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Sustainable export supply chains for ‘Calypso’ mango to China

Andrew Macnish[1], Daryl Joyce[1,2] and Peter Delis[3]

[1]Department of Primary Industries, [2]The University of Queensland, [3]Perfection Fresh Australia Pty Ltd.

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Acronyms

CQ	Central Queensland
DPI	Department of Primary Industries
FB	Flesh browning
FCWP	Flesh cavity with white patches
FNQ	Far North Queensland
NT	Northern Territory
PhD	Doctor of Philosophy
RD&E	Research, Development and Extension
RH	Relative humidity
VHT	Vapour heat treatment
UQ	The University of Queensland

Project Participants

This project was a collaboration between Perfection Fresh Australia Pty Ltd (cash co-investment), the Queensland Department of Primary Industries (DPI) (in-kind contribution) and The University of Queensland (UQ) (in-kind contribution).

Executive Summary

This project aimed to provide Australian mango growers and supply chain partners with greater knowledge, skills and confidence to deliver consistent export fruit quality. Working with Perfection Fresh Australia, a case study with the Calypso® cultivar was completed with a focus on China. While Calypso® mangoes are well received overseas, two internal quality defects (flesh browning; FB and flesh cavity with white patches; FCWP) can compromise export fruit. The project aimed to:

- Monitor and improve export supply chain handling practices for Calypso® mango fruit;
- Identify factors contributing to FB and FCWP and develop management solutions; and
- Increase grower and supply chain partner awareness and adoption of improved practices and technologies for reliably delivering more consistent fruit quality.

Calypso® fruit were sourced from orchards and pack houses in the Northern Territory (NT), Far North Queensland (FNQ) and Central Queensland (CQ) across five seasons from 2018/19 to 2022/23. Using modern real-time data loggers, the project team monitored 43 Calypso® export consignments. The initial monitoring identified that fruit were seldom pre-cooled at pack houses to the recommended 12-14°C. The fruit also experienced variable road freight durations of 3-10 days from pack houses to the vapour heat treatment (VHT) facility prior to export.

In 2018/19, exposure to elevated handling temperatures and long transit times triggered fruit ripening. The riper fruit were sensitive to damage (i.e. skin scald, flesh cavities) from the VHT, with 11-27% of fruit being graded out before export. Adoption of express road freight that reduced transit times by 2.0-2.5 days in 2019/20 ensured that fruit arrived unripe and more tolerant of VHT. This reduced the fruit grade out by 14.2-27.8% in 2019/20 relative to 2018/19.

Two PhD students were included in the project to identify factors that contribute to FB and FCWP development and expression. Their key findings included:

- FB was associated with fruit of advanced harvest maturity (i.e. >17% dry matter content) while FCWP was greatest in fruit of low maturity (i.e. <15% dry matter content);
- FB was present in VHT and non-VHT fruit whereas FCWP was observed only following VHT;
- FB was associated with extended supply chain handling times and/or elevated temperatures;
- NT fruit were generally more susceptible to FB while FCWP was highest in FNQ fruit;
- A low-N, high-Ca combination fertiliser treatment was generally associated with the lowest FCWP incidence, but fruit mineral status was driven more by crop load; and
- Fruit from a high crop load (>150 fruit/tree) had the least FCWP in association with higher Ca, Mg and B and lower K/Ca and K+Mg/Ca ratios. FB was linked to low B in fruit flesh.

It is recommended that growers target fruit from high crop load trees with low K+Mg/Ca ratios (≤ 20) for export markets that require VHT. Fruit should be harvested at an optimum maturity (i.e. 15-17% dry matter content) to reduce the risk of internal disorders. Sorting fruit using in-line near infra-red spectroscopy would ensure tolerant fruit of an optimal maturity are selected for VHT.

The project played an important role in supporting capacity building of two PhD students, pack house and VHT staff with problem solving skills for improving fruit export quality. In addition to optimising orchard nutrition and harvest maturity, the project highlighted the benefits of improving postharvest temperature management. This prompted one NT grower to invest $2 million into new forced-air cooling rooms and pack house roof insulation. Given that many Calypso® growers also produce other mango varieties, generic project learnings will be extended across the industry.

Introduction

Mango is an economically important horticulture crop in northern Australia, with an average annual total production of 69,493 tonnes worth $ 207 million over 5 years to 2023/24 (Hort Innovation Australia Limited, 2025). Mango fruit are harvested between July and March each season. The four main cultivars produced are 'Kensington Pride', 'B74' (marketed as Calypso®), 'R2E2' and 'Honey Gold' (Dillon et al., 2013). Most production is for the domestic market, while exports vary with each season and account for 4-12% of the national crop (Hort Innovation Australia Limited, 2025). Key export markets include New Zealand, Singapore, Hong Kong and the United Arab Emirates. Smaller volumes are also exported to Korea and China.

China is the second largest producer and consumer of mangoes in the world. In 2020, the Chinese market consumed 3.5 million tonnes of locally produced mangoes and imported an additional 84,140 tonnes (Gao et al., 2022). China is a priority market for imported mangoes given its increasing rates of year-round consumption and rapid expansion of the middle-class population (Chen et al., 2019a). A survey of Chinese importers, wholesalers and retailers highlighted that fruit quality defects and insufficient (<3 days) shelf life were key challenges when handling mangoes (Chen et al., 2019b).

Despite numerous attempts to develop mango exports to China, direct trade from Australia has remained static, averaging 100 tonnes per year between 2013/14 and 2018/19 prior to the global covid-19 pandemic (Hort Innovation Australia Limited, 2025). Over the same timeframe, an average of 2,383 tonnes per year of Australian mangoes were exported to nearby Hong Kong. Australian mango exports to China and Hong Kong averaged $10.2 million per year between 2013/14 and 2018/19 (Hort Innovation Australia Limited, 2025). Direct exports of Australian mangoes into mainland China are subject to vapour heat treatment (VHT) to meet a strict insect disinfestation protocol (Department of Agriculture, Fisheries and Forestry, 2024). Australian mangoes are exported by air or seafreight to Tier 1 cities (e.g. Beijing, Guangzhou, Shanghai) or Hong Kong.

Australian exporters have often struggled to build confidence with supply chain partners in China to expect consistent delivery of premium quality mangoes (Andrew Edwards, pers. comm., 2018). Managing environmental and production factors such as mineral nutrition, crop load and harvest maturity together with monitoring postharvest handling conditions (e.g. temperature) and fruit quality along the supply chain are essential elements of product traceability and improvement (Hofman and Ledger, 2006; Hofman et al., 2013). These approaches can help identify and correct deficiencies in management practices and demonstrate a commitment to problem solving that builds trust between supply chain businesses.

