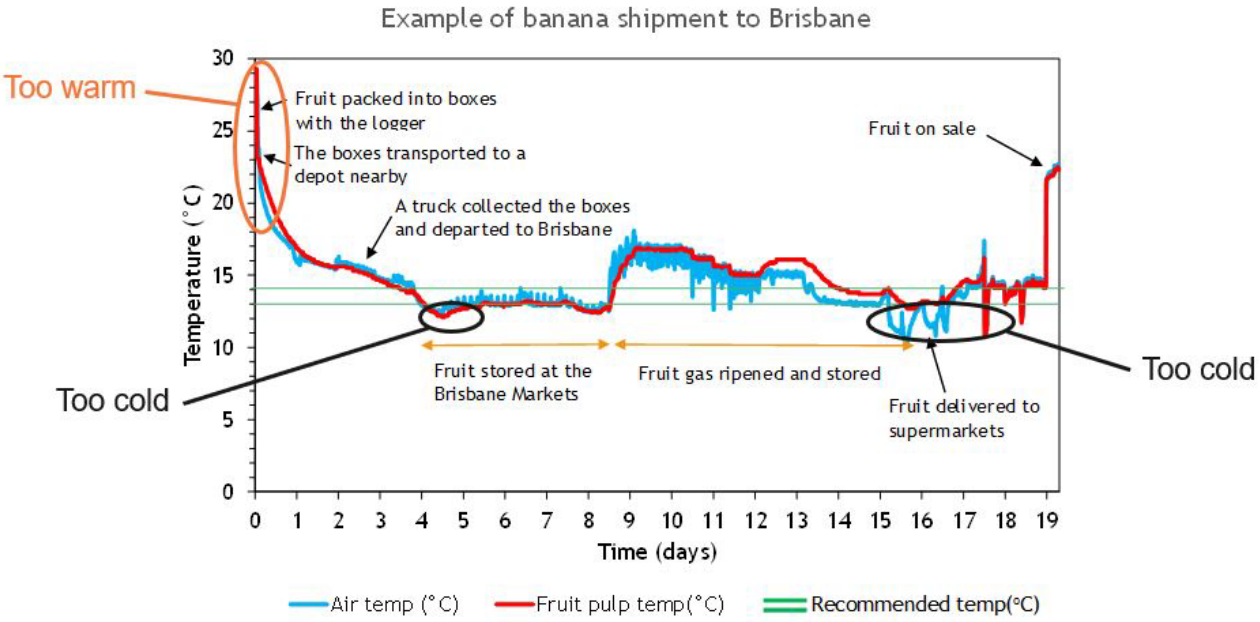

Figure 4. Changes in air and fruit pulp temperature within an Ecoganic® banana consignment along a domestic supply chain from a farm in Innisfail to a retail store in Brisbane, Australia.

While gas-ripening conditions for domestic market fruit were relatively consistent, export fruit were treated with ethylene for either 1, 2 or 3 days at 15-17°C across different consignments. This variable practice is probably a reflection of the ad hoc nature of filling export orders by the market consolidators. It increases the risk of dispatching fruit at different ripening stages and delivering inconsistent fruit quality and shelf life, leading to potential food waste. Across the 16 monitored export consignments, shelf life varied from 3-8 days, mainly due variable temperature management and ripening conditions.

A quarter (25%) of monitored domestic consignments and 69% of export shipments experienced temperatures <13°C for as little as 6 hours up to 9 days. This typically occurred during storage before or after ripening but also occasionally during unloading of trucks at retail distribution centres in winter at low ambient temperatures. The export fruit were also regularly exposed to <13°C as they were part of mixed commodity consignments that included vegetables and other fruit that required lower storage temperatures. Low temperature exposure was associated with development of minor to severe chilling injury in the Eocganic® and organic bananas that led to downgrading of price and/or outright rejection by the market. The export fruit were sometimes also subjected to relatively warm arrival and distribution temperatures of >18°C in markets. These variations in supply chain temperatures are broadly consistent with observations for other horticultural commodities that are exported by air from Australia to Asia (Ainsworth et al., 2018). Taken together, these deviations in procedures highlight the challenges of managing different handling scenarios and the potential for fruit waste. It pointed to opportunities for the project team to encourage adoption of more consistent practice.

