

Final report

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Contents

Contents 3

Public summary..... 4

Keywords 5

Introduction..... 6

Methodology 7

Results and discussion 9

Outputs 12

Outcomes 16

Monitoring and evaluation 20

Recommendations 22

Refereed scientific publications 23

References 24

Intellectual property 25

Acknowledgements..... 26

Appendices 28

Public summary

Fresh produce supply chains can be long, complex and time-sensitive with deviations in product handling conditions resulting in variable arrival quality and shelf life. This variability creates considerable risk for growers and their supply chain partners, including the potential for claims and lost value. The Serviced Supply Chains II (AM21000) project was a 4-year initiative to improve the consistency of fresh produce quality in domestic and export markets. Working with avocado, mango, strawberry and Summerfruit growers and supply chain businesses, the project:

- Developed predictive shelf-life models based on extensive supply chain monitoring and simulation trials
- Applied the models to develop decision aid tools and resources to inform improved handling practices and strategies
- Increased industry awareness and adoption of tools and resources to deliver more consistent fruit quality.

Key findings

- Fruit quality, shelf life and robustness for supply chain handling varied between cultivars, farms and seasons
- Variable seafreight duration for avocado (19-57 days) and Summerfruit (22-35 days) exports to Asian markets
- Inconsistent dispatch and road transport temperatures of >16°C (mango) and >5°C (strawberry) to domestic markets.

Major achievements

Predictive shelf-life models were developed for 10 cultivars of avocado, mango, strawberry and Summerfruit. Avocado ('Hass', 'Shepard') and mango ('Honey Gold') models were validated to within $\pm 1-4$ days of market observations. Nectarine ('Diamond Pearl', 'Polar Zee') and plum ('Angeleno', 'Black Ruby', 'Turtle Egg') models were within $\pm 0.7-2.9$ kg/cm² of observed fruit firmness on arrival and after ripening. Preliminary models for 'Cabrillo' and 'Red Rhapsody' strawberries could explain 68-73% of observed variation. During the 2025-26 season, 6 mango and Summerfruit growers and exporters trialled the technology, building confidence in performance and usability.

Pathway to industry uptake established

- A live prediction service, via integration with real-time data loggers through a commercial partnership with Escavox Pty Ltd, a supply chain monitoring and analytics provider
- Scenario-testing calculators through peak industry body websites via the www.freshintel.com.au platform.

Measurable improvements in supply chain performance demonstrated

Targeted monitoring supported improvement in cold-chain performance and fruit quality outcomes:

- Strawberry farm dispatch and market arrival temperatures decreased from an average 9.2°C in 2023 to 4.1°C in 2025 and was associated with a 34% increase in acceptable fruit remaining by day 7 of shelf life
- Variable 'Honey Gold' mango dispatch (13.4-25.0°C) and transport (13.5-20.7°C) temperatures in 2022/23 were reduced to within the optimal 12-16°C by 2024/25 resulting in a 33% improvement in shelf life consistency

Evidence supports practice change and investment decisions

- Avocado packing line monitoring identified critical control points contributing to nodule damage with one business implementing equipment changes to reduce damage by 37% relative to the previous season
- Strawberry consignment monitoring and simulation trials supported 2 businesses to invest in improved pre-cooling infrastructure, with one example indicating a potential benefit cost ratio (BCR) of 3.14
- 'Honey Gold' mango controlled atmosphere trials that increased storage potential prompted one business to adopt the technology to extend fruit availability by 4 weeks and achieve a BCR of 2.84
- Avocado consignment monitoring and results from simulation trials stimulated one export business to include data loggers in every shipment and use controlled atmosphere containers for seafreight.

Economic value demonstrated through case studies

Economic analysis case studies indicated positive returns from adopting project learnings such as the use of controlled atmosphere storage, real-time consignment monitoring and shelf-life prediction tools with a BCR of 1.93 to 4.76.

Awareness and adoption strengthened

By the end of the project, awareness of the shelf-life tools had increased to 50-80% of surveyed avocado, mango, strawberry and Summerfruit businesses. The shelf-life calculators were rated by 45% of survey respondents as critical for managing supply chain challenges while 80% of respondents were more aware of real-time monitoring technology. By the end of the project, 70% of respondents indicated that the project had addressed their key supply chain issues, 95% reported gaining new knowledge while 90% either had made or were planning to improve business practices.

Keywords

Avocado; mango; models; monitoring; predictive tools; shelf life; strawberry; Summerfruit; temperature.

Introduction

Australian fruit and vegetable growers have a reputation for producing high-quality, safe and nutritious fresh produce. To meet market expectations, growers must consistently deliver high quality fruit and vegetables. This starts with understanding consumer preferences. It requires careful cultivar selection, finely tuned agronomic programs and optimising supply chain logistics and handling conditions.

Fresh produce supply chains can be long, complex, time-sensitive and vulnerable to disruption due to a range of factors including adverse weather, labour shortages and geopolitical conflicts. Deviations in product handling conditions can significantly impact perishable fruit and vegetables resulting in variable arrival quality and shelf life. This variability creates considerable risk for growers and their supply chain partners, including the potential for claims and lost value. More than one-third of Australian fresh produce is discarded as waste from farm to fork (Food Innovation Australia Ltd, 2021). Estimates by the Australian Food Cold Chain Council suggest that poor temperature management in supply chains is responsible for \$2.96 billion of fruit and vegetable waste each year (Brodrribb et al., 2020).

Improving the consistency of product quality in domestic and export markets is a key priority for many of Australia's horticulture industries. It is critical for maintaining a competitive advantage and access to high value markets. For many businesses, the challenge is being able to identify where product quality is lost, quantify the consequence on remaining shelf life and prioritise corrective actions to deliver fresh produce that consistently meets market expectations. Inconsistent product quality and shelf life across harvest batches is usually related to differences in the initial quality and/or variation in supply chain handling conditions. Quantifying the impacts of these variables could inform development of decision aid tools such as mathematical models for predicting arrival quality and shelf life (Tijskens and Polderdijk, 1996). These tools could support a transition from traditional first-in, first-out logistics that assumes all produce is of equal quality to first-expired, first-out distribution that prioritises batches with the shortest shelf life (Hertog et al., 2014). This could lead to more efficient stock rotation and delivery of consistent quality and shelf life with less waste (Jedermann et al., 2014).

Shelf-life prediction models for 2 Australian mango and 3 nectarine cultivars were developed in the initial Serviced Supply Chains (AM15002) project (Macnish, 2021). The project also demonstrated the benefits of regular monitoring of fresh produce consignments to help identify, assess and manage supply chain handling risks. The general intent of the follow-on Serviced Supply Chains II (AM21000) project was to extend the shelf-life modelling approach to other commodities and cultivars to provide growers and supply chain businesses with the necessary decision support to deliver more consistent fresh produce quality to domestic and export markets.

The core objectives were:

- Develop predictive shelf-life models for a range of fresh produce that factor in pre- and postharvest conditions
- Apply the models to develop decision aid tools and updated best practice handling resources
- Host project content on peak industry body (PIB) websites to increase awareness and adoption of tools and resources.

Commencing in June 2022, the 4-year project aimed to increase grower and supply chain partner knowledge, skills and confidence to adopt consignment monitoring and shelf-life prediction technologies for improving fresh produce quality outcomes. The project team consisted of horticulture postharvest quality, technology and data science RD&E specialists from the Queensland Department of Primary Industries (DPI), Victoria Department of Energy, Environment and Climate Action (DEECA), Northern Territory Department of Agriculture and Fisheries (DAF) and the Western Australia Department of Primary Industries and Regional Development (DPIRD). The project included co-investment from Piñata Farms Pty Ltd and Summerfruit Australia Ltd plus avocado and strawberry R&D levies. Leading horticulture businesses that produce, market and export avocado, mango, strawberry and Summerfruit participated in the project.

Methodology

AM21000 was a large, complex national project with multiple co-investors including government, business and grower levies. With a focus on avocado, mango, strawberry and Summerfruit, the project was active year-round working with growers from across Australia plus their domestic and export supply chain partners. The underlying project philosophy was to utilise co-innovation and participatory learning approaches to ensure commercial relevance and maximum impact.

Project governance

A project reference group (PRG) was established to provide broad strategic advice. It was comprised of individuals with commercial experience in horticulture crop production, supply chains, logistics, export development, stakeholder engagement, technology adoption and commercialisation (Appendix 1). Industry advisory groups for avocado (Appendix 2) and strawberry (Appendix 3) were established to acknowledge the levy contribution to AM21000 and provide input and industry perspective into the work program and communication of key outputs. A project management committee (Appendix 4) aimed to bring together project co-investors to plan and coordinate work activities.

During the initial 6 months, the project team developed a monitoring and evaluation (M&E) plan (Appendix 5), risk register (Appendix 6), stakeholder engagement and industry communications strategy (Appendix 7), background IP register (Appendix 8) and a technology exploitation/commercialisation plan to guide the work program.

Contract variations

The project head agreement was varied 6 times to alter project scope, deliverables and timelines as circumstances changed. Notable changes included:

- Withdrawal of Nutrano Produce Group as a co-investor due to a business restructure
- Withdrawal of AUSVEG as the vegetable program co-investor due to concerns over managing transactions and administration whilst relying on DEECA to deliver the work through a separate subcontract
- Withdrawal of DEECA as the vegetable program co-investor because all 5 project staff were made redundant
- Ceasing work on the proposed information portal as no funds were available for ongoing maintenance
- A commitment to host project content on peak industry body (PIB) websites instead of the portal
- Reallocation of portal funds to a 6-month project extension to complete additional avocado and strawberry trial work.

A revised project M&E plan (Appendix 9) was developed in response to these changes.

Focus commodities

Separate work programs were established for avocado, mango, strawberry and Summerfruit. The commodity programs liaised with the respective co-investors, PIBs and industry advisory groups to identify grower collaborators. Initial meetings identified fruit quality and supply chain issues to be addressed by the project (Appendix 10). This informed development of RD&E plans (Appendix 11, 12) for each commodity. Pre- and post-season meetings were held each year with the co-investors, PIBs and industry advisory groups to plan activities, share learnings and review progress.

The avocado program was led by DPI and DPIRD and had an export focus. Avocado fruit were sourced from north Queensland (Qld), central Qld and Western Australia (WA). DPI, DAF and Piñata Farms managed the mango program, working with 'Honey Gold' growers in the Northern Territory (NT) and Qld plus their domestic supply chain partners. The strawberry program was led by DPI and focused on improving domestic supply chain outcomes with Qld and Tasmanian growers. SAL and DEECA led the Summerfruit program and worked with Victoria (Vic) growers and exporters.

Modelling and simulations program

The objective was to develop predictive shelf-life models for each commodity considering the influence of cultivar, environment (e.g. region, season), management (e.g. harvest maturity), market access protocols (e.g. irradiation) and supply chain (e.g. time, temperature) variables. The approach largely followed the methodology developed in AM15002.

Commercially graded fruit were sourced from different farms, blocks and regions. A series of laboratory-based simulation trials were completed to quantify shelf life responses to a range of domestic and export supply chain scenarios. Trial design was informed by monitoring product handling conditions from farms to importers or wholesalers (see capacity building and communications below). Postharvest temperature, time and relative humidity were the key variables studied. Where appropriate, treatments such as irradiation, controlled atmosphere storage and ripening with ethylene gas were included. Shelf life was assessed at 20°C (avocado, mango), 18°C (Summerfruit) or 4°C (strawberry). Trials were repeated over 3-4 years with multiple harvests to capture differences in fruit maturity and seasonal responses.

Based on suggestions from the co-investors, trial work also quantified impacts of other factors and treatments on fruit shelf life. This included testing the efficacy of edible surface coatings, 1-methylcyclopropene (1-MCP) and controlled atmosphere storage to extend the marketability of mangoes, quantifying impacts of delayed cooling after harvest on the shelf life of strawberries and evaluating the postharvest performance of large vs small avocado fruit. Where clear differences existed in shelf life responses, the project team engaged with growers to trace this back to farm, block, batch or treatment levels. Where warranted, additional monitoring of weather conditions before harvest was completed. In the final season, avocado fruit mineral nutrition status was related to internal quality following a seafreight simulation.

Model development involved determining the best fit for postharvest time temperature units (degree hours >0°C) and shelf life data. Relationships with other quality parameters (e.g. fruit firmness) were investigated. Models were optimised over time as new data was collected through simulation trials or consignment monitoring activities. Models were validated in commercial supply chains by comparing predicted and observed data, utilising third-party assessors in-market, as described below in the capacity building and communications program. The models were maintained on secure file servers at DPI and DEECA. Based on advice from the PRG, the project pursued 2 pathways for delivery of the prediction models to industry: 1) Automatic real-time prediction service integrated with consignment monitoring technology, 2) Manual input scenario-testing calculators available through PIB websites. In the final year of the project, mango and Summerfruit growers were invited to trial models developed in AM21000 and AM15002.

Capacity building and communications program

The objective was to provide growers and supply chain partners with new knowledge, skills, confidence and decision support resources and tools to manage risks and deliver more consistent fruit quality.

The program worked with growers and their supply chain partners to monitor avocado, mango, strawberry and Summerfruit consignments from pack sheds to domestic and export markets. Real-time data loggers were inserted into consignments at the pack shed. The recorded temperature, relative humidity and time data helped to guide the simulation trials but also identified deviations from best practice. The team identified third-party assessors in Australia and key export markets with capacity to provide objective fruit quality assessment reports back to growers and supply chain partners. Following consultation with growers, the project team developed a standard procedure for objectively assessing arrival quality and shelf life for each commodity. Training resources (e.g. videos, protocols) were delivered to assessors to ensure consistency in fruit quality assessment. A rapid reporting fruit quality assessment app was customised for avocado, mango and strawberry. Once fully established, the assessor network was designed to fulfill a dual purpose – 1) assess fruit arrival quality and shelf life for model validation in commercial consignments, and 2) offer a reliable, sustainable service for objective feedback on arrival quality and shelf life for growers and supply chain businesses.

A questionnaire was developed to document grower knowledge, skills, aspirations and adoption of improved practices and decision aid tools. Growers from each commodity group were interviewed in year 1 (2023) to establish a baseline for product handling knowledge, awareness of decision aid tools and barriers to adopting consignment monitoring and shelf-life prediction technologies. In the final year of the project (2026), a follow-up survey was completed to measure changes in awareness and adoption of tools and improved practices to better manage fruit quality along the supply chain.

The project team engaged an agricultural economist to quantify the economic impact of businesses adopting project findings. One cost benefit analysis case study for each of the 4 commodities was completed. The case studies involved interviewing growers and supply chain partners who had direct experience with the project.

While the project team worked in-depth with the co-investors and collaborating growers, generic learnings, recommendations and tools were shared with the broader horticulture industry through a suite of industry-facing communications. The team engaged directly with leading growers and exporters to increase awareness and uptake of project recommendations and tools. The team also worked with PIBs and their preferred communication channels to disseminate project content to the broader industry. This included delivery of:

- Decision aid tools based on shelf-life modelling that guide supply chain handling strategies
- Case study videos, articles and factsheets focused on grower adoption of project learnings, tools and resources
- Information products and resources to identify, assess and manage supply chain risks
- Media releases, social media posts to promote key developments and announcements to the broader industry
- Presentations at industry forums in key production regions and/or national conferences to increase awareness of project outcomes and opportunities to engage
- Whole-of-project workshops in 2022 and 2025 at the Hort Connections trade show to promote project activities and learnings plus demonstrate decision aid tools to a broad cross-section of industry.

Results and discussion

Avocado

The project worked with 14 NQ, CQ and WA growers and exporters to monitor 28 'Hass' and 14 'Shepard' consignments to Hong Kong, Japan, Malaysia, Thailand and Singapore from 2023 to 2025 (Appendix 13). Key learnings included:

- Seafreight supply chains into Asia varied in duration from 19 to 57 days depending upon the destination
- 'Hass' seafreight consignments were dispatched at 9.8°C and shipped at 7.0°C in 2023, above the recommended 5°C
- By 2025, average 'Hass' dispatch and seafreight temperatures reduced to 7.6°C and 5.8°C, respectively
- On average, 'Shepard' airfreight consignments took 17.3 days from dispatch to collection at the importer
- 'Shepard' handling temperatures were above the recommended 7°C across all seasons, with consignments averaging 11.4°C at dispatch, 10.1°C in the supply chain, and 14.5°C upon arrival at the importer
- Ten consignments did not meet the industry standard of at least 90% of ripe fruit displaying <10% quality defects
- Where consignments failed, it was mainly due to development of fruit body and stem-end rots in association with long supply chain duration, elevated handling temperatures and/or wet weather prior to harvest.