This project was established to develop and implement pre- and postharvest improvement strategies for producing more robust mango fruit suited to withstand export supply chain handling and consistently meet market expectations for product quality. A case study with the Calypso® cultivar was completed between 2018 and 2024 with a focus on the China market. Calypso® accounts for 25% of Australian domestic production (Horticulture Innovation Australia Limited, 2021). The ripe fruit have an appealing bright yellow skin with strong red blush pigmentation plus firm fibreless flesh and good retail shelf life (Figure 1; Anon, 2001; Hofman et al., 2010). Perfection Fresh Australia has the license to produce and market Calypso®. There are 15 registered growers in Australia. Like other cultivars, Calypso® is prone to quality defects that otherwise can limit export development.

The overall objective of this project was to improve the consistency of mango export fruit quality to increase supply chain confidence and double northern Australian mango exports to China to about $20 million per year. Perfection Fresh and DPI contributed to monitoring and improving fruit postharvest handling practices. Two PhD students through UQ were engaged to quantify key fruit

quality defects and devise orchard and harvest management practices to increase fruit robustness for export supply chains. General aims were:

1. Monitor and improve export supply chain handling practices for Calypso® mango fruit;
2. Apply technical research to identify underlying causes of Calypso® fruit quality defects and develop potential management solutions;
3. Drive the transfer of knowledge and skills that enable Calypso® mango growers and supply chain businesses to reliably deliver more consistent quality fruit to China; and
4. Maximise opportunities to share generic project learnings that benefit the broader Australian mango industry, adding value and confidence for the China opportunity.



Figure 1 Image of ripe Calypso® mango fruit.

Materials and methods

The underlying strategy of the project was to utilise co-innovation and participatory learning approaches (Dickinson et al., 2025) to ensure commercial relevance and maximum impact. While the project team worked in-depth with Perfection Fresh as the co-investing mango business, generic experiences, learnings and recommendations were shared with the broader industry through conference presentations, industry magazine articles and scientific journal papers (see Appendix 1) to increase knowledge and drive adoption of improved practices that produce and deliver more consistent fruit quality.

The project built off previous RD&E work with Calypso® mangoes that established postharvest handling procedures for the domestic supply chain (Whiley et al., 2006; Hofman et al., 2010; Hofman et al., 2014), including a best practice guide (Hofman and Whiley, 2010). These learnings were extended to improving export supply chains to China. Initial project work by Perfection Fresh was focused on monitoring and improving export supply chain handling practices during the 2018/19 and 2019/20 seasons. An in-depth study of fruit internal disorders and associated quality defects was completed by two PhD students during the 2020/21, 2021/22 and 2022/23 seasons.

Improving export supply chain practices (Perfection Fresh program)

Fruit quality assessment guide

A Calypso® mango quality assessment manual was developed for export markets (see Appendix 2). It was based off the 'B74' fruit quality assessment manual published by Hofman et al. (2013). The new manual was designed to provide a summarised standard method for assessing fruit quality in export markets. Photographs of common fruit skin and flesh quality defects were included.

Supply chain monitoring

Export supply chain handling temperatures and durations were monitored to identify opportunities for improving practices for delivering more consistent fruit quality. Calypso® consignments earmarked for export were tracked from pack houses near Katherine in the Northern Territory (NT) and Dimbulah in Far North Queensland (FNQ) to the VHT facility in Brisbane, Queensland during the 2018/19 and 2019/20 seasons. The project utilised real-time data loggers to remotely monitor fruit handling conditions along export supply chains (Figure 2). Loggers were included in at least two pallets per consignment at the top and middle tray layers. The loggers provided alerts when consignments were within 6 hours of the VHT facility. Fruit quality was assessed at packing, on arrival at the VHT facility and in export markets using the newly developed assessment manual.



Figure 2 Photographs of a real-time logger with external pulp probe (left) and its placement in a tray of Calypso® mango fruit (right).

In the 2019/20 season, a supply chain and fruit quality management specialist was based in the NT and FNQ to provide pack house staff with training in assessing and grading fruit quality for export markets. The specialist staff member also demonstrated how to install loggers and prioritise express handling of NT consignments for prompt transport to the VHT facility. A review of the supply chain monitoring program was shared with Calypso® growers at post-season meetings.

VHT trials

Fruit for export to China are typically graded and packed into fibreboard trays at pack houses for transport to the VHT facility. While this is efficient for pack house operations, it causes double handling at the VHT facility with staff needing to transfer fruit from trays into field bins for treatment. In 2018/19, the operational efficiency for fruit transported in trays or field bins was evaluated.

The potential to export Calypso® fruit by sea freight to China was evaluated in three trial shipments in 2018/19 and 2019/20. Export grade fruit were transported from NT and FNQ pack houses to the VHT facility for treatment. Palletised VHT fruit were loaded into 20- or 40-foot-long shipping containers and transported at a set point of 10.5°C under a controlled atmosphere of 5% CO_2 and 2% O_2, as per standard procedures. Data loggers were inserted into trays to monitor handling temperatures. Fruit quality was assessed at dispatch from VHT and upon arrival in China.

Towards the end of the 2018/19 season, some fruit samples developed internal flesh cavity formation once ripe. It was hypothesised that rapid cooling of fruit after VHT contributed to this quality defect. An exploratory trial was conducted to test this hypothesis. A total of 256 Calypso® mangoes were sourced from three growers. The fruit were 2, 4 and 8 days post packing. The fruit were cooled gradually in the VHT chamber or more rapidly to 20°C and 18°C by room or forced-air cooling, respectively. Once ripened, fruit internal quality was assessed.

Managing fruit quality disorders (PhD program)

While Calypso® and other Australian mango cultivars (e.g. R2E2) are generally well received in domestic and overseas markets, internal quality disorders that express after harvest represent a challenge for the industry. There is good understanding of some mango internal disorders such as jelly seed (Raymond et al., 1998) but poor knowledge of other emerging defects like flesh browning (FB) and flesh cavity with white patches (FCWP) that have been identified in export fruit (Figure 3).



Figure 3 Photographs of ripe Calypso® mango fruit in cross section showing internal quality disorder symptoms of flesh browning (FB) (left) and flesh cavity with white patches (FCWP) (right).

Two PhD students enrolled through UQ were engaged by the project to characterise the symptoms of FB and FCWP, quantify incidence and severity in fruit consignments and identify potential factors associated with their development and expression in Calypso® mango. The research program was based on an appreciation that if fruit are not inherently robust at harvest, then protocol treatments such as VHT and deviations from recommended supply chain handling practices may reduce internal quality. The research program spanned three mango seasons – 2020/21, 2021/22 and 2022/23.