The monitoring also revealed instances of logistics delays in the supply chain. Consignments that arrived late in Sydney and missed export schedules were held for up to 7 days until the next consolidated airfreight order. This included being stored for 3-4 days before gas-ripening at temperatures <13°C. This translated into fruit that had reduced shelf life and greater incidence and severity of chilling injury when fully ripe.

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While the monitoring has quantified a broad range of handling conditions experienced by Australian banana fruit, it also identified opportunities for improved handling practices to enhance supply chain performance and minimise physical and economic waste. For example, a consignment that arrived in Singapore displaying extensive chilling injury was found to have been stored at <13°C for 9 days in total by the exporter and importer before and after airfreight (Figure 5). The fruit were unmarketable and rejected by the customer, representing significant economic and reputational loss for PCEB. By working with the exporter and importer to encourage improved temperature management (i.e. 13-18°C), subsequent consignments arrived in Singapore at a more advanced ripening stage but without chilling injury and were well received by the retailer.

Figure 5. Photographs of Ecoganic® banana fruit on arrival in Singapore following airfreight from Australia. Fruit on the left from the first consignment were exposed to <13°C for 9 days during export handling and exhibited severe chilling injury. Fruit on the right from a second consignment were always maintained >13°C and did not develop chilling injury.

3.2 Developing a decision support tool

3.2.1 Supply chain simulations

A series of simulation trials were completed in the laboratory to quantify the impact of deviations in supply chain conditions on fruit quality. Each trial was designed to test different handling scenarios (e.g. temperature, time, ethylene) at the three critical control points identified in the monitoring activity. Most trials included a final step where airfreight conditions were simulated. Additional trials were completed to evaluate the potential of different packaging materials to reduce the risk of fruit quality loss and waste.

Adequate pre-cooling

Banana fruit in north Queensland are often harvested, graded and packed at high ambient temperatures of >30°C. This necessitates the removal of substantial field heat from packed fruit during pre-cooling. Trials completed by the project team demonstrated that rapid pre-cooling of packed Ecoganic® fruit from 31°C to 14°C in about 6 hours reduced rates of peel colour development by 22% relative to bananas that were gradually cooled to 14°C during 4 days of simulated road transport. Pre-cooling fruit to 13-14°C at the farm plays an important role in reducing premature ripening and colour development that otherwise exceed quality specifications at receival as set by ripeners and retailers.

Standard ripening procedures

Gassing Ecoganic® fruit with 100 parts per million of ethylene for 2 days at 16°C was found to be optimal for coordinating rapid even ripening. A longer treatment duration of 3 days offered no additional benefit and reduced the available time to deliver fruit to

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the market by 1 day. Reducing ethylene exposure time to 1 day at 14, 16 or 18°C was associated with non-uniform ripening plus a higher incidence of rot development in fruit. Ethylene treatment at 14°C delayed full yellow peel colour development by 1 day, as compared to fruit treated at 18°C. There were no significant differences in the fruit response when ripened at 16°C and 18°C.

Post-ripening temperature management

Consignment temperature management following gas-ripening was identified as a critical step for maintaining fruit quality and delivering a product that meets market expectations. Simulation trials established that reducing the post-ripening consolidation temperature from 20°C to 16°C delayed fruit ripening and peel colour development by about 4 days. Reducing the temperature further from 16°C to 13°C extended shelf life by an additional 6 days following typical airfreight to Asian markets.

Sensitivity to chilling injury

The sensitivity of Ecoganic® and organic fruit to chilling injury was determined for summer and winter crops across two seasons. Regardless of the harvest time and season, visible chilling injury developed following exposure to <13°C. This is consistent with reports for conventionally produced 'Williams' Cavendish banana fruit (Nguyen et al., 2003; Herppich and Zsom, 2021; Zhang et al., 2021). The severity of injury was inversely related to temperature, with decreasing temperatures and/or extended exposure time eliciting more damage. Exposure to <13°C also impaired fruit ripening and incomplete peel yellow development. Fruit produced in the summer were slightly more sensitive, with green fruit displaying visible symptoms following a 24-hour exposure to 10-12°C. Fruit from the winter crop developed chilling injury after a 48-hour exposure to 10-12°C. The relatively greater tolerance of winter fruit is presumably related to their acclimation to cooler temperatures during production. This data provides an opportunity to establish critical exposure thresholds to <13°C as part of best practice guidelines to reduce the risk of product waste.