A total of 45 supply chain simulation trials with 'Hass' fruit from NQ, CQ and WA and 'Shepard' fruit from NQ and CQ were completed (Appendices 14-41). Additional trials evaluated the risk of nodule damage, potential of edible coatings to extend shelf life, and fruit ethylene production response to cold storage (Appendices 42-49). Key findings included:

- Fruit quality and robustness for export supply chain handling varied between blocks, farms and seasons
- Small (count 28 or 30) fruit were best suited to long (>20 days) storage/supply chains than large count 20 fruit
- Late-season 'Hass' fruit with high (>30%) dry matter content exhibited 10 to 30% less shelf life than early fruit
- 'Hass' fruit stored best at 5°C in air for up to 20-30 days depending upon their robustness and timing of harvests
- 'Shepard' fruit quality did not differ between 5 and 7°C when stored for up to 10 days
- Internal chilling injury emerged in 'Shepard' fruit after 20 days at 5°C
- Skin darkening was a common defect in ripe 'Shepard' fruit, after 20 days of storage particularly in larger fruit
- Storage of 'Hass' at 5°C and 'Shepard' at 7°C in a controlled atmosphere (2% O₂, 5% CO₂) reduced the risk of chilling injury and skin darkening, retained fruit firmness and could extend shelf life
- Chilling injury was more severe when fruit started to soften while in storage
- Sensitivity to chilling injury appeared to relate to the relative nitrogen and calcium composition of fruit.

Shelf-life and chilling injury prediction models were developed and tested based on observations from over 10,000 fruit across 3-4 seasons (Appendix 50). Cultivar-specific time x temperature and time-temperature unit models predict shelf life as the time for fruit to reach firm and medium soft ripening stages. The models were validated against data collected from 12 export consignments and predicted shelf life to within ± 1.3 -1.6 days for 'Hass' and ± 3.0 -3.8 days for 'Shepard'. The models incorporate fruit production region, harvest time, size, maturity plus supply chain conditions and treatments and have been integrated into an industry-facing shelf-life calculator to guide handling and logistics decisions.

Mango

Across 3 seasons, 59 'Honey Gold' consignments from 6 growers in the NT (Darwin, Katherine) and Qld (Bowen, Bundaberg, Dimbulah, Mareeba) were monitored to a ripener in Melbourne (Appendix 13). In addition, a 'Honey Gold' export consignment was monitored from a Qld grower to Singapore in early 2025. Key learnings included:

- 70% of NT and 30% of Qld consignments were dispatched and transported above the optimal 12-16°C in 2022-23
- Average dispatch (13.4-25.0°C) and transport (13.5-20.7°C) temperatures in 2022/23 were also highly inconsistent
- The supply chain duration (5-14 days) varied considerably
- Inconsistent handling conditions resulted in variable shelf life of 8-20 days
- Treatment with ethylene accelerated ripening and led to more uniform shelf life of 4-13 days
- By 2024/25, growers reduced average dispatch temperatures to 15.4°C (NT) and 13.0°C (CQ) and average transport to 15.7°C resulting in slightly more consistent shelf life of 9-17 days in the absence of ethylene
- Differences in fruit maturity and rot incidence were also factors in shelf life variability.

Twenty simulation trials with 'Honey Gold' fruit from NT and Qld growers were completed over 3 seasons (Appendices 51-56). Additional trials evaluated the potential of edible coatings, 1-MCP and controlled atmosphere storage to extend shelf life, plus irradiation and ethylene treatment effects (Appendix 57). Key findings included:

- NT fruit stored best at 14°C to avoid the risk of under-skin browning while 12°C was optimal for Qld fruit
- Fruit from the Darwin area were most susceptible to rots and exhibited 2-4 days less shelf life than other regions
- Fruit held at 20°C and 90% relative humidity displayed 2.6 days less shelf life than those stored at 20°C and 65% relative humidity
- Ethylene treatment reduced shelf life by up to 3.4 days but coordinated more uniform ripening
- Holding ethylene-treated fruit at 12 or 14°C instead of 20°C delayed ripening and added up to 7 days of shelf life
- Irradiation at 150 Gy did not affect shelf life but exposure to 400 Gy reduced shelf life by up to 2 days
- Fruit could be stored for 21-28 days at 12°C under a controlled atmosphere (2% O₂ and 5% CO₂) and still deliver at least 10 days of shelf life at 20°C, with late-season Bundaberg fruit showing the greatest benefit
- A commercial trial utilising apple controlled atmosphere rooms was successful and highlighted an opportunity for late-season growers to extend fruit availability in the market.

Models to predict remaining shelf life and chilling injury were developed using time x temperature and time-temperature units approaches and included production region, fruit maturity, supply chain conditions and ethylene treatment parameters (Appendix 58). The time-temperature unit prediction models were trained on observations from over 8,000 fruit and validated to within an average ± 2.8 days of actual shelf life. In the 2025/26 season, model validation was extended to 13 domestic 'Honey Gold', 'Kensington Pride' and 'R2E2' consignments with cultivar-specific models predicting within an average ± 1.4 , ± 2.2 and ± 1.2 days, respectively, of observed shelf life (Appendix 58). The models were incorporated into a shelf-life calculator for growers and supply chain partners to quantify handling impacts.

Strawberry

From 2023 to 2025, 32 'Cabrillo', 'Petaluma', 'Red Rhapsody', 'Scarlet Rose', 'Stella' consignments from 7 growers in Qld and Tasmania were monitored to wholesalers or retail distribution centres in Melbourne, Sydney and Brisbane (Appendix 13). One export consignment was monitored from a Qld grower to Hong Kong in 2025. Key learnings included:

- Average dispatch and supply chain handling temperatures progressively decreased from 8.7 and 7.5°C in 2023 to 7.1 and 6.1°C in 2024 and 4.3 and 3.4°C in 2025, respectively, close to the recommended 0.5-4.0°C for strawberries
- Fruit temperatures on arrival in the market reduced from an average 9.7°C in 2023 to 3.9°C in 2025
- Average relative humidity during cooling and transport increased from 64% in 2023 to 83% in 2025, below an optimal 90–95% relative humidity
- The duration from packing to arrival in the domestic market varied from 1 to 4 days
- Fruit quality consistently improved as cold chain conditions were optimised, with the proportion of acceptable fruit remaining by day 7 of shelf life increasing from 26% in 2023 to 88% in 2024 before decreasing to 60% in 2025
- Despite improved postharvest handling conditions in 2025, a wider harvest window likely introduced more variation in fruit maturity that led to a reduction in shelf life.

From 2023 to 2026, 17 supply chain simulation trials were completed with 'Albion', 'Cabrillo' and 'Red Rhapsody' fruit from Qld (Appendices 59-66). An additional 9 trials with 'Cabrillo' and 'Red Rhapsody' strawberries quantified the impact of delays from harvest to cooling on fruit quality and shelf life (Appendix 67). Key findings included:

- Fruit shelf life and quality varied between farms, cultivars and seasons
- Strawberries stored best at 1-4°C and >90% relative humidity
- Holding fruit above 4°C for 1-2 days accelerated loss of quality and shelf life
- Fruit held at 15°C for 1 day reduced shelf life by 18-38% relative to fruit at 1°C
- Reducing relative humidity from 90 to 65% had a similar effect on shelf life as increasing temperature from 4 to 10°C
- When constantly held at 4°C and 65% relative humidity, fruit lost 2-3 times more weight and 36% shelf life than at 93% relative humidity
- A 2-hour delay at ambient (i.e. 25-30°C) between harvest and cooling increased weight loss and reduced shelf life
- An 8-hour delay at 25-30°C before cooling reduced shelf life by up to 50%.

Preliminary models were developed to predict average punnet shelf life (Appendix 68). For 'Red Rhapsody', storage and handling conditions together with seasonal effects explained more than 70% of the observed variation in shelf life. 'Red Rhapsody' models were validated using commercial shipment data and showed reasonable agreement with observed outcomes, with a tendency to slightly underestimate shelf life performance. For 'Albion' and 'Cabrillo', cultivar-specific models were developed using simulation trial data and achieved moderate alignment ($r^2 = 0.68-0.80$) with observations but still require validation under commercial conditions. Overall, the modelling approach could provide practical rules of thumb advice for linking storage conditions to shelf-life risk.

Summerfruit

Across 3 seasons (2023/24, 2024/25, 2025/26), 10 nectarine ('Diamond Pearl', 'Flavour Pearl', 'Majestic Pearl', 'Polar Zee'), 2 plum ('Black Ruby', 'Queen Garnet') plus 2 peach ('Snow Flame') export consignments were monitored from 4 growers in Vic via air and seafreight to China, Malaysia, Taiwan and Vietnam (Appendices 13, 69). Key findings included:

- Airfreight consignments were generally stored and transported at 8-18°C for 5-6 days
- The seafreight duration varied from 22 to 35 days while the average temperature was 0.1-0.8°C
- Initial fruit firmness at packing was 4.7-8.5 kg/cm² and decreased to 4.6-5.5 kg/cm² following seafreight before softening further to an eating ripe 1.2-2.8 kg/cm² after 4 days of ripening in the market at 18-22°C
- Air and seafreight temperatures avoided the critical 'kill zone' of 3-8°C that is associated with fruit quality disorders.

In the 2023/24 and 2024/25 seasons, 17 supply chain simulation trials were completed with 5 nectarine and 2 plum cultivars from Vic (Appendix 69). Additional trials in 2022/23 evaluated effects of growing region, modified atmosphere liners and stepwise cooling on nectarine, peach and plum storage disorders (Appendix 70). Key findings included:

- Simulated storage trials showed that cumulative time-temperature units or degree-hours was a reliable indicator of changes in fruit firmness, soluble solids content and the onset of internal disorders
- Demonstration that the DA meter can measure the optimal fruit physiological maturity and inform harvest schedules
- 'Majestic Pearl' and 'September Bright' nectarines grown in Swan Hill had higher susceptibility to storage disorders (e.g. flesh browning) than those grown in Tatura
- Stepwise cooling of 'Snow Fox' peaches to 12°C for 48 hours prior to simulated seafreight at 2°C reduced incidence of flesh browning by 25% for 43 days relative to fast cooling directly to 2°C
- Use of modified atmosphere liners in boxes instead of standard perforated liners reduced flesh browning in 'Majestic Pearl' and 'September Bright' nectarines and could potentially extend cold storage duration by up to 2 weeks
- Modified atmosphere liners and irradiation reduced 'Ruby Sugar' plum stem rot by 16 and 18%, respectively.

Models for predicting changes in nectarine and plum firmness, total soluble solids and internal disorders were developed using Gompertz and polynomial regression techniques (Appendix 69). The models were validated using simulation trial and export consignment monitoring data. In 2025/26, the models predicted fruit firmness on arrival and after ripening to within ± 0.7 kg/cm² in 2 out of 4 monitored consignments but deviated by $\pm 1.9-2.9$ kg/cm² in the other shipments (Appendix 71). Accurately predicting soluble solids content and internal disorders incidence was relatively more challenging. Seafreight and ripening conditions were generally outside the range tested in trials, highlighting the need to expand work to a broader range of scenarios for model development.

Outputs

A summary of major outputs from the project is provided below. For convenience, the outputs are grouped into 5 key deliverables with multiple linked or associated outputs. The descriptions below cite monitoring data that was collected to provide evidence of outputs and activities as per the revised project M&E plan (Appendix 9), where applicable.

Table 1. Output summary of predictive shelf-life tools

Output	Description	Detail
Predictive shelf-life models	Shelf-life prediction models and algorithms for 10 cultivars of avocado, mango, strawberry and Summerfruit were developed for Australian growers and supply chain partners.	Validated models are being made available to industry via shelf-life calculators through PIB websites (see below). The models will also be available to growers and exporters as a live prediction service, via integration with real-time consignment monitoring technology through a commercial partner (see below).
Database	A central database was developed to assist DPI staff to store and manage large, multi-season datasets generated by the project.	A MySQL database was developed for AM21000 datasets. This was an internal-facing resource for project staff through the DPI server. It accelerated progress with multivariate analysis of shelf life and quality data from over 65,000 fruit and 260 simulation trials and monitored shipments (Appendix 72).
Business plan	A technology exploitation plan was developed for DPI and Hort Innovation to assess the potential to commercialise the shelf-life prediction models.	A technology exploitation plan was delivered as part of the MS 103 report. This was an internal-facing document. It also helped to establish a tripartite equity participation agreement between DPI, Hort Innovation and DEECA.
Decision aid tools	The Fresh Intel (www.freshintel.com.au) website (Appendix 73) and 3 shelf-life calculators for selected varieties of avocado, mango and Summerfruit were developed for Australian growers and supply chain partners.	Calculators are being made available to levy payers and industry stakeholders through respective PIB websites (Appendix 74) via a link to the DPI Fresh Intel site. The avocado calculator is available at: https://avocado.org.au/best-practice-resource/packhouse/ The mango calculator is available at: https://www.industry.mangoes.net.au/resources/resources-library/predicting-mango-shelf-life/ The developer of the SAL website committed to include a link to the Fresh Intel Summerfruit calculator in May 2026.
Licence agreement	A licence agreement for non-exclusive rights to market the shelf-life models was developed for the licensee.	The licence agreement was shared with the licensee, Escavox Pty Ltd, an Australian supply chain monitoring and analytics provider. Escavox have proposed changes to some clauses in the agreement. DPI and Hort Innovation are developing a response. This is a confidential document.
Rules of thumb advice	Three fruit handling rules of thumb resources were developed to assist growers and supply chain partners to deliver more consistent product quality.	A mango quality assessment manual (Appendix 75) was published while three other best practice resources (Appendix 76) will be made available to industry via PIB websites: 1) Updated avocado export best practice handling guide, 2) Updated mango ripening manual, 3) Strawberry postharvest best practice factsheet. An article on determining optimal stone fruit maturity and impacts on storage potential was published in the Australian Tree Crop magazine (Appendix 77).

Table 2. Output summary of in-market quality assessment

Output	Description	Detail
Objective, standard quality assessment procedures for each commodity	Fruit quality assessment procedures for avocado, mango, strawberry and Summerfruit were developed for Australian and overseas assessors.	Electronic file copies of standardised quality assessment procedures were sent to each assessor (Appendix 78). Growers and industry representatives provided input into the assessment criteria. The assessment procedures will be made available to the broader industry via respective PIB websites.
Quality assessment and rapid reporting app	An existing fruit quality assessment app was customised to assist Australian and overseas assessors to rapidly record and report quality assessment data and images.	A quality assessment app was customised in partnership with Rudge Produce Systems (Appendix 79). The app was made available to 14 businesses that delivered avocado, mango and strawberry quality assessment services to the project. The assessors were trained in its use and successfully entered and shared fruit quality data in real-time. The app is available on request through Rudge Produce Systems. Growers have expressed an interest in using the app and building additional capability to include recording of packing shed quality data.
Training resources to facilitate in-country quality assessments	Quality assessment kits for avocado, mango, strawberry and Summerfruit were delivered to provide Australian and overseas assessors with competence to assess fruit quality to industry standards.	Quality assessment kits that included instructions, worksheets, image sets plus a video for using a durometer were made available to the assessors as electronic copies and via in-person training sessions (Appendix 78). The quality assessment kits for each commodity will also be made available to growers and exporters through PIB websites.
Competent, independent outturn assessors in 7 key export markets and Australia	Independent assessors from 16 businesses in 8 export markets (Hong Kong, India, Japan, Malaysia, New Zealand, Singapore, Thailand, Vietnam) plus Australia were trained to provide objective feedback on fruit arrival quality and shelf life to Australian growers and exporters.	The quality assessment service has been used to monitor and report on over 140 mango, avocado, strawberry and Summerfruit consignments (Appendix 13). Growers, exporters and marketers have expressed interest and confidence in engaging with assessors beyond the project. A factsheet (Appendix 80) with details and contacts for each assessor will be made available to avocado, mango, strawberry and Summerfruit growers and exporters via respective PIB websites. The factsheet will be promoted via a short article in PIB newsletters to increase awareness.