Characterising FB and FCWP symptoms and occurrence

Export quality Calypso® fruit were harvested from orchards near Katherine and Mataranka in the NT, Dimbulah in FNQ and Childers in Central Queensland (CQ). The fruit were transported to local pack houses where they were graded for uniform quality, placed into plastic field bins or fibreboard trays and pre-cooled to 12-16°C as per commercial practice. Fruit was transported by refrigerated trucks at about 16°C along commercial supply chains to the VHT facility in Brisbane within 5-6 days from the NT (~3,400 km) and 3-4 days from FNQ (~1,700 km). Fruit from CQ were transported to the VHT facility within 1-2 days (~350 km) in an air-conditioned (22°C) vehicle. In total, fruit from 43 consignments were monitored across the 2020/21, 2021/22, and 2022/23 seasons.

Upon arrival at the VHT facility, approximately 100 fruit (i.e. six trays of 15-17 fruit each) were randomly sampled from each consignment. Half of the fruit were subjected to VHT in line with the protocol accepted by China. The fruit core temperature was steadily raised over 3-4 hours to 47°C and held for 15 minutes at >90% relative humidity (RH) before being gradually cooled. The remaining half of the fruit were non-treated (i.e. no VHT) and kept at 18°C as controls. Following treatment, VHT and control fruit were transported in an air-conditioned (22°C) vehicle to a laboratory at the UQ Gatton campus, about 75 km away. Individual fruit maturity, expressed as the dry matter content was assessed by near infra-red spectroscopy or via the oven-dry method (Padda et al., 2011). Fruit were then maintained at 20°C and 90% RH until ripening to eating soft (Hofman et al., 2010).

At the eating soft stage, individual fruit were sliced longitudinally on both sides of the seed and assessed for incidence and severity of FB and FCWP. The severity of disorders found in individual fruit was subjectively rated using the following scale: 0 = none, 1 = slight, 2 = moderate, 3 = severe symptoms. Mesocarp flesh sections from fruit with and without FCWP and FB were excised, dried

at 65°C in a fan-forced oven for 3 days, and ground to fine powder using a laboratory scale mini ball mill. Total nitrogen (N) was measured using a carbon/nitrogen combustion analyser at 1250°C (Flanagan et al., 2022). Other minerals, including calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and boron (B), were measured using inductively coupled plasma-optical emission spectrometry (Altundag and Tuzen, 2011). All results were expressed as mg/kg on dry weight basis.

Identifying potential factors associated with disorders

A systematic review of the scientific literature revealed that factors responsible for mango internal disorders include growing location, nutrient imbalance (particularly Ca and N/Ca ratio), fruit maturity at harvest, and postharvest treatments, including exposure to phytosanitary treatments such as VHT (Esguerra et al., 1990; Raymond et al., 1998; Jacobi et al., 2001; Bally, 2006). Literature reviews are included in Appendices 3 and 4. Based on these findings, fruit harvest maturity and orchard nutrition were selected as factors for further study.

Fruit harvest maturity

The potential influence of fruit maturity at harvest in subsequent FB and FCWP development was evaluated during the 2021/22 and 2022/23 seasons. Three experiments replicated across both seasons were completed with fruit from the commercial orchard near Childers in CQ.

In the first experiment, fruit were sorted into three maturity classes (<15%, 15 - 17%, and >17% dry matter content) as determined in the field using a portable near infra-red spectroscopy device (Felix Instruments). Six trays of 20 fruit at each of the three maturity stages were picked at the same time as the commercial harvest. The fruit were transported in an air-conditioned vehicle (ca. 22°C) to the laboratory at the UQ Gatton Campus. Upon arrival, fruit were labelled, de-stemmed, and de-sapped in mango wash solution, followed by fungicide treatment. They were air-dried for 2 hours and stored at 16°C overnight. The next day, fruit were transported to the VHT facility in Brisbane. Three trays from each maturity class were exposed to VHT while the other half acted as non-treated controls. The fruit were returned to the laboratory for evaluation as described above.

For the second experiment, fruit were picked 1-2 weeks before, during and 1-2 weeks after the commercial harvest date with an average dry matter content of 14.5 to 17.4%. The fruit were exposed to VHT as described above. In 2022/23, additional fruit were pre-conditioned at 37°C for 12 hours prior to VHT. The fruit were returned to the laboratory for evaluation as described above.

In experiment three, fruit were sorted into two maturity classes based on a floatation technique in 2% salt solution (Kapse and Katrodia, 1996). Fruit that floated were considered less mature and sinkers were considered more mature. Both ‘floaters’ and ‘sinkers’ were subjected to VHT as described above. VHT and control fruit were assigned to two seafreight simulations: a controlled atmosphere of 3% O_2 and 5% CO_2 at 11 °C, and an ambient atmosphere at 11 °C, both for 21 days. The fruit were then held at 20°C for shelf-life evaluation as described above.

In 2022/23, the efficacy of commercial in-line near infra-red spectroscopy technology for sorting fruit by dry matter content was tested. Four hundred fruit each from an orchard in the NT and FNQ were randomly sampled at the VHT facility in Brisbane as consignments arrived. The fruit were taken to Gayndah (~325 km) in an air-conditioned car to a pack house equipped with in-line near infra-red spectroscopy. Spectra were collected on Inspectra2 unit (TOMRA) fitted with the Zeiss monolithic miniature 1 spectrometer with a Hamamatsu sensor and a tungsten halogen lamp for illumination.

Reflectance spectra ranging from 310 - 1100 nm of intact mangoes was collected from opposite sides of the widest section of each cheek at the equatorial region. A total of 1600 spectra were collected from 800 mangoes in total. Thereafter, fruit were transported back to the VHT facility in Brisbane. On the following day, half of the fruit were exposed to VHT while the remaining fruit acted

as controls. The fruit were assessed for shelf life and presence of disorders as previously described. Please refer to Appendix 3 for a more detailed methodology.

Orchard nutrition

The potential role of mineral nutrition in FB and FCWP development was explored in a multi-year experiment over three serial fruiting seasons at a commercial orchard near Childers in CQ. It primarily sought to explore effects of N- and Ca-based fertilisers on fruit mineral status and postharvest performance for export markets. The Calypso® trees were 16 years old in 2020 at a planting density of 8 m x 4 m. The soil texture was loam/sandy loam comprised of 82.5% sand, 7.8% silt and 9.7% clay. The soil electrical conductivity was < 0.15 dS/m and the cation exchange capacity was low at 3.3 meq/100g, suggesting a limited capacity to hold nutrients. The pH of the top 0 - 30 cm soil profile was neutral (7.5), and the 30 - 60 cm layer was mildly acidic (5.9).