Reducing chilling injury

Given that it may be impractical to always avoid exposure of bananas to <13°C in mixed commodity consignments, the project team evaluated the potential of insulated packaging to protect fruit against low temperatures. Closed Styrofoam boxes containing fruit at 15°C could be transferred to a 5°C room and maintained for up to 24 hours before the fruit core temperature dropped below 12°C. Wrapping conventional cardboard boxes in a layer of air-cell insulation could reduce the ingress of cold air from a 5°C storage room and delay fruit temperatures reaching 12°C for 5-7 hours. Investment in insulated packaging may help alleviate chilling injury and food waste in high-risk supply chains. Alternatively, it may be possible to build boxes of bananas last into mixed commodity consignments to minimise the exposure time to chilling temperatures.

Seafreight simulations

Several seafreight simulation trials were also completed, given the desire of PCEB to eventually transition away from mixed commodity loads and unrefrigerated airfreight. Seafreight temperatures of 13-15°C were found to be suitable for maintaining Ecoganic® fruit quality and delivering sufficient shelf life following a shipment duration of up to 3 weeks. This is in line with the handling practice adopted by major banana producing countries (e.g. Ecuador, Philippines) that seafreight 'Williams' Cavendish long distances to market (Kader et al., 2002). Up to 80% of Ecoganic® bananas developed mould on the fruit stem end when the shipment duration was extended to 4 weeks. This timeframe is sometimes required when exporting Australian fruit by sea to more distant markets in north Asia (e.g. Korea, Japan), The risk of mould development during long-term storage or shipment is likely heightened for organic or Ecoganic® fruit, as compared to conventional products that rely on synthetic fungicides.

Modified atmosphere packaging (MAP)

The project team evaluated the use of MAP in place of the industry standard perforated plastic liners in boxes for extending the storage potential of fruit. MAP is a well-established technique for reducing rates of fruit quality loss in combination with optimal

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postharvest temperature management. It relies on permeable packaging materials to allow CO_2 concentrations to increase and O_2 levels to decrease around the product. Simulating seafreight of Ecoganic® fruit at 13°C for 3-4 weeks in commercially available plastic or biodegradable MAP was more effective at reducing the potential for market rejection due to peel chilling injury, mould development and insufficient shelf life than standard box liners. CO_2 levels inside the closed MAP increased to 3-4.5% while O_2 decreased to 12-14% during the first 7 days of the trial until reaching a steady state. The MAP slowed rates of fruit colour development and reduced mould growth by 10-fold relative to fruit in perforated liners. Fruit maintained in MAP during seafreight developed a similar eating quality at ripe to bananas in the perforated liners and exhibited no off-flavours. Relative to industry-wide use of perforated plastic packaging, shipping fruit in modified atmosphere packaging increased shelf life by 1-2 days and could safely extend shipment duration to 4 weeks, necessary for reaching distant markets. MAP applied at the fruit packing step was also found to extend the storage life by 2-3 days at typical airfreight supply chain temperatures. However, there was substantial accumulation of condensation within the MAP that could potentially increase the risk of disease development on fruit.

3.2.2 Modelling and validation

Tool development

Data generated by the trials described above were used to develop a decision support tool based on mathematical (generalised linear) models for predicting the risk of chilling injury and the development of peel colour. A framework was developed whereby each decision point reflected handling steps that had the greatest impact on fruit quality. Initially structured as a flow chart with key decision points, the tool was reformatted as a poster for packhouse workers, while the more advanced features were utilised in the office by supply chain and export staff. The posters depict key supply chain decision points and recommendations for optimising air and seafreight conditions to reduce postharvest handling risks that result in fruit quality loss and waste. An interactive, manual data entry version of the tool was also developed using RStudio (Build 421 by the Posit team, 2023, PBC, Boston, MA, USA) (Figure 6).