Table 3. Output summary of cost benefit analyses

Output	Description	Detail
Economic analysis report	Independent economic analysis was commissioned by DPI to quantify the impact of adopting project learnings on business profit.	An economic analysis report (confidential) was delivered as part of the MS 109 report. This was an internal-facing document that contained confidential business information. The report presented economic analysis for avocado, mango, strawberry and Summerfruit businesses that adopted project findings. Generic learnings and economic data were made available to the wider industry as case studies (see below).
Co-investor case studies	Three case study articles, 1 video and 1 factsheet that document adoption of project findings by industry were developed for Australian growers and supply chain partners.	Five case studies of grower and exporter adoption were developed with supporting economic analysis (Appendix 81). Three articles (avocado nodule damage, 'Hass' avocado quality, mango controlled atmosphere storage) were published in industry magazines. An avocado case study video and factsheet will be made available via the avocado PIB website. A strawberry fruit pre-cooling case study factsheet is in draft form (Appendix 80).

Table 4. Output summary of information portal

Output	Description	Detail
Gap analysis and review of supply chain content on industry websites	A review of supply chain content on industry websites was completed for Hort Innovation as part of scoping potential for a project information portal.	A gap analysis and review of industry websites (Appendix 82) was delivered as part of the MS 103 report. This was an internal-facing document to inform development of a project information portal. The gap analysis and review was also shared with the PRG when evaluating plans to resource the proposed portal.
Industry consultation survey	A survey of growers, freight forwarders, exporters, retailers and PIBs was completed for Hort Innovation to quantify knowledge gaps and support for a project information portal.	An industry stakeholder survey report (Appendix 83) was delivered as part of the MS 103 report. This was an internal-facing document to inform development of a project information portal. The survey report was also shared with the PRG when evaluating plans to resource the proposed portal.
Portal framework	A framework for the project information portal was developed by DPI to guide the project team and webpage developer through the initial stages of building the site.	An information portal framework (Appendix 84) was delivered as part of the MS 104 report. This was an internal-facing document that was made available to Hort Innovation and the PRG to inform development of a project information portal. The framework was discussed at a portal workgroup meeting and was included in the procurement process.
Portal workgroup meeting outcomes	A procurement process was undertaken to identify a suitable developer of the proposed information portal and a summary report was provided to Hort Innovation and a project workgroup.	The procurement summary report was a confidential internal-facing document prepared by DPI and shared with Hort Innovation, the portal workgroup and the PRG. It is not intended to be made publicly available.

Table 5. Output summary of industry-facing communications products

Output	Description	Detail
Updated pre- and postharvest export handling guidelines	Four updated or new best practice handling guidelines for avocado, mango and strawberry were developed for Australian growers and supply chain partners.	Updated and new best practice handling guidelines were developed based on project learnings (Appendix 75). An updated mango quality assessment manual was published and is available via the mango PIB website. Three other avocado, mango and strawberry guidelines will be made available to industry via the respective PIB websites.
Case study presentations at industry forums	Forty-six case study presentations were delivered at avocado, mango, strawberry and Summerfruit industry forums for Australian growers and supply chain partners.	Case study presentations were delivered to 15 avocado, 11 mango, 5 strawberry, 9 Summerfruit and 6 cross-commodity regional, national and international industry forums (Appendix 85).
Factsheets, videos, articles, industry newsletters	Seven factsheets, 6 videos, 13 articles and 4 newsletter articles were published through avocado, mango, strawberry and Summerfruit industry communication channels for Australian growers and supply chain partners.	Key project learnings were made available to growers and supply chain partners through articles, factsheets, videos and industry newsletters with the content hosted on avocado, mango, strawberry and Summerfruit PIB websites (Appendices 77, 80, 86). An additional Summerfruit, avocado article and strawberry factsheet are in preparation (Appendix 76).
Workshops at major horticulture industry events	Two workshops were delivered at the national Hort Connections trade show that provided industry stakeholders with an introduction to the project and some key learnings and achievements.	An initial workshop was delivered in 2022 to 72 attendees from a wide cross-section of industry (Appendix 88). It provided an introduction to the project. A final workshop was held in 2025 with 88 people attending from different commodity groups, service providers and PIBs (Appendix 89). The workshop highlighted key learnings, case studies and achievements.

Outcomes

A summary of project outcomes is provided below, supported by monitoring data that provides evidence as per the revised M&E Plan (Appendix 10). All outcomes align with the following industry fund outcomes, strategies and KPIs.

Table 6. Industry fund outcomes, strategies and KPIs addressed by project AM21000.

Industry	Fund outcome	Strategy	KPIs
Avocado	Outcome 2: Industry supply, productivity and sustainability	Apply a systems research approach to improving quality of Australian avocados throughout the supply chain	Evidence of increased product quality management across avocado supply chains
Mango	Outcome 1: Demand creation	Prepare and adopt an updated export strategy to expand exports to high value markets.	Evidence of improved exporter capability into high-value markets.
Strawberry	Outcome 2: Industry supply, productivity and sustainability	Review postharvest and supply chain technologies to maximise quality and profitability, including establishing quality standards and a methodology to monitor quality	Increased grower knowledge on postharvest and supply chain technologies
Summerfruit	Outcome 1: Demand creation	Increase domestic demand and build international customer awareness for Australian Summerfruit through improving knowledge, attitudes and purchase intent.	Positive influence on consumer preference.

Table 7. Outcome summary

Outcome	Description	Evidence
50% of avocado, mango, strawberry and Summerfruit growers and exporters were aware of project-developed shelf-life prediction models, decision aid tools and/or rules of thumb.	The project improved awareness of shelf-life prediction models and associated decision aid tools and resources via a series of communication products, industry forum presentations and demonstration of shelf-life calculators.	An initial survey of 24 avocado, mango, strawberry and Summerfruit growers, marketers and exporters in 2023 showed there was limited knowledge of shelf-life prediction tools (Appendix 90). At the end of the project in 2026, 71% of avocado, 80% of mango, 50% of strawberry and 61% of Summerfruit industry respondents were at least moderately aware of the predictive shelf-life technology (Appendix 91).
25% of avocado, mango, strawberry and Summerfruit growers and exporters used or aspired to use project-developed shelf-life prediction models, decision aid tools and/or rules of thumb.	The project actively involved avocado, mango, strawberry and Summerfruit growers and exporters in testing of the shelf-life prediction models as part of domestic and export consignment monitoring activities. Towards the end of the project, growers and exporters were invited to trial the technology.	Six businesses representing more than 50% of mango and Summerfruit trade trialled the shelf-life prediction technology in 2025/26, tracking 21 domestic and export consignments (Appendices 58, 71). Six avocado exporters contributed 'Hass' and 'Shepard' export consignments for model testing in 2025 (Appendix 50). Two avocado exporters trialled the shelf-life calculator and indicated it would guide decisions about transport modes and destination markets. At the final survey, strawberry growers stated "it is early days" for the shelf-life prediction tools for berries (Appendix 91).

Table 7 continued. Outcome summary

Outcome	Description	Evidence
Avocado, strawberry, Summerfruit and Honey Gold mango collaborating producers and exporters were confident in the robustness, practicality and accuracy of the shelf life prediction models, decision aid tools and rules of thumb and had the knowledge and skills to use them.	The project invited and involved avocado, mango and Summerfruit growers and exporters in testing of the shelf-life prediction models and associated tools during monitoring of their own fruit consignments. This activity utilised trained assessors in domestic and export markets. Generic findings were shared with the broader industry via forum presentations and communication products.	An end of project survey highlighted that 45% of respondents rated the shelf-life calculators as critical for managing supply chain challenges (Appendix 91). Confidence in the shelf-life tools also increased between the initial 2023 and final 2026 surveys. In 2023, one of the most important barriers to using the tools was confidence in their output (Appendix 90). By 2026, only 7% of respondents indicated that ‘confidence in shelf life prediction output/error’ was still a barrier (Appendix 91).
Commercialisation of avocado, mango and Summerfruit shelf-life models	The project team developed a plan for commercialising the shelf-life models. A commercial partner was identified through a public EOI process. A licence agreement is pending. A real-time shelf-life prediction service will be made available to Australian growers and supply chain businesses.	Expressions of interest in commercialising the technology were received from 6 AgTech providers. Escavox was chosen as the preferred commercial partner and licensee. Escavox has incorporated a shelf-life prediction function on their consignment monitoring platform ahead of launching the real-time service (Appendix 92). Information exchange between the Escavox platform and the DPI Fresh Intel website was tested and provided live shelf-life predictions via an application programming interface (API) (Appendix 73). DPI filed an application to the Australian Trade Mark Office to register “Fresh Intel” as a logo to accompany commercial use of the shelf-life prediction algorithms. A factsheet was developed for mango and Summerfruit industry roadshows plus the 2025 Asia Fruit Logistica trade show to advertise the prediction service opportunity to industry (Appendix 80).
Increased knowledge and awareness of the benefits of controlled atmosphere storage to extend availability of late-season ‘Honey Gold’ mango fruit. Practice change to trial the technology at a commercial scale.	Project trials demonstrated that late-season ‘Honey Gold’ mango fruit from the Bundaberg area could be stored under a controlled atmosphere for up to 4 weeks. This could extend fruit availability in the market beyond the final harvest date. Trial findings were shared at industry forums and in a Mango Matters article.	Confidence from Piñata Farms to test the technology on a commercial scale in 2026 (Appendix 86). Fruit quality was well received by the market. Confidence that Piñata Farms could produce and market an additional 400,000 mango trays by extending the ‘Honey Gold’ season by 4 weeks. Feedback from a mango grower in the Bundaberg region who has proposed planting >8,000 more ‘Honey Gold’ trees to seize this opportunity. Economic analysis showed for every dollar invested by Piñata Farms in adopting the technology, \$2.84 would be earned by the business and growers.

Table 7 continued. Outcome summary

Outcome	Description	Evidence
Avocado, strawberry, Summerfruit and 'Honey Gold' mango producer and exporter collaborators established objective evidence and understanding of the primary sources of variable quality and shelf life that influence outturn quality and remaining shelf life.	Factors that contribute to variable fruit quality and shelf life were identified through the monitoring of >140 avocado, mango, strawberry and Summerfruit consignments and completing >120 simulation trials over the life of the project. Fruit robustness, harvest maturity, handling temperatures and supply chain duration were among key factors identified. This information was shared with growers and exporters through reports and broader industry communications.	At the final survey in 2026, 80% of respondents indicated their awareness of real-time monitoring had improved, relative to the initial survey in 2023 (Appendices 90, 91). By 2026, 85% of respondents considered monitoring to be important or essential. Accessing reliable in-market quality assessments was rated as important or essential by 75% of respondents. A workshop hosted by the project team in 2025 captured insights from industry participants on key factors contributing to variable quality (Appendix 89). The project observed improved dispatch and supply chain temperatures for avocado, mango and strawberry consignments between 2023 and 2025 (Appendix 13) as a result of project monitoring and an appreciation of risks to quality loss. One strawberry business invested in a new cold room to pre-cool fruit before packing because of the project. An avocado exporter started using a controlled atmosphere in every seafreight consignment to manage the risk of extended shipping durations. The project worked with an avocado packer to identify critical control points along their pack line that contributed to nodule damage in 'Hass' fruit. The business levelled out the pack line and replaced hard plastic baffles with soft brush-type baffles to reduce nodule damage by 37% (Appendix 45).
Australian businesses adopting project tools to deliver premium and predictable quality fruit show measurable economic, social and environmental benefits through case studies.	The project commissioned independent economic analysis to quantify the impact of adopting key recommendations and tools on business profitability. Four case studies were completed with growers and supply chain partners representing each commodity group under study. Each case study focused on economic returns to businesses. The cost of project research investment, social and environmental impacts were not considered.	Economic analysis demonstrated measurable benefits across 4 case studies: • Use of controlled atmosphere storage, real-time consignment monitoring and shelf-life prediction tools for 'Hass' avocado exports by The Avocado Collective and Jasper Farms was forecast to achieve a benefit cost ratio (BCR) of 4.76. • Adoption of real-time 'Honey Gold' mango consignment monitoring and shelf-life prediction by Piñata Farms achieved a BCR of 2.60. Adoption of controlled atmosphere storage to extend the 'Honey Gold' season delivered a BCR of 2.84. • Implementing improved pre-cooling and relative humidity control plus real-time domestic consignment monitoring by Ashbern Farms and SSS Strawberries was forecast to deliver a BCR of 3.14. • Adoption of optimal harvest maturity standards and real-time monitoring of white peach export consignments by SHARP Fruit and Premier Fresh Australia was estimated to achieve a BCR of 1.93.

Table 7 continued. Outcome summary

Outcome	Description	Evidence
Increased awareness and interest in the project and potential for future RD&E opportunities.	The project has increased awareness of achievements and future opportunities through industry forum meetings, including an industry-wide workshop in 2025. The workshop encouraged discussion from businesses and PIBs in attendance on how project learnings and tools could be applied to other commodity groups.	An end of workshop survey indicated that 83% of respondents had developed an increased understanding of the project (Appendix 91). Following the workshop, Summerfruit Australia approached DPI seeking a proposal for expanding shelf-life modelling to a broader range of conditions. A concept was developed by DEECA and DPI for Summerfruit SIAP meeting in March 2026. A major fresh produce marketer approached DPI seeking a proposal to expand models to additional cultivars. A concept was developed by DPI for contract research with the marketer. “Paddock to Port” workshops are planned for September and October 2026 in collaboration with the AV21005 Growing Robust Avocados project team and Avocados Australia Ltd to explore the potential to integrate production and postharvest factors into the decision aid tools. The end of project survey also included comments from participants on future RD&E needs (Appendix 91). A summary of what the shelf-life models can and cannot predict is included at Appendix 93.

Taken overall, the project has generated a substantial body of knowledge and commercial outcomes. Across 4 commodities, >140 monitored consignments and >120 simulation trials, the project has increased awareness of the risks to fruit quality loss in domestic and export supply chains. This includes differences in the storage potential of cultivars, regional and farm level variation in fruit robustness, deviations from optimal temperature and relative humidity management plus inconsistent and extended shipping durations. Simulation trials helped to quantify impacts of these factors plus test interventions such as controlled atmosphere storage and modified atmosphere box liners. These learnings have reinforced industry experience and drive practice change to improve fruit quality outcomes. Several businesses who participated in the project offered the following takeaways:

“The ability to incorporate shelf-life predictions with the data loggers would be an amazing tool and allow us to make more forward marketing decisions. Being able to tell your customer how much shelf life is left and how to manage fruit through ripening and distribution could add value to the Australian avocado offering.” Sophie Cremasco, COO, The Avocado Collective

“We are excited by the outcome from this research as it could make a real difference to the ongoing profitability of our late season growers. If we can extend the sales window by 4 weeks that enables us to collectively produce another 400,000 trays to be sold over the extended window.” Gavin Scurr, Managing Director, Piñata Farms

“This project has helped us understand, not only for our business but hopefully the wider industry, how important the cold chain is and the new technologies that are available to help understand where we may be failing.” Brendon Hoyle, General Manager, Ashbern Farms

“Being involved in this project has been crucial for us as a business and for the wider industry to learn what varieties are best suited for air or seafreight, to know when to pick the correct fruit maturity and then how to handle them through the supply chain.” Dean Morpeth, Director and Marketing, SHARP Fruit

Monitoring and evaluation

Below is a summary of project performance. Further information can be found in the project M&E report (Appendix 94).

Table 8. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
<i>Effectiveness</i> Has the project increased awareness and adoption of decision aid tools that reduce supply chain risks and enable delivery of more consistent fresh produce quality to domestic and export markets? Did the project engage commercial service providers to make the shelf-life prediction models available for industry uptake?	An initial survey of 24 avocado, mango, strawberry and Summerfruit growers, marketers and exporters in 2023 revealed limited knowledge of tools to predict shelf-life. By the final survey in 2026, 65% of respondents were moderately to extremely aware of shelf-life models and decision aid tools and considering adopting the technology. In addition, 80% of the final survey respondents were more aware of consignment monitoring technologies by 2026, as compared to 2023. The number of respondents who could deliver fruit with guaranteed shelf life increased from 42 to 65% for exports and 54 to 95% for domestic markets between 2023 and 2026 (Appendices 90, 91). The project ran an EOI process in 2024 to identify a partner to make the shelf-life models available as a real-time prediction service. Supply chain monitoring and data analytics provider, Escavox, was selected. A licence agreement is being finalised.	Commercialisation of the predictive shelf-life technology took 4+ years from scoping the opportunity in AM15000 to running an EOI process and developing a licence agreement in AM21000. While the project has ended, ongoing resourcing and supporting early adopters of the real-time prediction service will be critical to realise the full value and impact of the technology. In the interim, the project team has made the shelf-life prediction technology available to industry as manual input scenario-testing calculators based on advice from the PRG. This may help increase confidence in the technology and drive adoption of the real-time prediction service once it is available.
<i>Relevance</i> Has the project met the needs of industry co-investors and levy payers? Did the project align with the strategic investment priorities of industry, the funding agency and delivery partners?	From a final survey of 20 avocado, mango, strawberry and Summerfruit growers, marketers and exporters, 70% of respondents indicated that the project had addressed their key supply chain issues, 95% reported gaining new knowledge while 90% either had made or were planning to improve business practices (Appendix 91). The project had a strong focus on improving fruit quality along the supply chain, supporting market growth and accelerating innovation and adoption. This aligned with the investment priorities of the avocado, mango, strawberry and Summerfruit industries plus the co-investors.	While there has been progress towards delivering predictive shelf-life tools for strawberries, further work is needed to validate the preliminary models. Further R&D is needed to quantify the impact of production and seasonal factors on postharvest quality.