The N and Ca treatments were applied to plots of five trees. A guard tree was between each plot in the randomized complete block design experiment with three replicates and a guard row between each. Five treatments in season 1 (2020/21) and a sixth in seasons 2 (2021/22) and 3 (2022/23) were applied in addition to the farm-wide base fertiliser program. Fertiliser treatments in season 1 were: 1. control (no additional N or Ca); 2. low-N, nil-Ca (N: 50 g/tree); 3. high-N, nil-Ca (N: 100 g/tree); 4. low-N, high-Ca (N: 50 g/tree + Ca: 690 g/tree); and 5. high-N, high-Ca (N: 100 g/tree + Ca: 690 g/tree). N was applied as urea and Ca as microfine gypsum. The sixth treatment in the second and third season was: very high-N, high-Ca (N: 429 g/tree + Ca: 526 g/tree) as Ca nitrate.

Before treatment application in 2020, six soil samples from the start and end of each replicate plot were collected at 0 - 30 cm and 30 - 60 cm depth, where most feeder roots were present, using a 110 cm hand-held corer tube (Bally 2006). Soil samples were bulked and analysed for mineral concentrations. Subsequently, soil samples were taken from each replicate plot at bud swelling in seasons 2021 and 2022 and at fruit harvest in seasons 2020, 2021, and 2022. Leaf mineral analysis was completed at pre-flowering (bud swelling stage) and at fruit harvest in each season using 15-30 young fully expanded mature leaves from each replicate plot.

The influence of crop load on fruit internal disorders was also studied at a tree level. Four crop load categories were assessed: very low, low, medium and high that corresponded to <50, 50-100, 100-150 and >150 fruit per tree, respectively. During the experiment, irregular bearing was observed, with low to medium cropping in season 1, high cropping in season 2, and low cropping in season 3.

Thirty mature green fruit of 15-17% dry matter content were randomly harvested from each treatment plot from the outside of the canopy at all four tree quadrants. The fruit were harvested with long stems in the morning and transported in an air-conditioned vehicle (ca. 22°C) to a laboratory at the DPI Maroochy Research Facility near Nambour, Queensland. Upon arrival, fruit were labelled, de-stemmed, and de-sapped in mango wash solution, followed by fungicide treatment. They were air-dried for 2 hours and stored at 16°C overnight. The next day, fruit were transported to the VHT facility in Brisbane. Half of the fruit were exposed to VHT while the other half were maintained as non-VHT controls. Following treatment, all fruit were transferred to the laboratory at the UQ Gatton campus, for ripening at 20°C and quality assessment, including analysis of mineral concentrations, as described above. Please refer to Appendix 4 for a more detailed methodology.

Results

Improving export supply chain practices (Perfection Fresh program)

Supply chain monitoring

The project demonstrated that real-time data loggers were a reliable technology for remotely monitoring mango supply chain handling conditions. The autonomous reporting wireless loggers helped to increase awareness amongst Calypso® growers and Perfection Fresh marketing staff of variations in supply chain handling practices and associated impacts on fruit quality. By the end of the project, Perfection Fresh had adopted wireless consignment monitoring as a standard business practice for tracking domestic and export shipments.

The improved monitoring system included employing a specialist staff member at pack houses to identify opportunities for improving practices. A series of Calypso® export protocols were developed and shared with staff and growers. This supported training of pack house staff involved in key on-farm activities affecting fruit quality such as pallet handling, storage, loading and dispatch. More detailed information on the total number of pallets, fruit quality, maturity and count (size) was also sent to key personnel at the VHT facility within 24 hours of packing. The supply chain monitoring activity triggered the adoption of several improved procedures, especially in the NT, including:

- Adopting express logistics protocols to rapidly transport export fruit to the VHT facility;
- Placing export pallets into the most cooling-efficient cold rooms after packing;
- Improving pallet spacing to allow better cold air circulation through trays during pre-cooling;
- Setting truck trailer temperatures at 12-14°C to ensure fruit arrive at a green, unripe stage; and
- Loading export pallets at the rear of trailers to increase unloading efficiency at the VTH facility.

Despite these changes, the loading temperatures at farms in the NT and FNQ still varied between 16 and 26°C, sometimes resulting in fruit arriving too warm at the VHT facility. The real-time consignment monitoring revealed that if not adequately pre-cooled to 12-14°C, mango fruit will generally heat up in transit irrespective of the temperature setting of the refrigerated trailer. Warming of fruit during transport accelerated ripening and resulted in greater damage to fruit from VHT. These observations highlight opportunities for ongoing monitoring and improvement.

The high quality of data captured in this project allowed for cost benefit analysis of potential savings if investment was made into cooling infrastructure on farms. One of the NT growers installed new forced-air cooling rooms and improved pack house roof insulation, a $2 million investment as a direct result of project learnings. Mango fruit destined for the domestic market will also benefit from improved pre-cooling practices identified and implemented in this project.

The supply chain monitoring activity also identified considerable variation in transit time from the pack houses to the VHT facility (Table 1). In 2018/19, fruit consignments from the NT took 5-9 days to reach the VHT facility after packing. Longer transit times were associated with a greater proportion of the consignment having to be graded out due to heat damage to fruit (i.e. skin scald, flesh cavities) that developed after VHT (Figure 4). In 2019/20, the transit duration from pack houses to the VHT facility was reduced on average by 2 days from the NT and 2.5 days from FNQ using express trucks, whereby 2 drivers alternated shifts. The real-time data loggers allowed VHT staff to track consignments and follow up with freight companies if delays occurred. By adopting these procedures, the grading out of unsuitable NT and FNQ fruit due to damage from VHT was reduced by 27.8% and 14.2%, respectively, in 2019/20 relative to the 2018/19 season.

Table 1 Transit time (days) between packing of Calypso® fruit at pack houses and arrival at the VHT facility.