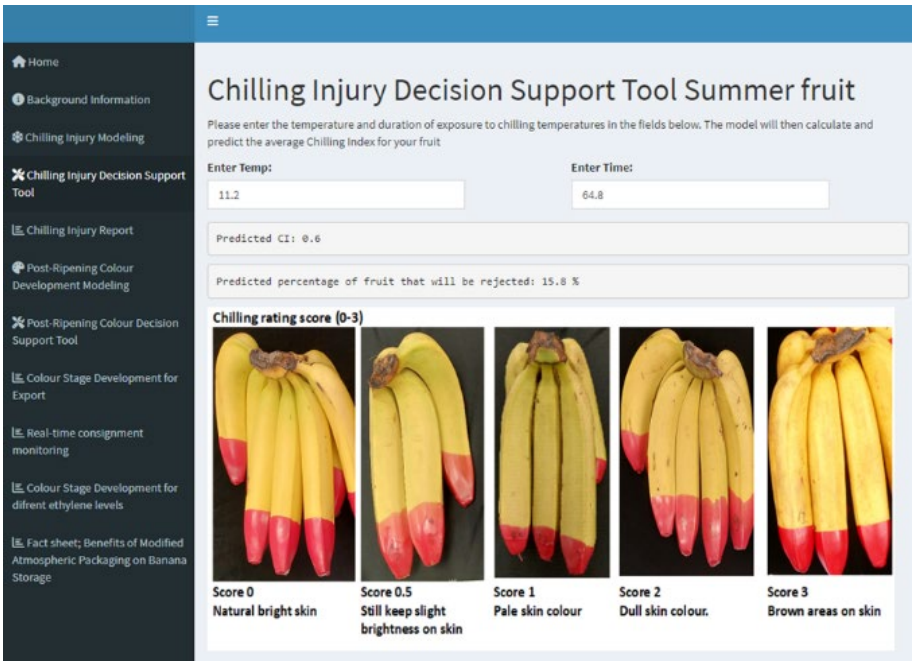

Figure 6. Screenshot of a banana handling decision support tool showing a predictive chilling injury function.

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Tool validation

The decision support tool was tested using data collected from four monitored airfreight consignments from north Queensland to Singapore. In shipments 1 and 2, Ecoganic® fruit were held at 3-5°C for a total of 4 and 8 days, respectively, by the Sydney freight forwarder and Singaporean importer. This practice is consistent with handling of a mixed consignment of temperate fruit and vegetables but ignores advice that bananas are chilling sensitive to temperatures <13°C. Based on previous storage trial data, the decision support tool predicted there was a high probability that fruit would develop chilling injury. This was independently confirmed by the market surveyor in Singapore.

In shipments 3 and 4, the exporter and importer followed instructions to maintain the banana boxes within the consignment at >13°C. Based on the monitored shipment temperatures of 13-18°C, the decision support tool correctly predicted that fruit from shipment 3 would exhibit a full yellow peel colour at inspection in Singapore. For shipment 4, the tool predicted that fruit would arrive in Singapore with 50-70% yellow peel colour based on handling conditions after ethylene treatment. This was confirmed by an independent surveyor. This exercise showed that the tool was able to accurately predict fruit quality and shelf life.

While the decision support tool is based on Ecoganic® banana responses to different supply chain conditions, it was used successfully to predict development of peel colour for organic and conventional 'Williams' Cavendish that were slowly cooled from 30°C in simulation trials. The tool also accurately predicted the severity of chilling injury in organic and conventional fruit stored at 7°C. This suggests that the general postharvest performance of organic, conventional and Ecoganic® fruit may not differ greatly.

3.3 Adopting improved practices to reduce waste

PCEB growers gained hands-on experience using modern consignment monitoring technology and interpreting the associated data to identify risks to product quality. By the end of the project, 50% of PCEB growers were independently deploying loggers into consignments and interpreting handling conditions data (Figure 7). This activity also highlighted opportunities for PCEB to improve communication and data sharing with their supply chain partners to achieve better fruit quality outcomes. PCEB growers were also supported to access independent feedback on fruit arrival quality and shelf life from trained professional surveyors in key markets.

Figure 7. Frank Sciacca (left) of PCEB and Angelo Russo (right) from Marlin Blue Pty Ltd placing a real-time data logger into boxes of Ecoganic® banana fruit.

With more regular monitoring and access to the simulation trial data plus the decision support tool, PCEB and their supply chain partners improved their knowledge of practices that reduce loss, extend shelf life and deliver more predictable fruit quality.

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Notification from the loggers when conditions deviated from best practice prompted the project team to work with PCEB supply chain partners to identify and correct poor temperature management before fruit quality was lost. The decision support tool that quantified potential impacts of these handling events on fruit quality provided the evidence, confidence and urgency to intervene.