Table 8 continued. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
<i>Appropriateness</i> Were the co-investors and broader industry stakeholders aware of project activities and resources? Did the project engage with industry levy payers and cross-commodity supply chain participants through their preferred learning style? How accessible were project resources and extension events to industry levy payers?	Project co-investors and the broader industry were kept aware of project activities and resources through the work of the Capacity Building and Communications program staff. A communications plan was developed in consultation with the PIBs. Thirty-one leading growers, packers and exporters representing the 4 commodities and major production regions were engaged in the project. Project content was made available via PIB websites and a range of communication channels (46 industry forum presentations, 13 articles, 7 factsheets, 6 videos, 4 newsletter articles) that cater for different learning styles.	There is an opportunity to package project content separately for each commodity to deliver a more tailored summary of achievement and impact for the different industry groups. This could extend to delivering separate webinars to each industry group. The project would have benefited from greater investment in extension and communication staff from all partners. This would have enabled earlier and more frequent communications, including engaging with industry more through other channels like social media.
<i>Efficiency</i> What proportion of industry stakeholders implemented project learnings? Did the project represent value for money for the co-investors and broader industry?	The project achieved the agreed targets efficiently in terms of cost and time. Project co-investors were engaged in the project to varying degrees. Efficient delivery of information products through industry communication channels helped to create interest in the project. Adoption of project learnings like controlled atmosphere storage for late-season 'Honey Gold' mangoes were achieved. Industry uptake of the predictive shelf-life models will require more time once the commercialisation process is finalised. The investment balance between monitoring, simulation trials, decision aid tools and capacity building represented value for money. Adoption of the decision aid tools should increase over time. This is supported by economic analysis case studies where 4 businesses who adopted project learnings should expect a return of between \$1.93 and \$4.76 for every \$1.00 invested. Economic analysis of the project investment is being undertaken ACIL Allen.	The project invested considerable time and funds into scoping the information portal. While the portal was ultimately never pursued, the activity identified critical content gaps on several industry websites. This information has stimulated efforts by PIBs to update and expand postharvest resources on their websites. The project demonstrated the value of employing a data scientist who established dedicated project database to store and manage trial and shipment monitoring data. There is potential to utilise the database in future projects. It could be used to produce more timely reports back to industry stakeholders. Data collection for the shelf-life models remains a labour-intensive activity with repeated simulation trials across multiple seasons required to generate robust datasets for commercial application. There may be potential to better use AI tools during model training in future.

Recommendations

Practical recommendations

- Produce avocado, mango, strawberry and Summerfruit of sufficient robustness to withstand the rigours of domestic vs export supply chain handling
- Harvest fruit at optimal maturity to ensure consistency in shelf life and eating quality
- Rapidly pre-cool and maintain avocados at 5-7°C, 'Honey Gold' mangoes at 12-16°C, strawberries at 1-4°C and Summerfruit at 0-2°C during transport and storage where possible to reduce quality loss
- Ensure fruit are cooled, transported and stored at 90-95% relative humidity to maximise shelf life
- Use controlled atmosphere storage at recommended temperatures when sea freighting avocados to reduce the risk of fruit softening, chilling injury and quality defects
- Explore the potential for controlled atmosphere storage to extend availability of late-season mango and avocado fruit for domestic and/or export markets
- Use real-time data loggers to regularly monitor cooling, transport and storage temperature and the time consignments spend in the supply chain to identify and correct potential risks to product quality, focusing on high risk supply chains and relating cumulative temperature time units to remaining shelf life
- Seek feedback on fruit arrival quality and shelf life in domestic and export markets from independent, reputable assessors to quantify the impacts of monitored handling practices on product performance and prioritise interventions where necessary
- Use cultivar-specific shelf-life models developed in projects AM15002 and AM21000 to inform decision making and deliver more consistent quality, particularly where supply chain conditions may vary from best practice.

Supporting adoption

- Continue to resource delivery of the shelf-life prediction technology based on recommendations in the exploitation plan to ensure the tools realise their full value and impact
- Support industry adoption of the shelf-life prediction tools during critical early stages of technology transfer, evaluate how growers and supply chain businesses use the tools for managing risks, and seek feedback on tool performance
- Quantify impacts of implementing the technology along the supply chain on industry capability to deliver more consistent fruit quality with less waste and use this information to identify where further RD&E may be required to improve and/or expand the models.

Future RD&E opportunities

- Expand the modelling and decision aid tools to consider the influence of production factors (e.g. mineral nutrition, disease management) and prevailing weather conditions on fruit robustness, particularly for commodities where significant variation in product performance occurs across harvest times, blocks, farms and regions
- Address gaps in the modelling to include options to predict shelf life under a broader range of postharvest handling conditions that are typical of commercial supply chains such as ethylene treatment and non-optimal temperatures found in mixed commodity storage environments
- Extend the shelf-life modelling approach to other commodities and cultivars that encounter variable supply chain conditions and/or exhibit differences in inherent storage potential to deliver more predictable quality outcomes
- Partner with technology service providers in Australia and overseas, tapping into additional expertise, value add opportunities and co-investment to drive rapid development of the shelf-life tools
- Support market access protocol development by evaluating product quality responses to promising insect disinfestation treatments under simulated and commercial handling conditions building off AM21000 datasets and utilising in-market assessors and associated tools and resources
- Evaluate the potential benefits of technologies (e.g. modified atmosphere packaging, surface coatings) and practices (e.g. controlled atmosphere storage) identified in AM21000 or those that are new to the market for their capacity to reduce supply chain risks and extend shelf life.

Refereed scientific publications

Journal article

Hale, G.A., Macnish, A.J., Plozza, T., Lopresti, J.P., 2024. Utilizing real-time data loggers to improve export supply chains of fresh fruit from Australia. *Acta Horticulturae* 1395, 225-232.

Whole book

Macnish, A., Duong, H., 2025. Mango quality assessment manual: A guide to assessing the postharvest quality of Australian mangoes (second edition). State of Queensland, 68 pp. [Mango Quality Assessment Manual](#)

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Intellectual property

The project is commercialising shelf-life prediction technology for a range of fruit crops. Predictive models and algorithms for selected varieties of avocado ('Hass', 'Shepard'), mango ('Honey Gold', 'Kensington Pride', 'R2E2'), nectarine ('Diamond Pearl', 'Flavour Pearl', 'Majestic Pearl', 'Polar Zee', 'September Bright') and plum ('Angeleno', 'Black Ruby', 'Turtle Egg') were developed by DPI and DEECA in projects AM15002 and AM21000. DPI also developed preliminary models for 'Cabrillo' and 'Red Rhapsody' strawberries in AM21000.

The project IP is protected as a trade secret. An IP register (Appendix 8) was developed to document background IP. The IP is owned by DPI and Hort Innovation as tenants in common based on background IP and combined co-investment across AM15002 and AM21000. Shares in any potential royalties were calculated based on relative co-investment in AM15002 and AM21000 by DPI, Hort Innovation and DEECA who each have an equity interest and stake in the IP. A tripartite equity participation agreement between DPI, DEECA and Hort Innovation was executed to formalise this arrangement. DPI consulted with all other AM15002 and AM21000 project collaborators and provided a warranty that no additional parties have an equity interest or claim to ownership of the IP.

A technology exploitation plan was prepared to assess the commercial potential of the shelf-life models and algorithms plus develop strategies for commercialisation. A public EOI process was pursued to identify a suitable commercialisation partner. Six applications were received. Non-exclusive marketing rights to the shelf life prediction algorithms were offered to Escavox, an Australian business who provides real-time supply chain monitoring and analytics services to the fresh produce industry. While a licence agreement was being developed and negotiated, DPI established a confidentiality agreement with Escavox to protect the IP and allow information sharing and testing of the algorithms. The licence agreement will have a term of 3 years. The technology will be limited to specified cultivars produced in Australia.

DPI filed an application to the Australian Trade Mark Office to register "Fresh Intel" as a logo to accompany commercial use of the shelf-life prediction algorithms. DPI was advised to provide evidence of the use of Fresh Intel alongside the algorithms to ensure it was sufficiently distinctive from the otherwise common meaning of this word combination. DPI secured the freshintel.com.au domain name. DPI created a website (Appendix 73) attached to this domain to house the shelf-life prediction algorithms. The website is run on a secure DPI server. An API was developed to automatically exchange information between Escavox and DPI when providing shelf-life predictions. During tracking of consignments, the API will receive machine-readable information about fruit (e.g. cultivar) and supply chain conditions from Escavox and respond with a prediction of remaining shelf life.

DPI and DEECA also developed shelf-life calculators that interact with the algorithms. The calculators were designed for users who wish to manually input fruit and supply chain conditions to test different scenarios. Separate calculators for avocado, mango and stone fruit (i.e. nectarine, plum) are available on the Fresh Intel website. The calculators are being made available to the broader industry via a link from Fresh Intel to respective PIB websites. DPI has established an authentication process with each PIB to ensure access is limited to Australian industry stakeholders.

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- Premier Fresh Australia (Frank Frappa, Legend Lin)
- Montague Farms (Rowan Little, Krys Lockhart, Indi Kebbell)
- SHARP Fruit (Dean Morpeth)
- Conti Orchards (Adrian Conti)
- VFS Exports (Colleen Dangerfield)
- Euri Gold Farms (Dale Williams)
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- GreenSkin Avocados (Robert Gray, Finn Gray)
- The Avocado Collective (Dawn Warmington, Josh Franceschi, Sophie Cremasco)
- Jasper Farms (Jacinta Foley)
- Costa Group (Lianre Van Zyl, Shara Jones)
- Australian Produce Partners (Piet Fontyn)
- Ashbern Farms (Brendon Hoyle, Richard Ross)
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- AgEconPlus (Michael Clarke)

Appendices

Appendix 1. Project reference group terms of reference
Appendix 2. Avocado advisory group terms of reference
Appendix 3. Strawberry advisory group terms of reference
Appendix 4. Project management committee terms of reference
Appendix 5. Original project monitoring and evaluation plan
Appendix 6. Project risk register
Appendix 7. Project stakeholder engagement and industry communication plan
Appendix 8. Background IP register
Appendix 9. Revised project monitoring and evaluation plan
Appendix 10. Key questions from co-investors
Appendix 11. Original RD&E workplans
Appendix 12. Updated RD&E workplans
Appendix 13. Consignment monitoring report
Appendix 14. NQ 'Hass' avocado simulation trials report 2022
Appendix 15. CQ 'Hass' avocado simulation trials report 2022a
Appendix 16. CQ 'Hass' avocado simulation trials report 2022b
Appendix 17. NQ 'Hass' avocado simulation trials report 2023
Appendix 18. CQ 'Hass' avocado simulation trials report 2023a
Appendix 19. CQ 'Hass' avocado simulation trials report 2023b
Appendix 20. NQ 'Hass' avocado simulation trials report 2024a
Appendix 21. NQ 'Hass' avocado simulation trials report 2024b
Appendix 22. CQ 'Hass' avocado maturity trials report 2024a
Appendix 23. CQ 'Hass' avocado maturity trials report 2024b
Appendix 24. CQ 'Hass' avocado controlled atmosphere trials report 2024a
Appendix 25. CQ 'Hass' avocado controlled atmosphere trials report 2024b
Appendix 26. NQ 'Hass' avocado simulation trials report 2025
Appendix 27. CQ 'Hass' avocado storage trials report 2025a
Appendix 28. CQ 'Hass' avocado storage trials report 2025b
Appendix 29. WA 'Hass' avocado storage trials report 2023-2025
Appendix 30. WA 'Hass' avocado storage trials report 2024
Appendix 31. WA 'Hass' controlled atmosphere storage trials report 2024
Appendix 32. WA 'Hass' avocado storage trials report 2025
Appendix 33. NQ 'Shepard' avocado simulation trials report 2023
Appendix 34. CQ 'Shepard' avocado simulation trials report 2023a
Appendix 35. CQ 'Shepard' avocado simulation trials report 2023b
Appendix 36. NQ 'Shepard' avocado simulation trials report 2024
Appendix 37. CQ 'Shepard' avocado simulation trials report 2024a
Appendix 38. CQ 'Shepard' avocado simulation trials report 2024b
Appendix 39. NQ 'Shepard' avocado simulation trials report 2025
Appendix 40. CQ 'Shepard' avocado simulation trials report 2025a
Appendix 41. CQ 'Shepard' avocado simulation trials report 2025b
Appendix 42. CQ 'Shepard' avocado 3°C tolerance trials report 2023-24
Appendix 43. CQ 'Shepard' avocado 5°C tolerance trials report 2023-24
Appendix 44. CQ 'Hass' avocado nodule damage report 2023

Appendix 45. CQ 'Hass' avocado nodule damage report 2025

Appendix 46. NQ avocado surface coating trials report

Appendix 47. NQ avocado low storage temperature trial report

Appendix 48. WA 'Hass' avocado ethylene assessment report 2024

Appendix 49. WA 'Hass' avocado ethylene assessment report 2025

Appendix 50. Modelling shelf life of avocados report

Appendix 51. 'Honey Gold' mango simulation trials report 2021/22

Appendix 52. 'Honey Gold' mango simulation trials report 2022/23a

Appendix 53. 'Honey Gold' mango simulation trials report 2022/23b

Appendix 54. 'Honey Gold' mango simulation trials report 2022/23c

Appendix 55. 'Honey Gold' mango simulation trials report 2022/23d

Appendix 56. 'Honey Gold' mango simulation trials combined report 2023/24

Appendix 57. 'Honey Gold' mango postharvest treatments combined report 2024/25

Appendix 58. Modelling shelf life of mango report

Appendix 59. 'Red Rhapsody' strawberry simulation trials report 2023

Appendix 60. 'Red Rhapsody' strawberry simulation trials report 2024a

Appendix 61. 'Red Rhapsody' strawberry simulation trials report 2024b

Appendix 62. 'Red Rhapsody' strawberry simulation trials report 2024c

Appendix 63. 'Red Rhapsody' strawberry simulation trials report 2025a

Appendix 64. 'Red Rhapsody' strawberry simulation trials report 2025b

Appendix 65. 'Albion' strawberry simulation trials report 2025

Appendix 66. 'Cabrillo' strawberry simulation trials report 2026

Appendix 67. 'Cabrillo' and 'Red Rhapsody' strawberry cooling delay trials report

Appendix 68. Modelling strawberry shelf life report

Appendix 69. Predictive modelling and export chain monitoring of nectarines and plums

Appendix 70. First year Summerfruit storage and modelling trials report

Appendix 71. Summerfruit model validation report 2025/26

Appendix 72. Database development report

Appendix 73. Fresh Intel website development report

Appendix 74. List of predictive shelf-life tools

Appendix 75. List of best practice handling guidelines

Appendix 76. List of pending resources

Appendix 77. List of industry magazine articles

Appendix 78. Fruit quality assessment kit

Appendix 79. In-market quality assessment report

Appendix 80. List of industry factsheets

Appendix 81. List of industry case studies

Appendix 82. Information portal gap analysis report

Appendix 83. Information portal industry stakeholder survey report

Appendix 84. Information portal framework

Appendix 85. List of industry forum presentations

Appendix 86. List of industry videos

Appendix 87. Newsletter articles

Appendix 88. Project workshop summary report 2022

Appendix 89. Project workshop summary report 2025

Appendix 90. Baseline survey of Australian producers

Appendix 91. Final survey of Australian producers

Appendix 92. Integrating shelf-life models with a consignment tracking platform

Appendix 93. What the shelf-life models can and cannot predict

Appendix 94. Project monitoring and evaluation report

Appendix 1

Project reference group terms of reference



Terms of reference for the project reference group

1 Introduction

This Terms of Reference (ToR) defines the purpose and arrangements for the AM21000 project reference group (PRG).