Season	Transit time (days) from NT pack house			Transit time (days) from FNQ pack house		
	Minimum	Maximum	Average	Minimum	Maximum	Average
2018/19	5.0	9.0	7.0	3.0	10.0	7.0
2019/20	4.0	7.0	5.0	3.0	4.0	3.5

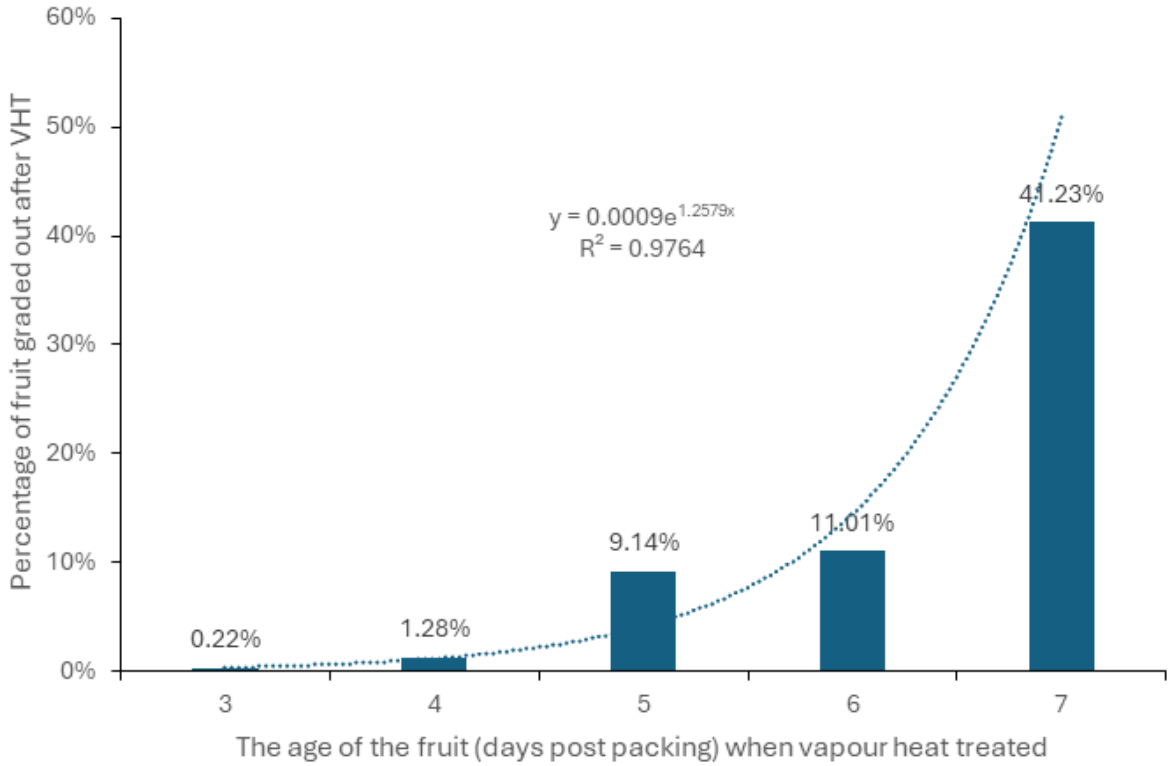


Figure 4 The age of Calypso® mango fruit (days post packing) when arriving at the VHT facility and the proportion of fruit graded out due to heat-related quality defects.

VHT trials

Transporting fruit in field bins instead of palletised trays increased operational efficiency at the VHT facility. Fruit in bins could be transferred directly into the treatment chambers, while fruit in trays had to be packed into new bins before VHT. Including a foam sheet in between each fruit layer in bins prevented abrasion and rub damage on fruit during transport. Packing fruit into bins at the farm reduced the labour cost at the VHT facility by saving time on tipping the fruit into bins and dealing with the unwanted empty trays. However, feedback from pack house staff was that packing into bins slowed down the pack line considerably. The pack line would need to be altered to accommodate packing into bins for export consignments.

For the first seafreight trial shipment, loggers inside trays showed that the average air temperature was 14.5°C. Inspection of the container upon arrival in Guangzhou indicated that the container set point had been increased from 10.5°C to 13°C without the knowledge of Perfection Fresh or the customer. The total transit time from dispatch in Brisbane to arrival in Guangzhou was 20 days.

Despite the use of a controlled atmosphere, fruit arrived over soft and were rejected by the customer. Some of the palletised fibreboard trays deformed and sagged during seafreight, causing pallets to partially collapse and bruise fruit.

In the second seafreight trial, all fruit received VHT at 8 days after packing. The fruit were maintained at 10.3°C to 11.8°C during seafreight. The fruit were 31-36 days old when eventually sold in China following storage by the customer. About 13% of the consignment was rejected because the fruit were over soft when dispatched to the retailer. The rejected fruit were the oldest in the consignment. Based on this result, limiting the gap between packing and VHT to 5-6 days should ensure no NT fruit are rejected in China.

In the third seafreight trial, the improved pallet wrapper, plastic corners and stronger trays used ensured no pallets collapsed or fruit were damaged. Because it took two VHT runs to fill a 40-foot container with 20 pallets, the export fruit were treated at different durations after packing. Almost half (48%) of the consignment was treated at 4 days post-packing, while 25% and 27% was treated at 6 and 7 days, respectively. Limited damage was observed on fruit following VHT. The cold chain temperature data post VHT was very good.

The trial work demonstrated that seafreight is a viable low-cost mode of transport for exporting large volumes of Calypso® mangoes to China. Seafreight could also be used to effectively extend the availability of Calypso® fruit in China. Exporting a mix of air and seafreight consignments would allow Perfection Fresh to manipulate the arrival time of fruit to maximise the export period and increase supply during more profitable market periods.

Australian mango exports to China increased 2.7-fold to peak at 272 tonnes in 2019/20 with a value of $1.9 million, relative to the previous 5 years. This increase coincided with year 2 of the project and the adoption of improved supply chain practices by Calypso® growers. Thereafter, mango exports to China decreased by 28% to 195 tonnes worth $1.4 million per year in association with global supply chain disruption due to the covid-19 pandemic and geopolitical tensions.

Cavity formation in fruit that was observed in the 2018/19 season was not related to the rate of fruit cooling after VHT. There was no significant effect of fruit age, or time between packing and VHT on the presence of cavities. No flesh cavities were found in the non-treated control group. This suggests that flesh cavities are a heat-related injury. Cavities and white patches have previously been related to heat injury (Jacobi et al., 2001). However, not all VHT fruit developed cavities, so there are likely other contributing factors. These findings laid the groundwork for the PhD studies.