Monitoring of three consignments to Hong Kong and Japan in 2023 revealed that supply chain partners had adopted improved handling practices. For example, Ecoganic® bananas exported in a mixed commodity pallet were always maintained at >13°C. This contributed to a reduction in physical waste from an initial 10% of all export consignments in 2020 to 0% in 2023. The monitoring data and decision support tool were also used to convince a Hong Kong importer that fruit stored at <12°C needed to be promptly transferred to a warmer storage environment to avoid chilling injury and food waste. PCEB adopted a similar approach to reduce unnecessary fruit waste by 59% in their domestic supply chains from an estimated 10% of consignments in 2020 to 4% in 2023.

PCEB also used the decision support tool to test potential handling scenarios and impacts on fruit quality prior to committing to export Ecoganic® consignments to Japan for the first time. Japan maintains a strict market access protocol for Australian bananas whereby the fruit must arrive in a green unripe state or else be rejected and discarded. Two export handling scenarios were tested; 1) airfreight direct from Cairns in north Queensland to Tokyo, and 2) road freight to Sydney prior to airfreight. Based on simulation trial data, the tool predicted the risk of excessive peel colour development was moderate to high for fruit transported via Sydney and low if air-freighted directly from Cairns. Accordingly, PCEB decided to export the fruit directly from Cairns to Tokyo and given that handling temperatures were generally 13-15°C, the fruit retained a green peel required for entry into Japan.

Economic analysis of remote monitoring of banana export conditions highlighted how the technology can be cost effective in minimising fruit waste. For example, in two monitored export consignments in 2022, a $100 investment in real-time loggers could have alerted supply chain partners to a potential chilling injury event. Moving the fruit to a warmer storage environment could have reduced peel chilling injury severity by 65%. The exporters could also have cancelled the shipment and redirect damaged fruit to a local cake processor. This scenario could have reduced economic loss by up to $9,000 and prevented 1,980 kg of physical waste.

Project learnings and recommendations for delivering more consistent fruit quality and minimising food waste have been extended to the broader banana industry through a series of industry-facing communication products, as listed below:

Articles

- Archer, J., Nguyen, M., Macnish, A., Veivers, S. (2023). Modern monitoring technologies for improving supply chain performance. *Australian Bananas* **67**, 35.
- Archer, J., Nguyen, M., Macnish, A., Veivers, S. (2023). Real-time consignment monitoring: Unpacking the costs and benefits. *Australian Bananas* **69**, 37.
- Fight Food Waste CRC (2020). Focusing on reducing food waste in the export banana supply chain. Available at: https://www.freshplaza.com/latin-america/article/9214306/focusing-on-reducing-food-losses-in-the-export-banana-supply-chain/ (Accessed 6 May 2020).
- Macnish, A., Mazhar, S., Sole, D., Johnston, B. (2020). Project puts supply chain in spotlight. *Australian Bananas* **58**, 10.
- Macnish, A., Archer, J., Nguyen, M. (2024). Australian bananas on the international stage. *Australian Bananas* **70**, 34-35.

Conference presentations

- Archer, J., Nguyen, M., Macnish, A., Veivers, S. (2023). Modern monitoring technologies for improving supply chain performance. Australian Banana Industry Congress, Cairns, Australia, May 18-19. Attended by 350 industry representatives.

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- Archer, J., Nguyen, M., Macnish, A. (2024). Predicting the risk of banana fruit chilling injury based on postharvest handling conditions. IX International Postharvest Symposium, Rotorua, New Zealand, Nov 11-15. Attended by 55 researchers.
- Macnish, A., Archer, J., Nguyen, M., Sciacca, F., Sciacca, D., Picker, G. (2023). Banana supply chain monitoring and simulation identifies critical control points. Australian Banana Science Symposium, Cairns, Australia, May 17. Attended by 100 research, funding agency and industry personnel.
- Macnish, A., Sciacca, F., Sciacca, D., Archer, J., Nguyen, M., Picker, G. (2022). Supply chain monitoring and improvement to reduce banana quality loss. 2022 National Food Waste Summit, Brisbane, Qld, Australia, 23-24 November. Attended by 30 research and industry personnel.