2 Background

The Queensland Department of Primary Industries is delivering the Hort Innovation-funded project 'AM21000 Serviced Supply Chains II'. The overall objective is to provide Australian horticulture growers and exporters with knowledge, tools and confidence to successfully manage current supply chain risks, including the transition from air to seafreight, and deliver more consistent product quality. Key outputs will include:

- Monitoring systems and tools that identify areas for improvement
- Updated handling guidelines for increasing consistency of quality, shelf life and export value
- Decision aid tools that enable prediction of remaining shelf life on arrival in export markets
- An information portal that facilitates industry-wide access to the decision aid tools.

The project commenced in June 2022 and will end by 30 April 2026. It has a national focus and co-investment from avocado and strawberry levies plus cash from Piñata Farms, Queensland DPI, Northern Territory DAF and Western Australia DPIRD. Summerfruit Australia Ltd are also contributing cash through a Victoria Government grant with the Victoria DEECA subcontracted to deliver this component.

3 Terms of Reference

3.1 Purpose

The PRG is a key advisory mechanism within the project governance structure. The PRG is responsible for advising the broad strategic direction of the project, assisting in identifying opportunities and mitigating risk. The PRG will also be tasked with providing a horticulture-wide perspective on trends and innovation that may be relevant to the project. The PRG will bring together individuals with commercial expertise and experience in supply chain improvement and logistics, horticulture crop production, export business development, stakeholder engagement, technology adoption and RD&E project management.

3.2 Scope

The principal scope of the PRG will be to provide general advice on project direction during planning and as it progresses. Advice may be sought on activities, strategies, outputs and technical details. The PRG will support the project leader and wider team to efficiently deliver high impact outcomes on-time. This will include but is not necessarily limited to:

- Implementing project strategic direction
- Establishing the project Monitoring and Evaluation plan
- Reviewing annual work plans and progress against deliverables
- Delivering feedback on activities and outputs (e.g. quality, timeliness, commercialisation opportunity)
- Ensuring advice meets the needs of growers, supply chain partners and other key horticulture industry stakeholders
- Recommending solutions to potential constraints or other issues.

3.3 Term

The project management committee will operate during the effective life of the project from 24 June 2022 to 30 April 2026.



3.4 Membership

The PRG will comprise the following representatives from across business, peak industry bodies and research development corporations:

- Jenny Margetts (P2P Business Solutions), independent chair and business development specialist
- Alex Doyle (Woolworths), sustainability and strategic sourcing lead for fruit and vegetables
- Anthony Baker/Andrea Magiafoglou (Hort Innovation), R&D Manager Market Access
- Anthony Dobson (Tropical Pines), supply chain logistics, former fruit exporter/freight forwarder
- Ian Jensen (FIRST Management), innovation strategy, former manager MLA market access research
- Kate Taylor (QUT), industry engagement, technology transfer, commercialisation
- Robert Gray (Green Skin Avocados), producer, marketer and exporter, former mango industry CEO
- Terry Rudge (Rudge Produce Systems), produce quality inspection service provider
- Andrew Macnish (DPI), AM21000 project leader and PRG secretariat
- Trevor Ranford/Charlotte Brunt (Summerfruit Australia Ltd), Summerfruit peak industry body
- Angela Atkinson (Berries Australia), Strawberry peak industry body
- Ex officio positions (project program leaders) as required.

3.5 Roles and Responsibilities

Members of PRG will:

- Attend meetings by virtual platforms or in-person and contribute expertise to the project
- Provide strategic advice on how to deliver the project most effectively
- Act as a 'sounding board' to the project leader and key personnel
- Comment on the appropriateness of activities as per the Monitoring and Evaluation plan
- Confirm that project outputs are 'fit for purpose', useful and relevant for stakeholders
- Consider advice provided by project co-investors and other stakeholders
- Identify operational risks that may negatively impact project delivery

3.6 Meetings

- All meetings will be led by the independent chair
- Meeting agendas and minutes will be distributed by the PRG secretariat
- Relevant information and meeting minutes will be provided within 1 week of meetings
- Two meetings will be held each year and will coincide with milestone reporting as outlined in the project head agreement:
 - Meeting 1: October 2022
 - Meeting 2: February 2023
 - Meeting 3: October 2023
 - Meeting 4: April 2024
 - Meeting 5: October 2024
 - Meeting 6: April 2025
 - Meeting 7: October 2025
 - and as required.
- Meetings will be by virtual platforms with some face-to-face meetings held as appropriate.

3.7 Confidentiality

Some matters discussed at the PRG meetings may be of a confidential nature and must be treated as such by members.

3.8 Conflicts of Interest

Any conflicts of interest will need to be declared by PRG members as per standard Corporate Governance expectations.

Appendix 2

Avocado advisory group terms of reference



Terms of reference for the avocado advisory group

1 Introduction

This Terms of Reference (ToR) defines the purpose and arrangements for the AM21000 avocado advisory group.

2 Background

The Queensland Department of Primary Industries (DPI) is delivering the Hort Innovation-funded project 'AM21000 Serviced Supply Chains II'. The overall objective is to provide Australian horticulture growers and exporters with knowledge, tools and confidence to successfully manage current supply chain risks, including the transition from air to seafreight, and deliver more consistent product quality. Key outputs will include:

- Monitoring systems and tools that identify areas for improvement
- Updated handling guidelines for increasing consistency of quality, shelf life and export value
- Decision aid tools that enable prediction of remaining shelf life on arrival in export markets
- An information portal that facilitates industry-wide access to the decision aid tools

The project commenced on 24 June 2022 and will end by 30 April 2026. It has a national focus and investment from avocado and strawberry levies plus cash from Piñata Farms (mangoes), Queensland DPI, Northern Territory DAF and Western Australia DPIRD. Summerfruit Australia Ltd are also contributing cash through a Victoria Government grant with the Victoria DEECA subcontracted to deliver this component. Queensland DPI will lead the project with support from Northern Territory DAF and Western Australia DPIRD.

3 Terms of Reference

3.1 Purpose

The avocado advisory group is part of the project governance structure and acknowledges the levy contribution to AM21000. The advisory group will provide input and industry perspective into the work program and communication of key outputs. The advisory group will bring together industry and project representatives with expertise and experience in avocado production and exports, supply chain logistics, innovation and technology plus RD&E strategy and investment management.

3.2 Scope

The principal scope of the avocado advisory group will be to provide general advice on planning, implementation and communication of project activities, including:

- Project activities and annual work plans
- Project monitoring and evaluation
- Industry collaborators in key production regions
- Fruit quality assessment protocols
- Coordination with other avocado industry investments
- Opportunities and channels for communication of project learnings and products
- Feedback on outputs (e.g. quality, timeliness, commercialisation opportunity)

3.3 Term

The avocado advisory group will operate during the effective life of the project from 24 June 2022 to 30 April 2026.

3.4 Membership

Nominated industry representatives will form the core of the group, with initial membership including:



- Antony Allen or delegated representative, The Avolution
- Brent Chambers or John Walsh, Simpson Farms
- Cormac TeKloot or Shara Jones, Costa Group
- Flora Zhang, Avocados Australia Ltd
- Jake Binney, Avorama
- Robert Gray, Green Skin Avocados
- Sophie Cremasco, The Avocado Collective
- Anthony Baker/Andrea Magiafoglou (Hort Innovation)
- Jodie Campbell, DPI (Secretariat)
- Ex officio positions (project leader, WA DPIRD program leader) as required
- Hayleigh Dawson, Avocados Australia Ltd (observer as required)

3.5 Roles and Responsibilities

Members of the avocado advisory group will:

- Attend meetings by phone/virtual platforms or in-person and contribute experience and expertise to the project
- Share insights and advice relevant to avocado activity planning and implementation
- Facilitate introductions to potential collaborating avocado growers and supply chain partners
- Review and approve project outputs and communication products related to avocados
- Identify and address operational risks that may negatively impact project delivery
- Confirm that project outputs are 'fit for purpose', useful and relevant for the avocado industry

3.6 Meetings

- All meetings will be chaired by Jodie Campbell from DPI
- Meeting agendas and minutes will be distributed by Jodie Campbell as secretariat
- Relevant information and meeting minutes will be provided within 1 week of meetings
- Two meetings per year will be held to coincide with six monthly project milestone reporting at the end of January and July each year:
 - Meeting 1: February 2023
 - Meeting 2: August 2023
 - Meeting 3: February 2024
 - Meeting 4: August 2024
 - Meeting 5: February 2025
 - Meeting 6: August 2025
 - and as required.
- Meetings will mostly be held by teleconference or as face-to-face meetings, as appropriate
- Consideration will be given to conducting meetings at other locations (e.g. interstate) and times to tie in with industry events or forums if there are tangible benefits
- A summary of key discussion topics from each meeting will be shared with project leaders of other related avocado levy funded investments.

3.7 Confidentiality

Matters discussed at the avocado advisory group meetings may be of a confidential nature and must be treated as such by members.

3.8 Conflicts of Interest

Any conflicts of interest will need to be declared by advisory group members as per standard Corporate Governance expectations

Appendix 3

Strawberry advisory group terms of reference



Terms of reference for the strawberry advisory group

1 Introduction

This Terms of Reference (ToR) defines the purpose and arrangements for the AM21000 strawberry advisory group.

2 Background

The Queensland Department of Primary Industries (DPI) is delivering the Hort Innovation-funded project 'AM21000 Serviced Supply Chains II'. The objective is to provide Australian horticulture growers, marketers and exporters with knowledge, tools and confidence to successfully manage current supply chain risks and deliver more consistent product quality. Key outputs will include:

- Monitoring systems and tools that identify areas for improvement
- Updated handling guidelines for increasing consistency of quality, shelf life and domestic/export value
- Decision aid tools that enable prediction of remaining shelf life on arrival in domestic/export markets
- An information portal that facilitates industry-wide access to the decision aid tools

While the contract came into effect on 24/6/2022, the project effectively commenced in November 2021 and will end by 30 April 2026. It has a national focus and investment from avocado and strawberry levies plus cash from Piñata Farms (mangoes), Queensland DPI, Northern Territory DAF and Western Australia DPIRD. Summerfruit Australia Ltd are also contributing cash through a Victoria Government grant with the Victoria DEECA subcontracted to deliver this component. Queensland DPI will lead the project with support from Northern Territory DAF and Western Australia DPIRD.

3 Terms of Reference

3.1 Purpose

The strawberry advisory group is part of the project governance structure and acknowledges the levy contribution to AM21000. The advisory group will provide input and industry perspective into the work program and communication of key outputs. The advisory group will bring together industry and project representatives with expertise and experience in strawberry production and exports, supply chain logistics, innovation and technology plus RD&E strategy and investment management.

3.2 Scope

The principal scope of the strawberry advisory group will be to provide general advice on planning, implementation and communication of project activities, including:

- Project activities and annual work plans
- Project monitoring and evaluation
- Industry collaborators in key production regions
- Fruit quality assessment protocols
- Coordination with other strawberry industry investments
- Opportunities and channels for communication of project learnings and products
- Feedback on outputs (e.g. quality, timeliness, commercialisation opportunity)

3.3 Term

The strawberry advisory group will operate during the effective life of the project from 1 November 2021 to 30 April 2026.



3.4 Membership

Nominated industry representatives will form the core of the group, with initial membership including:

- Jennifer Rowling, Berries Australia (Chair)
- Brendan Hoyle, Ashbern Farms, Qld (domestic and exports)
- Daniel Rollo, Vic
- Tanya Gidley, Driscoll's
- Anthony Baker/Andrea Magiafoglou, Hort Innovation
- Jodie Campbell, DPIF (Secretariat)
- Ex officio positions (project leader, other DPI project team, other Berries Australia personnel, WA DPIRD program leader) as required

3.5 Roles and Responsibilities

Members of the strawberry advisory group will:

- Attend meetings by phone/virtual platforms or in-person and contribute experience and expertise to the project
- Share insights and advice relevant to strawberry activity planning and implementation
- Facilitate introductions to potential collaborating growers and supply chain partners
- Review and approve project outputs and communication products related to strawberries
- Identify and address operational risks that may negatively impact project delivery
- Confirm that project outputs are 'fit for purpose' and relevant for the strawberry industry

3.6 Meetings

- All meetings will be chaired by Jennifer Rowling
- Meeting agendas and minutes will be distributed by Jodie Campbell as secretariat
- Relevant information and meeting minutes will be provided within 1 week of meetings
- Two meetings per year will be held to coincide with six monthly project milestone reporting at the end of January and July each year:
 - Meeting 1: September 2022
 - Meeting 2: March 2023
 - Meeting 3: September 2023
 - Meeting 4: March 2024
 - Meeting 5: September 2024
 - Meeting 6: March 2025
 - and as required.
- Meetings will mostly be held by teleconference or as face-to-face meetings, as appropriate
- Consideration will be given to conducting meetings at other locations (e.g. interstate) and times to tie in with industry events or forums if there are tangible benefits
- A summary of key discussion topics from each meeting will be shared with project leaders of other related strawberry or other berry levy funded investments.

3.7 Confidentiality

Matters discussed at the strawberry advisory group meetings may be of a confidential nature and must be treated as such by members.

3.8 Conflicts of Interest

Any conflicts of interest will need to be declared by advisory group members as per standard Corporate Governance expectations.

Appendix 4

Project management committee terms of reference



Terms of reference for the project management committee

1 Introduction

This Terms of Reference (ToR) defines the purpose and arrangements for the AM21000 project management committee.

2 Background

The Queensland Department of Primary Industries (DPI) is delivering the Hort Innovation-funded project 'AM21000 Serviced Supply Chains II'. The overall objective is to provide Australian horticulture growers and exporters with knowledge, tools and confidence to successfully manage current supply chain risks, including the transition from air to seafreight, and deliver more consistent product quality. Key outputs will include:

- Monitoring systems and tools that identify areas for improvement
- Updated handling guidelines for increasing consistency of quality, shelf life and export value
- Decision aid tools that enable prediction of remaining shelf life on arrival in export markets
- An information portal that facilitates industry-wide access to the decision aid tools

The project commenced in June 2022 and will end by 30 April 2026. It has a national focus and co-investment from avocado and strawberry levies plus cash from Piñata Farms, Queensland DPI, Northern Territory DAF and Western Australia DPIRD. Summerfruit Australia Ltd are also contributing cash through a Victoria Government grant with the Victoria DEECA subcontracted to deliver this component.

3 Terms of Reference

3.1 Purpose

The project management committee is responsible for providing oversight, guidance and coordination of project programs, activities, planning and outputs. The committee will bring together project collaborators/delivery partners with expertise and experience in RD&E project management and stakeholder engagement and communication, particularly for the commodities under study.

3.2 Scope

The principal scope of the project management committee will be to provide the necessary support to project programs and the wider team to efficiently deliver high quality deliverables on-time by:

- Setting expectations for project programs, activities and deliverables.
- Establishing the project delivery structure.
- Implementing project strategic direction, in consultation with the project reference group.
- Project monitoring and evaluation.
- Ensuring adequate resourcing for activities across and within project programs.
- Delivering feedback on program planning and outputs (e.g. quality, timeliness, commercialisation opportunity).
- Prioritising and coordinating opportunities for communication of project learnings and products.
- Reporting to the project reference group on relevant progress, constraints or other issues.

3.3 Term

The project management committee will operate during the effective life of the project from 24 June 2022 to 30 April 2026.



3.4 Membership

Nominated delivery partner representatives will form the core of the project management committee, with initial membership including:

- Andrew Macnish, DPI and project leader plus secretariat.
- John Lopresti/Mark O’Connell, DEECA and leader of Summerfruit and Vegetables programs.
- Sohail Mazhar/Upendra Shekhawat, DAF lead.
- Dario Stefanelli, DPIRD lead.
- John Agnew, DPI and leader of Capacity Building and Communications program.
- Yiru Chen, DPI and leader of Modelling and Simulations program.
- Anthony Baker/Andrea Magiafoglou, Hort Innovation and AM21000 project manager, as required.
- Ex officio positions (avocado, strawberry program leaders) as required.

3.5 Roles and Responsibilities

Members of the project management committee will:

- Attend meetings by phone/virtual platforms or in-person and contribute experience and expertise to the project.
- Provide recommendations relevant to project program activity planning and implementation.
- Consider advice provided by the project reference group, co-investors and other stakeholders.
- Review and approve project plans, outputs and communication products.
- Identify and address operational risks that may negatively impact project delivery.
- Confirm that project outputs are ‘fit for purpose’, useful and relevant for stakeholders.