Managing fruit quality disorders (PhD program)

Characterising FB and FCWP symptoms and occurrence

FB and FCWP were the principal internal quality defects observed in export and domestic Calypso® mango fruit consignments during this project. FB was characterised by the presence of diffuse brown discolouration of the flesh, usually near the seed. The monitoring of Calypso® consignments over three seasons revealed that FB was present in both VHT and non-VHT fruit. Symptoms developed as fruit approached the eating soft ripe stage. Considerable variation in FB incidence existed in fruit sampled from different orchard blocks, seasons, and monitored consignments. Overall, FB was highest in fruit from the NT relative to those from FNQ. FB was not observed in CQ fruit. FB incidence was highest in the 2022/23 season, as compared to 2020/21 and 2021/22.

Fruit sampled from monitored consignments that had a relatively high average dry matter content (i.e. >17%) generally exhibited higher incidence of FB. Fruit from consignments that had lower average dry matter content (<15%) generally developed less FB. Early-season fruit that had relatively low dry matter content displayed lower FB incidence compared to late-season fruit with a higher dry matter content. FB incidence also showed a significant positive correlation with transit

time from the pack house to the VHT facility and elevated handling temperatures. In terms of relationships with mineral nutrition composition, a negative correlation between FB and fruit flesh B concentration was also observed.

FCWP manifested as dry white honeycomb-like cavities with starchy, tough lesions in the inner mesocarp near the seed. It was observed only in VHT fruit destined for export markets. In contrast to FB, FCWP was observed exclusively in VHT fruit. Considerable variation in FCWP incidence and severity was also observed among growing regions, seasons, orchard blocks and monitored supply chains. For example, NT fruit had significantly less FCWP than those from FNQ. The incidence of FCWP in 2022/23 was significantly less than 2020/21 and 2021/22.

Consignments that consisted of fruit with relatively high average dry matter content generally exhibited a comparatively low incidence of FCWP. Fruit harvested early in the season had a relatively low dry matter content but were prone to developing high levels of FCWP. There was no significant correlation between the FCWP incidence and postharvest handling conditions. There was a significant positive correlation between FCWP and fruit flesh (K+Mg)/Ca ratios.

Taken together, these observations provide circumstantial evidence that harvest maturity and mineral nutrition may be important factors that influence fruit sensitivity to FB and FCWP.

Fruit harvest maturity

Laboratory trials completed during the 2021/22 season confirmed that FCWP was only observed in VHT fruit. FCWP incidence and severity was greatest in fruit with <15% dry matter content. FCWP incidence and severity in VHT fruit with >15% DMC were similar to untreated controls. No FB was observed in 2021/22.

Fruit harvested late in the season showed a 70% reduction in FCWP relative to early-season fruit. Fruit conditioned at 37°C for 12 hours prior to VHT also developed significantly less FCWP, with a seven-fold reduction in early harvest compared to four-fold reduction in late harvest (Table 2). These results indicated that less mature fruit (<15% DMC) were more susceptible to FCWP after VHT which is consistent with similar findings for ‘Kensington Pride’ mangoes (Jacobi et al., 2001). Similarly, Esguerra et al. (1990) and Brecht et al. (2020) reported that less mature mango fruit were prone to cavity formation after VHT / hot water treatment.

Table 2 Fruit maturity, VHT and preconditioning treatment effects on the incidence and severity of FCWP and FB in Calypso® mango fruit during the 2021/22 season. Severity was rated using the following score: 0 = none, 1 = minor, 2 = moderate, 3 = severe.

Disorder	**Harvest time and fruit dry matter content (%)**		**Treatments**		
	Early-season (14.5%)	**Late-season (17.4%)**	**No VHT**	**Plus VHT**	**Conditioning plus VHT**
FCWP					
Incidence (%)	26.9 ± 11.2	8.3 ± 3.4	0.0 ± 0.0	45.0 ± 11.9	7.8 ± 3.0
Severity (score)	0.3 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.5 ± 0.2	0.1 ± 0.0
FB					
Incidence (%)	0.0 ± 0.0	2.9 ± 1.5	1.7 ± 1.7	1.7 ± 1.7	0.8 ± 0.8
Severity (score)	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

A flotation technique was not able to distinguish fruit of different dry matter content. The incidence of FB that developed in fruit following a 21-day seafreight simulation at 11°C was reduced from 71.1% to 33.3% when maintained under a controlled atmosphere instead of ambient air. These results suggest that FB is associated with long storage times. Other studies also suggest that mango FB is a function of storage time and temperature (Hofman et al., 2010; Brecht et al., 2020).

The efficacy of employing commercial in-line near infra-red spectroscopy for dry matter content sorting was tested. The in-line technology effectively predicted mango fruit maturity based on dry matter content and soluble solids (Figure 5). This information was used to predict the occurrence of FCWP with 73% accuracy. It was not as accurate at predicting FB presence. Nevertheless, relationships between these disorders and fruit maturity at harvest were clear. Less mature fruit were more susceptible to FCWP. More mature fruit were more susceptible to FB. Thus, sorting fruit using in-line near infra-red spectroscopy technology could help to ensure that only relatively tolerant fruit are directed, including via VHT, into export market channels.