Factsheets

- Archer, J., Nguyen, M., Macnish, A. (2024). Benefits of modified atmosphere packaging for bananas. CRC End Food Waste factsheet. (Draft)
- Nguyen, M., Archer, J., Macnish, A. (2024). Reducing banana chilling damage during transport. CRC End Food Waste factsheet. (Draft)
- Veivers, S., Archer, J., Nguyen, M., Macnish, A. (2024). Real-time consignment monitoring for improving supply chain performance. CRC End Food Waste factsheet. (Draft)

Press release

- Queensland Government (2023). Queensland bananas and melons make groundbreaking voyage to Japan market. Available at: https://statements.qld.gov.au/statements/99229 (Accessed 24 November 2023).

Scientific papers

- Archer, J.R., Nguyen, M., Macnish, A.J. (2024). Predicting the risk of banana fruit chilling injury based on postharvest handling temperature and time. *Acta Horticulturae* (draft).

Social media posts

- Queensland Government (2023). Queensland-grown bananas in Japan. Available at: https://www.facebook.com/QldAgriculture/videos/queensland-grown-bananas-in-japan/1567137647440440/ (Accessed 23 November 2023).

Webinars

- Macnish, A., Archer, J., Nguyen, M., Sciacca, D., Picker, G. (2022). Supply chain monitoring and improvement to reduce banana fruit quality loss. CRC Fight Food Waste Lunchtime Series webinar. Zume. 5 April 2022. Attended by 16 research, development and extension specialists.
- Macnish, A., Sciacca, F., Archer, J. (2024). Improving banana supply chain performance for consistent fruit quality. Queensland Department of Agriculture and Fisheries webinar. Microsoft Teams. 22 February 2024. Attended by 29 banana growers, transporters, exporters, national retailers and project staff.

The project information products along with the interactive version of the decision support tool are planned to be hosted on the Better Bananas (www.betterbananas.com.au) industry website to enable easy access by growers and supply chain businesses.

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4. Conclusions and Recommendations

The project achieved its core objective of generating new knowledge and developing industry capacity to reduce banana fruit quality loss and waste along export supply chains from 10% of all consignments in 2020 to 0% by 2023. The project team supported growers to remotely monitor export handling conditions and fruit quality, delivered a decision support tool to guide improved supply chain performance and shared project learnings to promote greater industry awareness and adoption. This approach assisted growers and supply chain businesses to identify, assess and manage handling risks that were otherwise compromising fruit quality, causing physical waste and loss of reputation as trusted suppliers of a premium horticultural product.

There is potential to extend project learnings and the data-driven decision support tool to further develop Australian banana exports and improve domestic supply chain performance and fruit quality outcomes. Additional RD&E will be needed to increase awareness amongst the broader banana industry of the value of combining supply chain monitoring and the decision support tool for delivering more consistent fruit quality. The project conclusions complement elements of a recently reported banana industry waste action plan (Akbar et al., 2024) and the need for improving supply chain handling practices, data collection/sharing and collaboration.

The following recommendations are offered for businesses aiming to minimise waste in Australian banana export supply chains:

1. Establish a dedicated staff member to manage banana export monitoring and improvement. The position would be responsible for evaluating the risk profile of different supply chains, coordinating consignment monitoring, interpreting data and working with supply chain partners to implement improved practice, where necessary.
2. Regularly monitor banana export consignments at greatest risk of encountering sub-optimal supply chain handling conditions using modern real-time data loggers. Improve temperature management where there is an ability to intervene. In due course, potentially scale back monitoring activities as the risk reduces.
3. Request objective feedback on banana fruit quality on arrival in export markets to quantify the impacts of deviation in consignment temperature management on product performance. This will inform decisions for prioritising improvements where the greatest impact can be reliably achieved.
4. Ensure that banana fruit are pre-cooled to 13-14°C prior to dispatch from the farm. Consider investing in forced-air cooling infrastructure at farms to help remove field heat from packed fruit. Identify chain partners (e.g. transporters) with the necessary cold-chain knowledge and equipment to maintain fruit at optimal handling temperatures.
5. Apply a standard 2-day ethylene treatment to trigger uniform banana fruit ripening. Maintain fruit at 13-16°C post-ripening and ensure all fruit reach a standard peel colour (e.g. 50% yellow) before airfreight to provide predictable shelf life.
6. Consider using insulated packaging to reduce the risk of chilling injury to banana fruit when stored and transported in mixed commodity loads at low (<13°) temperature. Request that freight forwarders/exporters build boxes of bananas into mixed commodity loads last to minimise the exposure time to temperatures <13°C.
7. Consider exporting entire air or seafreight containers of bananas where demand exists for larger volumes. Use modified atmosphere packaging in place of the standard perforated plastic liners to reduce mould development on organic and Ecoganic® fruit if the seafreight duration exceeds 3 weeks. Consider sustainable biodegradable packaging materials.
8. Access the decision support tool to ensure more meaningful information can be extracted from consignment monitoring data. Share data with supply chain partners to inform decisions on consignment handling and marketing. Utilise the tool to guide decisions on modes of transport and pathways to market to reduce the risk of fruit quality loss and disputes.