3.6 Meetings

- All meetings will be chaired by the project leader.
- Meeting agendas and minutes will be distributed by the committee secretariat.
- Relevant information and meeting minutes will be provided within 1 week of meetings.
- Meetings will be held every 2 months or out of session as required.
- Meetings will be by teleconference with some face-to-face meetings held as appropriate.
- Consideration will be given to conducting meetings at other locations (e.g. interstate) and times to tie in with industry events or forums if there are tangible benefits.

3.7 Confidentiality

Some matters discussed at the project management committee meetings may be of a confidential nature and must be treated as such by members.

3.8 Conflicts of Interest

Any conflicts of interest will need to be declared by committee members as per standard Corporate Governance expectations.

Appendix 5

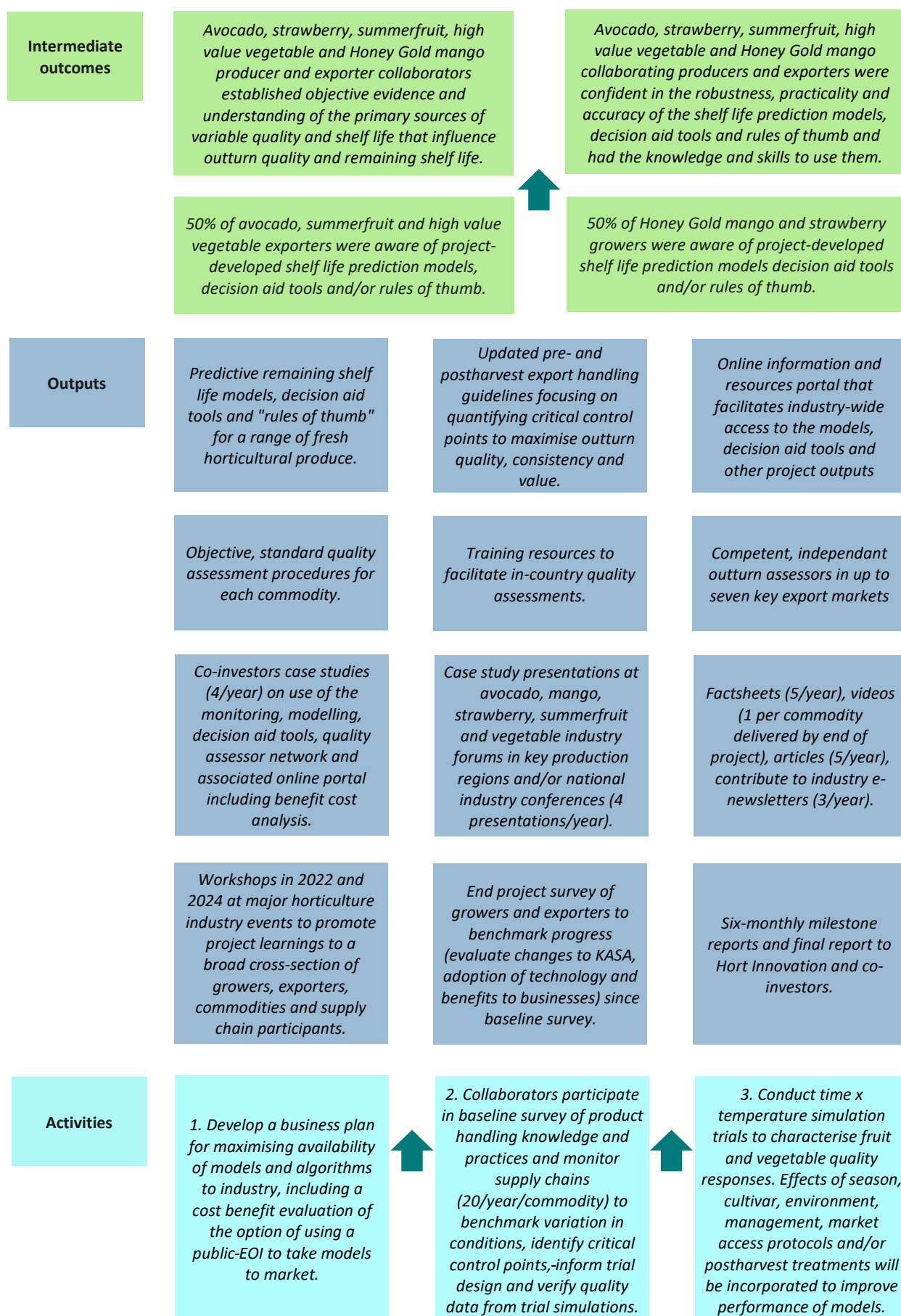
Original project monitoring and evaluation plan

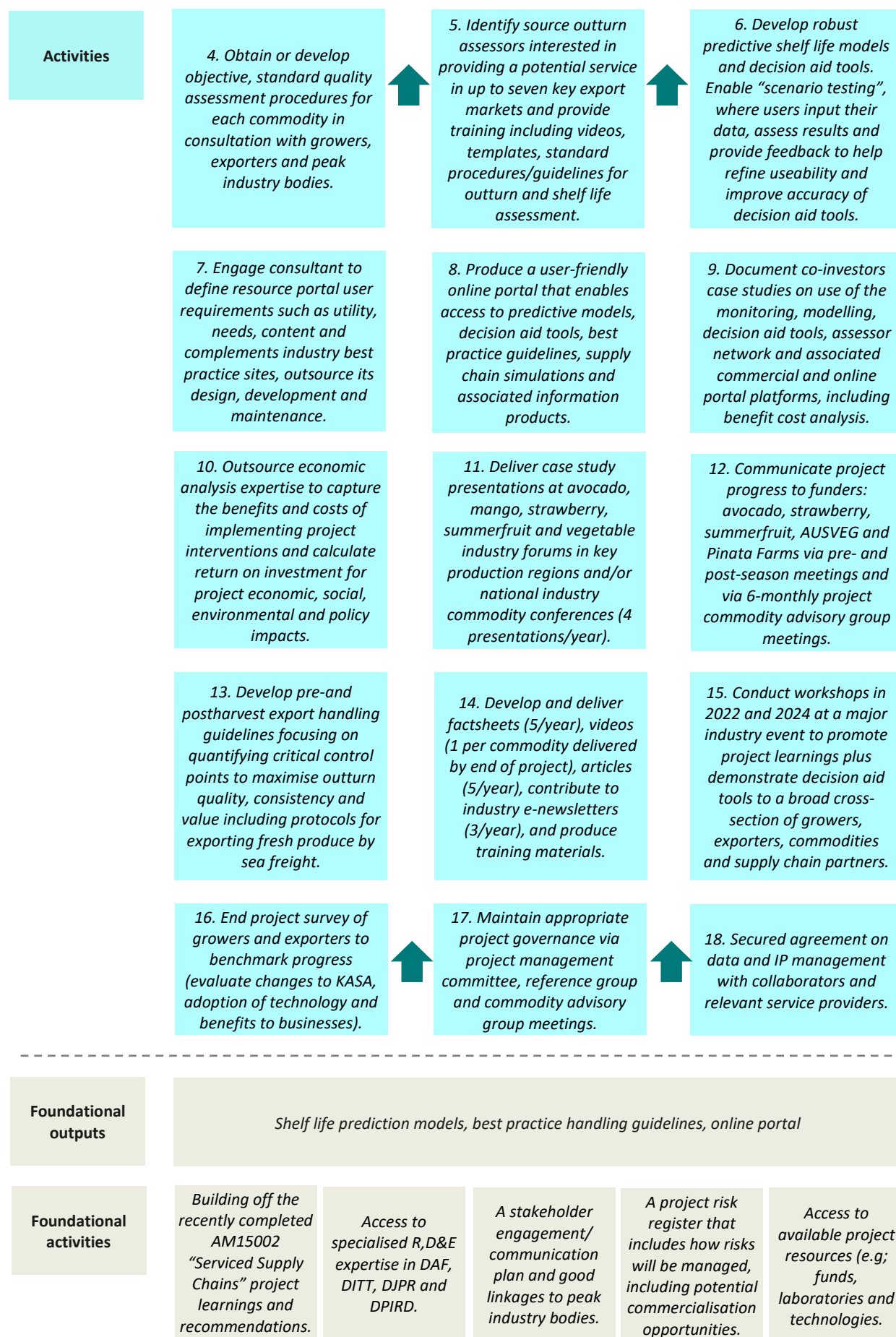
Project and delivery partner details

Project title	<i>Serviced Supply Chains II</i>
Project code	<i>AM21000</i>
Delivery partner (Organisation)	<i>Department of Agriculture and Fisheries</i>
Lead researcher	<i>Dr Andrew Macnish</i>
Date completed/updated	<i>October 26, 2022</i>

1. Program logic

Relevant SIP outcome(s)	<u>Avocado</u> <u>Outcome 2:</u> Industry supply, productivity and sustainability. <u>Strategy 6:</u> Apply a systems research approach to improving quality of Australian avocados throughout the supply chain. <u>KPI:</u> Evidence of increased product quality management across avocado supply chains.
	<u>Berry (strawberry)</u> <u>Outcome 2:</u> Industry supply, productivity and sustainability. <u>Strategy 4:</u> Review new postharvest and supply chain technologies to maximise quality and profitability, including establishing quality standards and a methodology to measure and monitor when quality is below consumer expectations. <u>KPI:</u> Increased grower knowledge on postharvest and supply chain technologies
	<u>Mango</u> <u>Outcome 1:</u> Demand creation. <u>Strategy 3:</u> Prepare and adopt an updated export strategy to expand exports to high value markets. <u>KPI:</u> Evidence of improved exporter capability into high-value markets.
	<u>Summerfruit</u> <u>Outcome 1:</u> Demand creation. <u>Strategy 3:</u> Increase domestic demand and build international customer awareness for Australian summerfruit through improving knowledge, attitudes and purchase intent. <u>KPI:</u> Positive influence on consumer preference.
	<u>Vegetable</u> <u>Outcome 1:</u> Industry supply, productivity and sustainability. <u>Strategy 6:</u> Support improvements to maintain product integrity through food safety systems and processes, production and storage techniques, and correct handling procedures through the supply chain, and mitigate associated industry risks <u>KPI:</u> Enhanced food quality and safety, reduced opportunity for food tampering and more effective crisis management.
End-of-project outcomes	Avocado, summerfruit and high value vegetable exporters are equipped with more objective information and tools to better assess production and supply chain risks, enabling them to make more informed cultivar, transport mode and market choices in order to raise profitability by delivering increased volume of consistently high-quality produce with maximum shelf life.
	Increased market demand and profitability of Honey Gold mangoes and strawberries by consistently producing and delivering more predictable high-quality fruit to domestic market and importers with maximum shelf life for both the retailer and the consumer.
	25% of avocado, summerfruit and high value vegetable exporters used or aspired to use project-developed shelf life prediction models, decision aid tools and/or rules of thumb to select best-fit cultivars, modes of transport and identify and manage production and supply chain risks affecting quality and remaining shelf life.
	25% of Honey Gold mango and Strawberry growers used or aspired to use project-developed shelf life prediction models, decision aid tools and/or rules of thumb to identify and manage production and supply chain risks affecting quality and remaining shelf life.
	Australian businesses adopting project tools to deliver premium and predictable quality fruit and vegetables show measurable economic, social and environmental benefits through case studies.





2. Project M&E scope

Key evaluation questions

Table 1: Project key evaluation questions

Key evaluation questions	Project-specific questions
Effectiveness	
1. To what extent has the project achieved its expected outcomes?	<i>To what extent has the project increased awareness and adoption of decision aid tools that reduce supply chain risks and enable delivery of more consistent fresh produce quality to domestic and export markets?</i>
	<i>Did the project engage commercial service providers to make the shelf life prediction models available for industry uptake?</i>
Relevance	
2. How relevant was the project to the needs of intended beneficiaries?	<i>To what extent has the project met the needs of industry co-investors and levy payers?</i>
	<i>How well did the project align with the strategic investment priorities of industry, the funding agency and delivery partners?</i>
Process appropriateness	
3. How well have intended beneficiaries been engaged in the project?	<i>To what extent were the co-investors and broader industry stakeholders aware of project activities and resources?</i>
4. To what extent were engagement processes appropriate to the target audience/s of the project?	<i>Did the project engage with industry levy payers and cross-commodity supply chain participants through their preferred learning style?</i>
	<i>How accessible were project resources and extension events to industry levy payers?</i>
Efficiency	
5. What efforts did the project make to improve efficiency?	<i>What proportion of industry stakeholders implemented project learnings?</i>
	<i>Did the project represent value for money for the co-investors and broader industry?</i>

3. Performance expectations, data collection and analysis

Table 2: Project monitoring plan

Logic level	What to monitor	Performance expectation (KPIs) and/or monitoring questions	Data collection – method (e.g. survey) and source (e.g. growers)	Timing of, and responsibility for, data collection
Foundational activities				
Building off the recently completed AM15002 “Serviced Supply Chains” project learnings and recommendations	<i>Recommendations incorporated into AM21000 objectives</i>	<i>Recommendations adopted</i>	<i>AM15002 final report recommendations</i>	<i>Milestone reporting (Project Leader)</i>
Access to specialised R,D&E expertise in DAF, DITT, DJPR and DPIRD	<i>Formation of project team</i>	<i>Roles in project fulfilled</i>	<i>Professional and industry networks</i>	<i>Milestone reporting (Project Management Committee)</i>
A stakeholder engagement/ communication plan and good linkages to peak industry bodies	<i>Roadmap for all project communication</i>	<i>Complete at start of project for Project Reference Group and Project Management Committee and update as necessary</i>	<i>Use mandatory response table application as source</i>	<i>Report to Project Reference Group (Project Leader)</i>
A project risk register that includes how risks will be managed, including potential commercialisation opportunities	<i>Project risk management</i>	<i>Complete at start of project for Project Reference Group and Project Management Committee and update as necessary</i>	<i>Use mandatory response table application as source</i>	<i>Report to Project Reference Group (Project Leader)</i>
Access to available project resources (e.g. funds, laboratories and technologies)	<i>Resources accessed</i>	<i>Resources are adequate to conduct all activities</i>	<i>Professional and industry networks</i>	<i>Milestone reporting (Project Management Committee)</i>
Activities and outputs				
1. Develop a business plan for maximising availability of models and algorithms to industry, including a cost benefit evaluation of the option of using a public EOI to take models to market	<i>Testing and refining of algorithms and DAT accuracy and functionality with a view to commercial value</i>	<i>Enhanced distribution and adoption of project findings through business planning</i>	<i>Experimental results records (Modeling and Simulation team)</i>	<i>Draft plan in 1st 6 months. Milestone report (Project Leader)</i>
2. Collaborators participate in baseline survey of product handling knowledge	<i>Collaborator KASA Supply chain critical control points</i>	<i>Survey response rate at least 25% Map and monitor 20</i>	<i>Baseline survey (collaborators); Records of supply chain discussions (collaborators); real-time</i>	<i>Baseline survey year 1 and monitoring ongoing.</i>

and practices and monitor supply chains (20/year/commodity) to benchmark variation in conditions, identify critical control points, inform trial design and verify quality data from trial simulations		<i>supply chains each year per commodity</i>	<i>logger data (company platform)</i>	<i>Milestone report (Capacity Building and Communications Program Leader)</i>
3. Conduct a series of time x temperature storage trials to characterise fruit and vegetable quality responses. Effects of season, cultivars, environment, management, market access protocols and postharvest treatments, as appropriate to the commodity, will be incorporated to improve model performance	<i>Time x temperature simulation trials effecting produce quality and shelf life (includes impact of risk factors identified in commercial supply chain monitoring)</i>	<i>Conduct time x temperature trials for each commodity in each season to quantify and refine the impact of risk factors on quality and shelf life</i>	<i>Data set collation and report development</i>	<i>Milestone reporting (Modelling and Simulations Program Leader)</i>
4. Obtain or develop objective, standard quality assessment procedures for each commodity in consultation with growers, exporters and peak industry bodies	<i>External and internal quality parameters for each commodity</i>	<i>Industry consensus achieved in the development of objective, standard quality assessment procedures for each commodity</i>	<i>Current industry records of commodity specifications collated and refined through discussion and debate between commodity experts and project team</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
5. Identify source outturn assessors interested in providing a potential service in up to seven key export markets and provide training including videos, templates, standard procedures / guidelines for outturn and shelf-life assessment.	<i>Training activities Outturn assessor activities</i>	<i>Outturn assessors identified in up to seven key export markets including Singapore, Japan, Thailand, Malaysia, Indonesia, Hong Kong, Korea Assessors received appropriate resources and training to conduct quality and shelf life assessments to set standards</i>	<i>List of suitable assessors Training resources and training records Outturn assessment reports</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
6. Develop robust predictive shelf life models and decision aid tools. Enable “scenario testing”, where users input their data, assess results and provide	<i>Development of predictive models to simulate the impact of risks and variables on remaining shelf life Testing and refinement of decision aid tools with users</i>	<i>Algorithms and decision aid tools for predicting end of shelf life are developed for each commodity Output from predictive models demonstrate that simulated versus</i>	<i>Data set collation and report development User scenarios and decision aid tools outputs recorded</i>	<i>Milestone reporting (Modelling and Simulations Program Leader)</i>