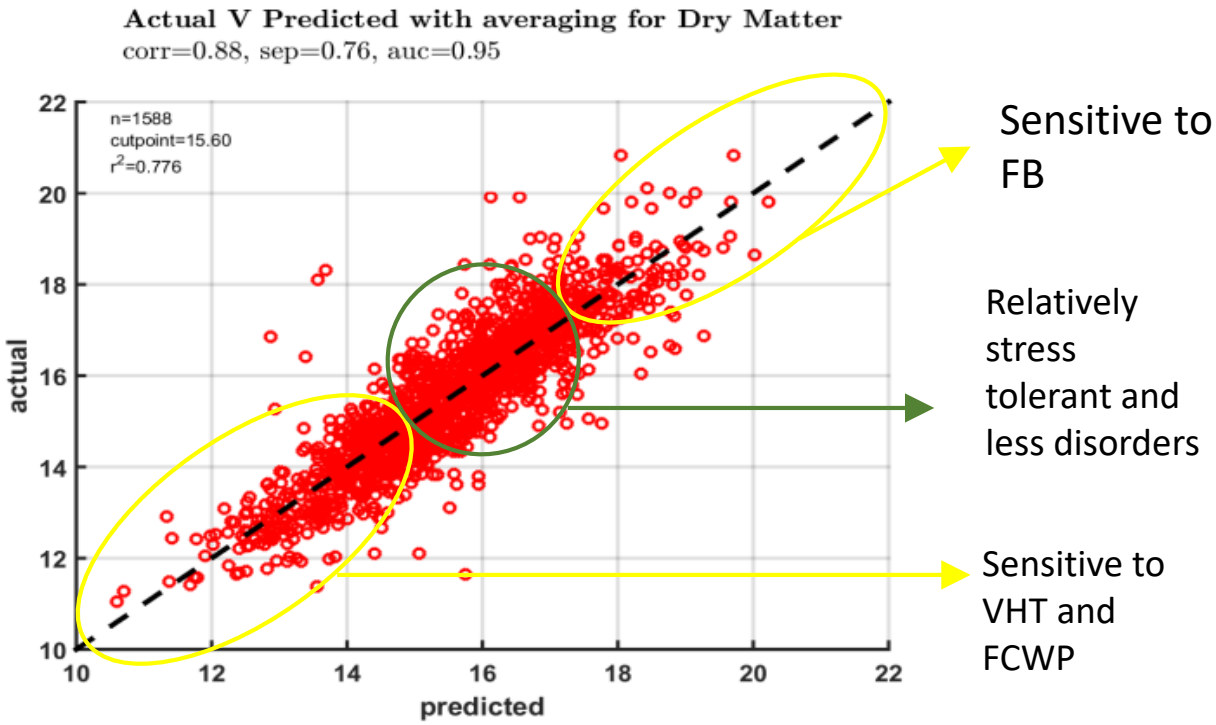


Figure 5 Relationship between in-line near infra-red spectroscopy predicted and measured total dry matter content for Calypso® mango fruit. Spectra were collected at mature hard green stage for the prediction and reference values were assessed when fruit reached the eating ripe stage.

Orchard nutrition

The role of orchard nutrition was explored in a multi-year experiment at a commercial orchard in CQ. The supplementary N and Ca fertiliser treatments applied in this project generally did not influence nutrient availability as judged by soil and leaf tests (Appendix 4). An exception was the low-N, high-Ca combination of 50 g N/tree plus 690 g Ca/tree which increased exchangeable soil Ca. While treatment effects were inconsistent across seasons, low-N, high-Ca combination also significantly improved Ca and Mg levels in fruit flesh in 2021/22 (Appendix 4). Flesh N, N/Ca, K/Ca, and (K+Mg)/Ca were all significantly lower in response to the low-N, high-Ca combination treatment in season 2020/21.

Fruit yield was generally unaffected by the fertiliser treatments. Biennial bearing was observed, with 2020/21 and 2022/23 being off-years with medium to low crop load and yield, while 2021/22 was an on-year with a significantly higher crop load and yield.

The low-N, high-Ca combination fertiliser treatment was associated with the lowest FCWP incidence of 40% and severity of 0.57 in season 2020/21. However, this result was not repeated in 2021/22 as overall fruit quality was better with very low expression of FCWP and no significant effect of fertiliser treatments. In season 2022/23, the lowest incidence of FCWP (0%) was again observed in the low-N, high-Ca combination treatment. Lower incidence and severity of FCWP could be associated with higher Ca availability in soil at pre-flowering stage in this treatment and subsequently lower mineral nutrient ratios in fruit at harvest. In general, Ca concentration increases rapidly in mango during early fruit development and gradually decreases during cell expansion and maturation phases (Joyce et al., 2001). This means higher availability of Ca at flowering and early developmental stages could likely improve overall fruit Ca status at harvest and fruit robustness.

Overall, the fruit mineral status was evidently driven more by crop load and less by supplementary N and Ca supply. Crop load, expressed as the number of fruit per tree, showed linear positive correlations with fruit Ca ($r = 0.68$), Mg ($r = 0.81$) and B ($r = 0.50$), and negative correlations with fruit K ($r = -0.57$), K/Ca ($r = -0.74$), and K+Mg/Ca ($r = -0.73$). With data pooled across the three seasons, trees with high crop load (>150 fruit) had a significantly lower incidence (9%) of FCWP disorder in association with higher Ca, Mg and B and lower K/Ca and K+Mg/Ca ratios (Table 3). Based on the findings above, growers might consider targeting Calypso® fruit from high crop load trees with inherently low K+Mg/Ca (≤ 20) that is associated with relatively more robust fruit for export to markets that require VHT.

Table 3 Calypso® mango fruit flesh mineral analysis from trees of four different crop load categories when averaged across the 2020/21, 2021/22 and 2022/23 seasons. Means followed by the same letter in each column are not significantly different.

Crop load	Fruit per tree	FCWP incidence (%)	N (%)	K (%)	Ca (mg/kg)	Mg (mg/kg)	B (mg/kg)	N/Ca	K/Ca	(K+Mg)/ Ca
Very low	<50	22 b	0.45 ab	1.20 a	406 c	389 c	8.03 b	11.64 a	30.57 a	31.56 a
Low	50-100	48 a	0.40 b	1.18 ab	461 bc	435 b	8.80 b	9.22 ab	26.69 b	27.67 b
Medium	100-150	33 b	0.42 ab	1.11 bc	509 ab	448 b	8.93 b	8.45 b	22.46 c	23.36 c
High	>150	9 c	0.51 a	1.06 c	523 a	494 a	9.08 a	9.71 ab	20.82 c	21.79 c

Maintaining an optimum balance of mineral nutrients is critical for maximising fruit robustness, especially when targeting export markets where fruit needs to withstand postharvest rigours such as VHT. While it was hypothesised that the N/Ca ratio could be the major determining factor of fruit internal defects, the (K+Mg)/Ca ratio showed more consistent correlations with FCWP across different seasons and regions. FB was linked to individual mineral concentrations, particularly low B in fruit flesh.

Recommendations

This project brought together commercial and RD&E partners to generate new knowledge, skills and confidence to establish viable supply chains for Australian mangoes to China. Communication products were developed to support mango growers and their supply chain partners to improve the robustness of fruit for export handling. While the project focused on a Calypso® mango case study, the generic experiences and learnings are applicable to other Australian mango varieties.

The following recommendations are offered for businesses aiming to deliver more consistent mango fruit quality to protocol markets such as China.

1. Monitor and manage orchard nutrition and crop load to produce robust mango fruit that can withstand the rigours of export handling, including exposure to VHT. Prioritise trees with a relatively high crop load and inherently low K+Mg/Ca ratio (i.e. ≤ 20) to supply fruit for export markets and reduce the risk of FCWP. Maintain B at recommended levels to reduce FB;
2. Harvest fruit at an optimum maturity (i.e. 15-17% dry matter content) to reduce the risk of internal disorder development. Consider using in-line near infra-red spectroscopy to rapidly sort fruit by dry matter content. Redirect less mature fruit that are susceptible to VHT and FCWP to non-protocol markets. Avoid long supply chains for more mature fruit to reduce FB;
3. Build capacity in pack house staff to monitor and improve pre-cooling and supply chain handling practices. Promptly pre-cool fruit at the pack house to the recommended 12-14°C. Reduce the transport time from the pack house to the VHT facility to 5 days or less to ensure fruit arrive at a green, unripe state suitable for VHT; and
4. Establish a modern supply chain monitoring and improvement program that utilises real-time data loggers to assure delivery of more consistent fruit quality to export markets. Share information on handling conditions and fruit quality with supply chain partners to demonstrate a commitment to problem solving and continuous improvement.