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9. Access on-the-ground resources in export markets to connect to potential customers. Increase trust and collaboration between supply chain members by collecting and sharing performance data (e.g. cold chain temperatures, quality on arrival). Data sharing is critical to ongoing improvement.
10. Invest in RD&E that improves domestic and export banana supply chain performance by providing industry with the necessary knowledge, skills and confidence to consistently deliver predictable fruit quality. Evaluate technologies (e.g. modified atmosphere packaging) and practices (e.g. forced-air cooling) to reduce the risk of fruit quality loss and waste.

5. Impact and Ongoing Monitoring

In 2020, 10% of PCEB banana consignments were rejected by the market because the fruit did not meet retail quality specifications. This represented an estimated 572 tonnes in physical waste and $1.75 million in revenue loss per annum. The introduction of supply chain monitoring and adoption of improved practices helped to eliminate all physical waste in PCEB export consignments by 2023. It also led to a 59% waste reduction in PCEB domestic loads to 4% of all consignments. This corresponded to a combined reduction of 286 tonnes of banana waste, saving $762,960 in annual revenue loss in 2023. Delivery of more consistent fruit quality also provided PCEB with the confidence to export 1,000 kg pallets of Ecoganic® fruit to Hong Kong and Japan in 2023. The increase in export volume was accompanied by enhanced customer satisfaction and demand for repeat orders.

Adoption of the decision support tool and monitoring technology to reliably predict and consistently deliver high quality bananas to export markets could also support a shift from unrefrigerated airfreight to higher volume, lower cost seafreight with greater temperature control. There is significant demand in Asian niche markets for Australian organic and Ecoganic® bananas. Delivery of more predictable fruit quality should boost the reputation of Australian growers as preferred suppliers. Improved cold chain management and fruit arrival quality via seafreight is projected to support export growth of up to 25-fold or $2 million over the next 10 years. The lessons learnt from this export study should also be relevant for improving domestic banana supply chains.

The project played an important role in building industry capacity to monitor and improve export fruit quality. The legacy of this project will also be measured through ongoing adoption of monitoring technologies and the decision support tool. Increased volume and value of Australian banana exports and a shift from unrefrigerated airfreight to controlled temperature seafreight will be other objective measures of ongoing project impact to monitor.

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APPENDIX A – Project Summary

‘Supply chain monitoring and improvement to reduce banana quality loss’

KEY POINTS

- According to the Australian Food Cold Chain Council, poor temperature management along the supply chain is responsible for $2.96 billion of fruit and vegetable waste each year (Brodribb et al., 2020).
- Accurate monitoring of perishable fresh produce temperatures during postharvest handling is an important traceability requirement to identify the root cause of any product quality loss and waste.
- Pacific Coast Eco Bananas (PCEB), a grower cooperative in north Queensland, produce Ecoganic® and organic ‘Williams’ Cavendish banana fruit using a certified sustainable farming system.
- While the fruit are in significant demand in domestic and export markets, PCEB have no visibility and control over their fruit once it leaves the farm which limits their ability to ensure product quality always meets expectations.

THE CHALLENGE

An estimated 10% of Australia banana consignments are rejected by the domestic and export market each year because the fruit arrive over-ripe or with chilling injury, presumably because they are handled too warm or cold. PCEB export fruit are typically air-freighted with other commodities that require low (e.g. 5°C) storage temperatures that can cause chilling injury in bananas. There is currently no monitoring of PCEB consignment temperatures which limits the capacity of growers and their supply chain partners to identify, assess and manage handling risks that may otherwise compromise fruit quality.

THE OPPORTUNITY

This project aimed to provide Australian banana growers and their supply chain partners with increased knowledge, skills, tools and confidence to successfully manage postharvest handling risks, reduce waste and deliver more predictable fruit quality. The project team worked with growers and their supply chain partners to monitor and improve existing supply chain handling practices.