feedback to help refine useability and improve accuracy of decision aid tools		<i>observed results are highly comparable</i>		
7. Work with a consultant to define resource portal user requirements such as utility, needs, content and complementarity with current industry best practice sites, seek offers to design, develop and maintain the portal	<i>Progress towards identifying industry needs with respect to Portal content, functionality and site host</i>	<i>Industry priority expectations of portal defined Suitable entity to design portal identified</i>	<i>Consultant portal scoping report Portal working group records/recommendations</i>	<i>Milestone reporting (Project Management Committee)</i>
8. Produce a user-friendly online portal that enables access to predictive models, decision aid tools, best practice guidelines, supply chain simulations and associated information products	<i>Portal content and functionality</i>	<i>Portal completed and project-developed resources hosted successfully, decision aid tools functioning correctly and resources / information accessible to users</i>	<i>Outputs from portal</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
9. Document co-investors case studies on use of the monitoring, modelling, decision aid tools, assessor network and associated commercial and online portal platforms	<i>Impact of project activities on changes to co-investor attitudes and practices</i>	<i>Case studies documented to encourage industry adoption of project findings</i>	<i>Project team engagement with collaborating growers and exporters (records of scenarios tested and results)</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
10. Outsource professional economic analysis to capture the benefits and costs of implementing project interventions and to calculate return on investment for the overall project, in terms of economic, social, environmental and policy impacts	<i>Impact of project activities on changes to co-investor attitudes, practices and profitability</i>	<i>Case studies documented including benefit cost analysis to encourage industry adoption of project findings</i>	<i>Resource economist develop benefit cost analysis from project team engagement with collaborating growers and exporters</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
11. Deliver case study presentations at avocado, mango, strawberry, summerfruit and vegetable industry forums in key production regions	<i>Level of communication of project outputs and outcomes (specifically - presentation of case studies)</i>	<i>4 case study presentations/year delivered at industry forums, positive participant feedback forms</i>	<i>Forum agendas, presentations, participant feedback forms</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>

and/or national industry conferences (4 presentations/year)				
12. Regularly communicate project progress to funders: avocado, strawberry, summerfruit, AUSVEG and Pinata Farms via pre- and post-season meetings	<i>Funders aware of the project progress and upcoming activities at pre- and post-season meetings</i>	<i>Target and non-target industry growers/exporters aware of the project and opportunities to improve their practices</i>	<i>Records of communications and products developed with target peak industry bodies, DAF and Hort Innovation</i>	<i>Milestone reporting (Project Management Committee)</i>
13. Develop pre-and postharvest export handling guidelines focusing on quantifying critical control points to maximise outturn quality, consistency and value including protocols for exporting fresh produce by sea freight	<i>Level of communication of project outputs (specifically - pre-and postharvest export handling guidelines and rules of thumb)</i>	<i>Pre-and postharvest export handling guidelines and rules of thumb developed and accessed by growers/exporters</i>	<i>Information collected from growers, exporters, supply chain partners, outturn assessors and markets</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
14. Develop and deliver factsheets (5/year), videos (1 per commodity delivered by end of project), articles (5/year), contribute to industry e-newsletters (3/year), and produce training materials	<i>Level of communication of project outputs</i>	<i>Communication resources (factsheets (5/year, videos 1 per commodity delivered by end of project, articles 5/year, contribution to industry e-newsletters 3/year) developed and accessed by growers/exporters</i>	<i>Information collected from growers, exporters, supply chain partners, outturn assessors and markets</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
15. Conduct project workshops in 2022 and 2024 at a major horticulture industry event (e.g. Hort Connections) to promote project activities and learnings plus demonstrate decision aid tools to a broader cross-section of growers, exporters, commodities and supply chain participants.	<i>Level of communication of project outputs and outcomes</i>	<i>Representatives from the fresh produce industry updated on recent project achievements (including demonstrating decision aid tools) and recommendations for improving handling practices and product quality in 2022 and 2024</i>	<i>Information collected from growers, exporters, supply chain partners, outturn assessors and markets</i>	<i>Milestone reporting (Capacity Building and Communications Program Leader)</i>
16. End project survey of growers and exporters to benchmark progress (evaluate changes to	<i>Growers and exporters awareness, perceptions and practices</i>	<i>Benchmark report on changes in growers, exporters awareness, perceptions and practices including</i>	<i>Survey of target industry growers and exporters at end of project involvement</i>	<i>Milestone reporting (Capacity Building and</i>

KASA, adoption of technology and benefits to businesses)		<i>outturn quality and shelf life expectations</i>		<i>Communications Program Leader)</i>
17.Maintain appropriate project governance by conducting planned project Management committee, Reference group and Commodity Advisory group meetings	<i>Project governance</i>	<i>Strategic and agile use of resources and opportunities</i>	<i>Records of governance, meeting minutes</i>	<i>Milestone reporting (Project Management Committee)</i>
18. Secured agreement on data and IP management with collaborators and relevant service providers	<i>Data and IP management</i>	<i>IP template developed as a platform to proceed with negotiations</i>	<i>Records of data and IP agreements with collaborators</i>	<i>Milestone reporting (Modelling and Simulations Program Leader)</i>
Intermediate outcomes				
Avocado, strawberry, summerfruit, high value vegetable and Honey Gold mango producer and exporter collaborators established objective evidence and understanding of the primary sources of variable quality and shelf life issues that influence outturn quality and shelf life	<i>Grower and exporter collaborator KASA</i>	<i>Subjective assessment of an understanding of the primary sources of variable quality and shelf life issues that influence outturn quality and remaining shelf life</i>	<i>Survey of target industry growers and exporters</i>	<i>At start and end of project involvement (Capacity Building and Communications Program Leader)</i>
Avocado, strawberry, summerfruit, high value vegetable and Honey Gold mango collaborating producers and exporters were confident in the robustness, practicality and accuracy of the shelf life prediction models, decision aid tools and rules of thumb and had the knowledge and skills to use them	<i>Grower and exporter collaborator KASA</i>	<i>Subjective assessment of target ndustry growers and exporters' confidence in the predictive shelf-life tools and other resources and information produced by the project</i>	<i>Survey of target industry growers and exporters</i>	<i>At end of project for Final Report (Capacity Building and Communications Program Leader)</i>
Exporters attributed to at least 50% of avocado, summerfruit and high value	<i>Grower and exporter collaborator KASA</i>	<i>Subjective assessment of target ndustry growers and exporters' confidence in the</i>	<i>Survey of target industry growers and exporters</i>	<i>At end of project for final report (Capacity Building and</i>

vegetable export volume were aware of and aspired to use project-developed shelf life prediction models, decision aid tools and/or rules of thumb		<i>predictive shelf-life tools and other resources and information produced by the project</i>		<i>Communications Program Leader)</i>
Growers associated with at least 50% of Honey Gold mango and Strawberry domestic volume were aware of and aspired to use project-developed shelf life prediction models decision aid tools &/or rules of thumb	<i>Grower and exporter collaborator KASA</i>	<i>Subjective assessment of target industry growers and exporters' confidence in the predictive shelf-life tools and other resources and information produced by the project</i>	<i>Survey of target industry growers and exporters</i>	<i>At end of project for final report (Capacity Building and Communications Program Leader)</i>
End-of-project outcomes				
By 2025, those exporters attributed to at least 25% of avocado, summerfruit and high value vegetable export volume used project-developed shelf life prediction models, decision aid tools and/or rules of thumb to select best-fit cultivars, modes of transport and identify and manage production and supply chain risks affecting quality and remaining shelf life	<i>Levy and co-investment funded R,D&E Outcomes</i>	<i>Percentage of export volume in target industries, in which project-developed shelf life prediction models, decision aid tools and/or rules of thumb were used to identify and manage production and supply chain risks affecting quality and remaining shelf life</i>	<i>Survey of target industry collaborating exporters</i>	<i>At start and end of project involvement (Capacity Building and Communications Program Leader) Final Report (Project Leader)</i>
By 2025, growers responsible for at least 25% of Honey Gold mango and Strawberry domestic volume used project-developed shelf life prediction models, decision aid tools and/or rules of thumb to identify and manage production and supply chain risks affecting quality and remaining shelf life	<i>Levy and co-investment funded R,D&E Outcomes</i>	<i>Percentage of domestic volume in target industries, in which project-developed shelf life prediction models, decision aid tools and/or rules of thumb were used to identify and manage production and supply chain risks affecting quality and remaining shelf life</i>	<i>Survey of target industry collaborating growers</i>	<i>At start and end of project involvement (Capacity Building and Communications Program Leader) Final report (Project Leader)</i>

4. Reporting, learning and continuous improvement

The project will employ several strategies to ensure that continuous improvement and adaptive management approaches are embedded in the decision making process. Table 3 (below) outlines these strategies and how they will be used to ensure the following:

- The project remains on track in delivering benefit to industry and other stakeholders
- Project learnings are relevant and clearly communicated and understood
- Adaptive management strategies are correcting areas of deficiency or issues that may have been unforeseen in the establishment phase
- Formal measures (e.g. variations) are being considered by the project team, project reference group, and Hort Innovation to maximise outcomes.

Table 3: Continuous improvement strategies

Strategy	Intended use	Methods of reporting	Timing
Project reference group meetings	Ensure meeting agenda includes items related to project tracking / discussion on what is working and what is not Adopt recommendations where they are supported by evidence and stakeholders	Meeting minutes	Every 6 months
Regular meetings with Hort Innovation project lead	Use collective knowledge of Hort Innovation to ensure project is maximising opportunities and linking with relevant initiatives	Report back to project reference group, project management committee and broader project team Consider formal variations New agreements developed	Every 6 months
Learnings from project team, commodity advisory groups and co-investors	Adapt RD&E workplans to cater for new opportunities and arising issues	Commodity advisory group meetings Co-investor meetings Project management committee meetings Project team meetings Project workshops	Every 2 to 6 months
Project reports – communication	Use milestone reporting periods to develop communication products outlining project status and progress to broader industry	Multiple channels (as per communications plan)	Every 6 months
Final report	Collection of learnings and outcomes from across the project timespan and activities Quantify performance against key evaluation questions from the M&E plan and proposed project legacy products (e.g. online portal, shelf life prediction models)	Formal report accepted by Hort Innovation	End of project (2025)

Appendix 6

Project risk register

Project Risk Register template

Project Risk Register: Delivery Partner Portal – AM21000 – Serviced Supply Chains II

The risk What could happen?	Potential risk causes/sources What could happen? What would cause it?	Potential risk impacts How would the risk impact on delivery of the project?	Risk controls What controls are in place, or will be in place, to manage the risk?	Risk likelihood with controls in place <i>Refer to Table 2. Risk likelihood scale</i>	Risk consequence with controls in place <i>Refer to Table 3. Risk consequence scale</i>	Treated risk assessment <i>Refer to Table 4. Risk assessment matrix</i>	Risk evaluation Could you defend this level of risk is acceptable? <i>Yes/No</i>	Person responsible Who is the person/s responsible for monitoring and managing the risk?
<i>Loss of key project personnel</i>	<i>Resignation, retirement, extended sick leave</i>	<i>Loss of key knowledge, experience and capacity; A pause in project momentum; Loss of stakeholder confidence in project delivery</i>	<i>Project team are committed to achieving project outcomes; The team has a good overlapping balance of skills and experience across RD&E disciplines and commodities; Regular project team meetings to share information on progress; Central storage of project data/information; There is sufficient funding for the duration of the project to manage costs associated with staff loss and recruitment; The project leader and collaborators will develop strategies to counter unexpected changes in staffing</i>	<i>Possible</i>	<i>Minor</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader and senior staff from collaborators</i>

<i>Avocados Australia, AUSVEG, Berries Australia and Summerfruit Australia do not effectively meet their commitments to industry coordination, engagement and extension</i>	<i>Poor understanding or communication of their role in the project; Failure to regularly engage with all project collaborators</i>	<i>Poorer engagement by growers and exporters of avocados, strawberries, vegetables and summerfruit; Less trialling and adoption of project tools and practices</i>	<i>Early and regular communication of M&E plan and agency/individual responsibilities; Ensure PIB representation through industry advisory groups and project reference group as appropriate</i>	<i>Unlikely</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader and Capacity Building and Communications Program Leader</i>
<i>Unable to monitor 20 supply chains per commodity each year</i>	<i>Insufficient interest from growers/exporters; High workload and missed opportunities; Growers committed to other higher or urgent priorities in their business</i>	<i>Unable to capture the range of impacts on produce quality; Fewer case studies; Gaps in simulation trial design; Delays in output delivery; Poor adoption of project recommendations</i>	<i>Use the influence and advice of the project reference group and commodity advisory groups to encourage grower/exporter participation; Use of regional staff; Engage with PIBs; Promote benefits of participation in industry newsletters; Engage with multiple businesses; Awareness of competing priorities (e.g. labour issues) within businesses</i>	<i>Unlikely</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader, commodity program leaders, project reference group and commodity advisory group membership</i>
<i>Inability to secure outturn assessors of sufficient quality and value for money in some key markets</i>	<i>Language barriers stall forming arrangements; One size fits all price based on claims; Some assessors more comfortable with specific commodities</i>	<i>Unable to capture feedback on produce quality responses to handling conditions; Poor adoption of project recommendations</i>	<i>Investigate options for other assessors through TIQ, Austrade, exporters and importers; Stage assessors in some markets over time, favouring more assessments in the other markets</i>	<i>Possible</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader and program leaders</i>

<i>Turnover of outturn assessors</i>	<i>Resignation or retirement; Change in business priorities; Loss of customers</i>	<i>Need to identify and retrain new assessors; Loss of stakeholder confidence in delivery of assessor; Reduced reputation of project with exporters; Poor adoption of project recommendations</i>	<i>Investigate options for other assessors through TIQ, Austrade and importers; Staging some assessors in selected markets over time</i>	<i>Possible</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader and program leaders</i>
<i>Co-investors terminate before end of project or financial contributions reduced</i>	<i>Change of key contact resulting in change of attitude towards project or business encounters financial difficulties; Project outcomes not meeting their expectations</i>	<i>Unable to meet some or all project outputs and outcomes</i>	<i>Early and regular communication of project M&E plan and agency / individual responsibilities; Ensure co-investor representation on commodity advisory groups; Ensure co-investor management team is committed; Seek project variation to scale back relevant activities; Six monthly meetings with key managerial and operational staff from each co-investor to review project progress and expectations; Awareness of potential issues within the business and loss of engagement in project activities</i>	<i>Possible</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader</i>

<i>Low grower, exporter and supply chain engagement in regional forums</i>	<i>Growers, exporters unable or unwilling to attend; Adoption activity content apparently not relevant; Growers, exporters unwilling to experiment with decision aid tools</i>	<i>Low uptake of new practices; Underachievement of intended project outcomes</i>	<i>Development of stakeholder engagement plan; Early establishment of industry networks; Close liaison with PIBs; Team members with knowledge transfer expertise</i>	<i>Unlikely</i>	<i>Minor</i>	<i>Low</i>	<i>Yes</i>	<i>Project leader & Capacity Building and Communications Program Leader</i>
<i>Shelf-life models are poorly correlated with “real-life” experience in commercial supply chains</i>	<i>Large variability in impact of genetic, environment and management variables on shelf-life</i>	<i>Fewer and less accurate decision aid tools produced; Low uptake of new tools and practices; Underachievement of intended project outcomes</i>	<i>Robust trials design; Good experimental techniques, including sufficient replication; Collection of adequate and relevant data sets; Testing and refining of models with co-operators</i>	<i>Unlikely</i>	<i>Major</i>	<i>Medium</i>	<i>Yes</i>	<i>Project Leader and Modelling and Simulations Program Leader</i>
<i>Broader commodity industry lack interest in changing practices</i>	<i>Poor attendance at regional workshops</i>	<i>Fewer results to motivate others, Slower industry adoption</i>	<i>Make more detailed investigation of barriers; Utilise a broader range of extension tools and resources; Consider use of alternative training tools, videos, web content etc</i>	<i>Unlikely</i>	<i>Minor</i>	<i>Low</i>	<i>Yes</i>	<i>Project leader and Capacity Building and Communications Program Leader</i>
<i>Standalone tools and resources portal is not supported by most growers, exporters and PIBs</i>	<i>Portal partially/not developed or developed and poorly utilised; Perception of duplication of existing resources</i>	<i>Failure to deliver on a KPI; Poor engagement and awareness of project outcomes by broader industry</i>	<i>Engage a well-qualified consultant to conduct the gap analysis; Ensure an entity with high level digital systems experience is contracted to design, develop and test the portal; Scope capacity of PIB websites for hosting</i>	<i>Possible</i>	<i>Minor</i>	<i>Medium</i>	<i>Yes</i>	<i>Portal Working Group, Capacity Building and Communications Program Leader and Project Leader</i>