References

Altundag, H., Tuzen, M. (2011). Comparison of dry, wet and microwave digestion methods for the multi element determination in some dried fruit samples by ICP-OES., *Food and Chemical Toxicology* **49**, 2800-7.

Anon (2001). *Mangifera indica* Mango 'B74'. *Plant Varieties Journal* **14**, 45-46.

Bally, ISE 2006, 'The effect of preharvest nutrition and crop load on fruit quality and postharvest disease in mango (*Mangifera indica* L.)', PhD thesis, University of Queensland.

Brecht, J.K., Sargent, S.A., Kader, A.A., Mitcham, E.J., Maul, F., Brecht, P.E., Menocal, O. (2020). Mango postharvest best management practices manual, vol. 2020, Institute of Food and Agricultural Sciences, University of Florida, USA.

Chen, Y., Son, T., Ainsworth, N. (2019a). Selling Australian mangoes to China directly through e-commerce. *Mango Matters* **34**, 20-21.

Chen, X., Zuo, A., Settre, C., Qi, W. (2019b). Challenges and opportunities for meeting the requirements of Chinese mango markets. Australian Centre for International Agricultural Research and Griffith University, Nathan. 28 pp.

Department of Agriculture, Fisheries and Forestry. (2024). Manual of Importing Country Requirements. Mangoes. https://micor.agriculture.gov.au/Plants/Pages/China_CN/Mangoes.aspx (Accessed 17 June, 2024).

Dickinson, G.R., Bennett, D.M., Bally, I.S.E., Orr, R., Empson, M., Quddus, S., Robson, A.J., Walsh, K.B. (2025). Facilitating industry adoption of intensive mango practices and new ag-technologies in Australia. *Acta Horticulturae* **1415,** 69-76.

Dillon, N.L., Bally, I.S.E., Wright, C.L., Hucks, L., Innes, D.J., and Dietzgen, R.G. (2013). Genetic diversity of the Australian national mango genebank. *Scientia Horticulturae* **150**, 213-226.

Esguerra, E.B., Brena, S.R., Reyes, M.U., Lizada, M.C.C. (1990). Physiological breakdown in vapor heat-treated 'Carabao' mango'. *Symposium on Tropical Fruit in International Trade* **269**, 425-34.

Flanagan, B., Williams, B., Sonni, F., Chen, P., Mikkelsen, D., Gidley, M. (2022). *In vitro* fermentation profiles of undigested fractions from legume and nut particles are affected by plant tissue architecture and entrapped macronutrients. *Food & Function* **13**, 5075-88.

Gao, A., Luo, R., Huang, J., Zhao, Z., Chen, Y., Wang, Y., Yu, H., Wei, T. (2022). Mango industry development status of China in 2020. *Advances in Agriculture, Horticulture and Entomology* **175**, 1-7.

Hofman, P.J., and Ledger, S.N. (2006). Using a supply chain approach to guide R&D. *Acta Horticulturae* **699**, 219-226.

Hofman, P., Whiley, T. (2010). Calypso Best Practice Guide – From Tree to Taste. Horticulture Australia Ltd, Sydney. 50 pp.

Hofman, P.J., Whiley, A., Marques, J.R., Stubbings, B.A., Taylor, L.A., and Stirling, L.J. (2010). Development of best practice pre- and postharvest of B74 mango: Phase II. Final report MG06005, Horticulture Australia Ltd, Sydney. 269 pp.

Hofman, P., Holmes, R., Barker, L. (2013). B74 mango quality assessment manual: A guide to assessing the postharvest quality of B74 mangoes. State of Queensland. 64 pp.

Hofman, P.J., Marques, J.R., Macnish, A.J., and Joyce, D.C. (2013). Interaction between production characteristics and postharvest performance and practices for fresh fruit. *Acta Horticulturae* **1012**, 55-70.

Hofman, P.J., Joyce, D., Macnish, A., Marques, R., Stubbings, B., Whiley, A.W., Brown, K, Gray, R., Nguyen, M., Li, G., Tram, A., Davies, J., and Banos, C. (2014). Reducing skin damage and improving postharvest efficiency of Calypso mango: Phase III. Final report MG10008. Horticulture Australia Ltd, Sydney. 189 pp.

Hort Innovation Australia Limited (2021). Mango Strategic Investment Plan 2022-2026. Hort Innovation Australia Limited, Sydney. 30 pp.

Hort Innovation Australia Limited (2025). Australian Horticulture Statistics Handbook 2023/24. Hort Innovation | Australian Horticulture Statistics Handbook 2023/24 (Accessed 30 June, 2025).

Jacobi, K.K., MacRae, E.A., Hetherington, S.E. (2001). Postharvest heat disinfestation treatments of mango fruit. *Scientia Horticulturae* **89**, 171-93.

Joyce, D., Shorter, A., Hockings, P. (2001). Mango fruit calcium levels and the effect of postharvest calcium infiltration at different maturities. *Scientia Horticulturae* **91**, 81-99.

Kapse, B.M., Katrodia, J. (1996). Ripening behaviour of 'Kesar' mangoes in relation to specific gravity. *Acta Horticulturae* **455**, 669-78.

Padda, M.S., do Amarante, C.V., Garcia, R.M., Slaughter, D.C., Mitcham, E.J. (2011). Methods to analyze physico-chemical changes during mango ripening: A multivariate approach. *Postharvest Biology and Technology* **62**, 267-74.

Raymond, L., Schaffer, B., Brecht, J.K., Crane, J.H. (1998), Internal breakdown in mango fruit: symptomology and histology of jelly seed, soft nose and stem-end cavity. *Postharvest Biology and Technology* **13**, 59-70.

Whiley, A.W., Hofman, P.J., Christiansen, H., Marques, R., Stubbings, B., Whiley, D.G. (2006). Development of best practice protocols for production of Calypso mango. Final report for project FR02049. Horticulture Australia Ltd, Sydney. 159 pp.

Appendices

Appendix 1. List of project outputs

Appendix 2. Calypso® mango quality assessment manual

Appendix 3. PhD thesis by Amit Kanal

Appendix 4. PhD thesis by Muhammad Asad Ullah