Figure 1. Photograph of Ecoganic® banana fruit with chilling injury after exposure to low supply chain temperatures.

OUR RESEARCH

SUPPLY CHAIN MONITORING

The project team supported PCEB growers to monitor 51 random Ecoganic® and organic banana consignments along domestic and export supply chains. Modern real-time autonomous reporting data loggers were used to monitor handling conditions, while trained assessors in-market recorded fruit quality. The monitoring program aimed to identify opportunities for improving handling practices.

DEVELOPING A DECISION SUPPORT TOOL

Parallel supply chain simulation trials were conducted to quantify the impacts of different handling scenarios on banana fruit quality. A decision support tool based on mathematical modelling of trial data was developed for

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predicting fruit quality responses. This program aimed to assist growers and their supply chain partners to assess and manage supply chain risks to fruit quality.

ADOPTING IMPROVED PRACTICES

The project team shared project learnings to promote greater banana industry awareness and adoption of improved handling practices and technologies that reduce fruit quality loss and waste. The project aimed to build capacity of businesses along export and domestic supply chains to deploy monitoring technologies, interpret data efficiently and act on opportunities to improve fruit quality.

Figure 2. Banana growers, Frank Sciacca and Angelo Russo, placing a data logger into an Ecoganic® banana box.

OUTCOMES

The project achieved its core objective of generating new knowledge and developing industry capacity to reduce banana fruit quality loss and waste along PCEB export supply chains from 10% of all consignments in 2020 to 0% by 2023. The project team supported growers to remotely monitor handling conditions and fruit quality to identify risks to product quality. Key findings included:

- 80% of consignments were dispatched too warm (>20°C) which accelerated fruit peel colour development;
- Export fruit were exposed to variable gas-ripening durations of 1-3 days which led to inconsistent quality and shelf life; and
- 25% of domestic road freight loads and 69% of export airfreight consignments were exposed to temperatures of <13°C, which was associated with fruit chilling injury and market rejection.

By the end of the project, 50% of PCEB growers were independently deploying modern remote monitoring technology into consignments and interpreting handling conditions data. The project team developed a decision support tool that was based on modelling fruit responses to variable handling conditions. The tool incorporated a series of best practice handling guidelines that assisted growers and their supply chain partners to prioritise improved handling practices and reduce the risk of advanced peel colour development and chilling injury. The project team encouraged broader industry awareness of the monitoring technologies and decision support tool via a series of information products (e.g. articles, webinars, factsheets).

IMPACT

The introduction of supply chain monitoring and adoption of improved practices helped to eliminate all physical waste in PCEB export consignments in 2023. It also reduced food waste along the domestic supply chain by 59% in 2023, relative to 2020. Compared to pre-covid (i.e. 2020) figures, this represented 5.2 and 281 tonnes in export and domestic supply chain waste reduction, respectively, saving a combined $762,960 in annual revenue loss. Delivery of more consistent fruit quality also provided PCEB with the confidence to export entire 1,000 kg pallets of Ecoganic® fruit to Hong Kong and Japan in 2023 for the first time. This increase in export volume was accompanied by enhanced customer satisfaction and strong demand for repeat orders. Delivery of more predictable fruit quality should boost the reputation of Australian growers as preferred suppliers.

NEXT STEPS

The project played an important role in building industry capacity to monitor and improve export fruit quality. The legacy of this project will be measured through ongoing adoption of monitoring technologies and the decision support tool. An increased volume and value of Australian banana exports and a shift from unrefrigerated airfreight to controlled

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temperature seafreight will be other objective measures of ongoing project impact to monitor. Project learnings and benefits could be extended to improving Australian domestic banana supply chain practices and fruit quality outcomes.

PROJECT TEAM

Andrew Macnish, John Archer, Minh Nguyen, Shanara Veivers (Queensland Department of Primary Industries)

Dianne Sciacca, Frank Sciacca (Pacific Coast Produce)

PROJECT REPORTS/PUBLICATIONS

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PROJECT WEBPAGE

https://endfoodwaste.com.au/projects/supply-chain-monitoring-and-improvement-to-reduce-banana-quality-loss/

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APPENDIX B – Supporting Materials

A1. Summary of export and domestic consignment monitoring

A2. Summary of supply chain simulation trials

A3. Supply chain best practice manual and development of a decision support tool

A4. Project information products

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