			<i>project tools resources and information; Develop a strategy for maintaining the portal after project completion</i>					
<i>Border and travel restrictions</i>	<i>Global pandemic; Geopolitical issues</i>	<i>Difficulty in delivering consignment monitoring, assessor network, decision aid tools validation and general extension activities.</i>	<i>Monitor the risk in consultation with project co-investors plus industry and government stakeholders; Utilise the geographical spread of project partners to develop local solutions; Use other mediums of communication and extension to achieve project impacts</i>	<i>Possible</i>	<i>Minor</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader</i>
<i>Natural disasters/adverse climate events</i>	<i>Floods, drought, storm damage to crops and infrastructure</i>	<i>Unable to meet project deliverables on time</i>	<i>Delay milestones and/or extend the duration of the project through a contract variation</i>	<i>Possible</i>	<i>Moderate</i>	<i>Medium</i>	<i>Yes</i>	<i>Project leader</i>

Appendix 10

Key questions from co-investors

Background information for planning project activities and investment by Piñata Farms

Business:	Piñata Farms
Crop:	Mango
Cultivars:	Honey Gold
Growing region:	Darwin, Katherine and Mataranka (NT), Burdekin, Tablelands and Bundaberg (Qld)
Export markets:	Previously U.S. and Asia, now almost all domestic
Transport mode:	Road to Brisbane and then airfreight (export) or direct by road to capital cities (domestic)
Quality issues:	Variable quality and shelf life across harvests and districts that doesn't align with 'first-in, first-out' mentality
Key objective:	To predict fruit retail quality and shelf life to tailor management practices and provide a more consistent offering to customers
Expected project outcome:	• Greater knowledge of the impacts of different production, district and handling practices on fruit quality and shelf life • Confidence to implement improved practices to deliver more predictable quality mangoes to domestic and international markets • Increased market demand and profitability due to consistently meeting retailer and consumer expectations
Expected project outputs:	• Guidelines on optimal production, harvest and postharvest practices that increase the consistency of quality, shelf life and value of mango exports • Decision aid tools that enable prediction of fruit quality on arrival in domestic and export markets plus remaining shelf life • Monitoring systems and tools that identify areas for improvement
Questions to answer:	• What are the optimal production, harvest, postharvest and transport conditions to ensure fruit arrive with sufficient and consistent shelf life for consumers? • What is the impact of growing district and variations in pre- and postharvest practice on fruit suitability to export or domestic supply chains? • Can shelf life be reliably predicted to encourage a shift in the supply chain approach from 'first-in, first-out' to 'first-expired, first-out'?



Background information for planning project activities and investment specific to avocados

Crop:	Avocado
Cultivars:	Hass, Shepard
Main growing regions:	North and central Qld, WA
Export markets:	Singapore, Malaysia and Hong Kong plus Japan (fruit fly free WA)
Transport mode:	Road to Brisbane, Sydney or Perth and then air or seafreight
Quality issues:	Variable quality and shelf life across harvests, farms and seasons
Key objective:	Monitoring and managing risks associated with disrupted export supply chains, including the transition from air to seafreight, to deliver more consistent quality to customers, developing exporter capacity and confidence
Expected project outcome:	• Knowledge of the impacts of different production region, farm and handling practices on fruit quality and shelf life • Confidence to implement improved practices to deliver more predictable quality avocados to international markets • Increased market demand and profitability due to consistently meeting retailer and consumer expectations
Expected project outputs:	• Monitoring systems and tools that identify areas for improvement • Updated guidelines on harvest and postharvest practices that increase the consistency of quality, shelf life and value of avocado exports • Decision aid tools that enable prediction of remaining shelf life on arrival in export markets based on management practices and monitored conditions
Questions to answer:	• Identify the risks to delivering consistent quality fruit to export markets • Quantify the impact of production region, farm, block, harvest maturity and/or consolidation time on fruit suitability to air or seafreight supply chains? • What shelf life extension technologies (e.g. controlled atmospheres) will be necessary during seafreight to deliver sufficient and consistent shelf life? • Can shelf life be reliably predicted to encourage a shift in the supply chain approach from 'first-in, first-out' to 'first-expired, first-out'?



Background information for planning project activities and investment specific to strawberries

Crop:	Strawberry
Target growing regions:	South-east Qld
Target markets:	Domestic market, exports include Hong Kong, Singapore, New Zealand
Quality issues:	Variable quality and limited shelf life across varieties, production systems and time of season
Key objective:	To document current state of industry supply chain practices, monitor and improve domestic supply chain conditions and fruit quality, quantify impacts of market access treatments (e.g. methyl bromide fumigation) and postharvest handling practices on cultivar performance, work with growers to improve retail quality and shelf life and develop capacity and confidence to export
Expected project outcome:	• Greater knowledge of the impacts of postharvest treatment and handling practices on cultivar performance and shelf life • Confidence to implement improved practices to deliver more predictable quality fruit to domestic and international markets • Increased market demand and profitability due to consistently meeting market expectations • Extension of project learnings to other berry crops such as rubus and alignment with other export development investments (e.g. MT20004)
Expected project outputs:	• Monitoring systems and tools that identify areas for improvement • Updated guidelines on harvest and postharvest practices that increase the consistency of quality, shelf life and value of fruit • Decision aid tools that enable prediction of fruit quality on arrival in domestic and export markets plus remaining shelf life • Analysis of shelf life extension technologies or practices such as packaging or controlled atmospheres that reduce quality issues
Questions to answer:	• What is the impact of variations in postharvest practice (e.g. temperature before fumigation) on fruit quality and suitability for domestic and export supply chains? • Which cultivars are best suited to export handling? • What harvest, postharvest and transport conditions ensure fruit arrive with sufficient and consistent shelf life for consumers?



Background information for planning project activities and investment specific to Summerfruit

Crop:	Summerfruit
Target growing regions:	Victoria
Target markets:	China, Vietnam, Malaysia, Singapore
Quality issues:	Variable storage life potential across cultivars
Key objective:	Determine storage potential of cultivars to identify those that are suited to air and seafreight handling, evaluate and validate innovative practices and technologies to reduce internal disorders and extend storage life
Expected project outcome:	• Greater knowledge of cultivar performance and their suitability to air vs seafreight supply chains • Confidence to implement improved practices/modes of transport to reduce the risk of poor fruit quality arriving in international markets • Increased market demand and profitability due to consistently meeting market expectations
Expected project outputs:	• A cultivar performance screening protocol that can be used to determine storage potential for current and new export cultivars • Decision aid tools that enable prediction of fruit quality on arrival in export markets plus remaining shelf life for selected stone fruit cultivars • Guidelines and fact sheets for export handling, including commercial implementation of stepwise cooling to reduce internal disorders • Analysis of shelf life extension technologies or practices such as modified atmosphere packaging or dynamic controlled atmospheres
Questions to answer:	• Which cultivars are best suited to export handling? • What is the impact of variations in standard postharvest practice (e.g. temperature, fumigation) on fruit quality and suitability for export? • What other postharvest practices and technologies can be implemented to reduce the risk of poor fruit quality after export?

Appendix 11

Original RD&E workplans



AM21000 Serviced Supply Chains II RD&E workplans

Project summary

AM21000 Serviced Supply Chains II is a 3.5-year (2022-2025) investment in providing Australian horticulture industries with the necessary decision support for managing export and domestic supply chain risks and delivering consistent fresh produce quality. It is funded by the Hort Frontiers International Markets Fund, Avocado and Strawberry research and development levies, and contributions from the Australian Government. It includes co-investment from the Department of Agriculture and Fisheries, Queensland (DAF), the Department of Industry, Tourism and Trade, Northern Territory (DITT), the Department of Energy, Environment and Climate Action, Victoria (DEECA), the Department of Primary Industries and Regional Development, Western Australia (DPIRD), Pinata Farms Pty Ltd and Summerfruit Australia Ltd.

The project has three key objectives:

- Extend the success of the initial Serviced Supply Chains “Monitoring to Improve” project to additional varieties, commodities and freight modes.
- Develop decision aid tools based on predictive shelf life models via the inclusion of additional parameters such as production district, pre-harvest factors and phytosanitary treatments.
- Improve accessibility of the associated decision aid tools via a specialised digital interface.

The project has a focus on avocado, mango, strawberry and Summerfruit.

Commodity RD&E workplans

The following RD&E workplans provide background information and a general overview of proposed project activities for each commodity. The original workplans were developed soon after project commencement in 2022. They were recently reviewed and revised in consultation with growers, exporters and peak industry body representatives to ensure the workplans remain relevant and on track.

Avocado program outline

Avocado RD&E activities

DAF leads the AM21000 project and together with DPIRD will also manage the avocado RD&E program. Avocado project work will be focused on improving export supply chain performance and decision making with fruit sourced from the three main Australian production regions. The avocado work program has three core RD&E components:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- Develop predictive time x temperature shelf life models for 'Hass' and 'Shepard' avocados using fruit from farms in north and central Queensland plus Western Australia production regions. The simulations would be designed to predict fruit quality and shelf life emerging from likely conditions in sea and airfreight consignments.
- Evaluate the influence of production (e.g. farm, block), harvest (e.g. fruit maturity, size) and postharvest (e.g. +/- postharvest fungicide, consolidation time for green fruit protocol, controlled atmosphere, surface coatings) variables on fruit and model performance
- Align/complement work with other industry investments
 - AV21005 "Growing robust avocados"
 - AV21000 "Avocado export strategy 2022-2026"
 - AV20004 "Avocado market access and trade development"

2. Monitoring and the surveyor network

- Monitor fruit outturn quality and handling conditions (about 20 consignments/year) to identify risks, validate models and provide reliable feedback on fruit quality to exporters
 - Source fruit from three production regions with at least two different suppliers per region
 - Track consignments to Singapore, Malaysia, Hong Kong, India, Japan and Thailand by mix of air and seafreight (+/- controlled atmosphere)
- Create agreed fruit quality assessment procedures with a focus on objective measures
- Identify and train up professional produce surveyors (and potentially importers) in the four key markets to reliably assess fruit quality at outturn and ripe

3. Capacity building and communication products

- Support the transition from air to seafreight as a priority for many grower-exporters
- Develop rules-of-thumb for those unlikely to use predictive models
- Scope potential to develop an online information portal to house project resources
- Deliver project information products via regular industry communication channels
- Link in with the avocado industry regional and export forums to share learnings
- Update and complement existing best management practices resources
- Case study presentations with growers and exporters but also include importers/retailers

Avocado RD&E workplan

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2023	<i>Complete time x temperature simulation trials</i> ‘Hass’ and ‘Shepard’ avocados will be sourced from two growers each in north Queensland (NQ) and central Queensland (CQ) while ‘Hass’ fruit will be sampled from Western Australia (WA) production regions. The fruit will be exposed to simulated export temperatures (e.g. 5-20°C) and times (e.g. 4-45 days) that reflect monitored air and seafreight conditions. Project staff in Queensland and WA will quantify the quality and shelf life response of fruit during simulated export conditions, aligning observations to current industry quality standards. <i>Evaluate the influence of other variables</i> As part of the time x temperature simulation trials, the influence of additional production (e.g. farm, block), harvest (e.g. fruit maturity, size) and postharvest (e.g. controlled atmospheres) variables will be evaluated. The variables will be chosen in consultation with participating growers and exporters. <i>Align the work with other industry investments</i> Ensure the project work complements activities in AV21005, AV21000 and AV20004.	<i>Create a fruit quality assessment procedure</i> In consultation with growers and exporters, build off existing resources to assemble a simple avocado fruit quality assessment guide for use in export markets. Include objective measures (e.g. durometer) of quality. <i>Establish an overseas assessor network</i> Identify professional produce quality assessors (adding importers as the opportunity arises) in four key markets who have the capacity to independently assess Australian consignments. <i>Deliver training in fruit quality assessment</i> Deliver face-to-face training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback, with Australian exporters in attendance. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 export ‘Hass’ and ‘Shepard’ consignments from the three production regions (with at least two different suppliers per region) to Singapore, Malaysia, Hong Kong and Japan (WA) by air and seafreight. Quantify handling conditions. Rely on trained assessor to provide objective feedback on fruit quality and shelf life.	<i>Identify collaborating growers/exporters</i> Assemble an avocado industry working group to advise on potential collaborators, priority work areas and project communication channels. <i>Establish project IP policy</i> Develop an information management policy with participating collaborators. <i>Complete initial survey of growers and exporters</i> Canvas views from co-investors, collaborators and broader industry on awareness of decision aid tools, the proposed online portal platform utility, and comments on project expectations, envisaged benefits and barriers. <i>Communicate preliminary project findings</i> Share trial, monitoring and simulation data at post-season review meetings and at industry export and regional forums.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2024	<i>Complete time x temperature simulation trials</i> Repeat season 2023 simulation trials that quantify ‘Hass’ and ‘Shepard’ fruit responses to time x temperature regimes, based on consignment monitoring conditions. <i>Evaluate the influence of other variables</i> Access historical records from growers, where available, to select production and postharvest factors that potentially contribute to product quality loss. Monitor potential production (e.g. blocks, nutrition, rainfall, spray history). and postharvest variables on fruit performance. Expand the trials to include evaluation of additional variables on fruit quality and shelf life. <i>Develop preliminary decision aid tools</i> Databases will be established. Predictive models will be developed by determining best fits for postharvest time, temperature units and other key variables with observed fruit quality and shelf life. Rules-of-thumb advice will be developed for industry members unlikely to use predictive models.	<i>Deliver follow-up training to assessors</i> Refine the standard quality assessment protocol and training materials for ‘Hass’ and ‘Shepard’ avocados. Provide refresher training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback. Develop a ‘Shepard’ fruit quality assessment guide and provide to assessors. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 export consignments from the three production regions to four markets via sea and airfreight. <i>Verify accuracy of predictive models</i> Monitor at least three shipments of ‘Hass’ from harvest to export markets to verify accuracy of preliminary models.	<i>Deliver information products</i> Develop information products that show how the collaborating growers/exporters use of the models helped to identify, assess and manage risks to product quality associated with production factors and/or export supply chain conditions. Promote guidelines or rules of thumb present in the modelling to the collaborators, and wider commodity industries. <i>Develop an online project information portal</i> Form a working group to commission gap analysis of portal needs. Evaluate expression of interest from software developers to establish and maintain the online project portal. <i>Case study presentations</i> Develop videos and articles focused on case studies of collaborator use of the modelling, decision aid tools and associated commercial and online portal platforms.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025	<i>Complete time x temperature simulation trials</i> Repeat season 2024 simulation trials from NQ and CQ that quantify ‘Hass’ and ‘Shepard’ responses to time x temperature regimes, based on consignment monitoring conditions. <i>Evaluate the influence of other variables</i> Where possible, correlate production (e.g. blocks, farms, nutrition) and postharvest (e.g. controlled atmosphere) factors or treatments with quality and shelf life responses. <i>Simulate variations in supply chains</i> Based on preliminary time x temperature storage responses of ‘Hass’ avocados, run computer simulations to predict outturn quality and remaining shelf life based on potential variations in production, harvest maturity, consolidation time and supply chain handling conditions to inform management practices and freight decisions. <i>Deliver decision aid tools</i> Based on trial data and simulations, develop guidelines or rules of thumb to maximise fruit quality for export vs domestic markets and minimise risks of quality loss. Refine interactive decision aid tools and make available to participating supply chains to test and validate during commercial shipments. Update existing best practice resources.	<i>Promote assessor network</i> Review and provide follow-up training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback. Encourage Australian exporter participation in this activity. <i>Validate accuracy of predictive models</i> Monitor at least three shipments of ‘Hass’ from harvest to export markets to verify accuracy of preliminary models.	<i>Implementing project recommendations</i> Support growers and exporters to modify practices based on trial results. Complete benefit cost analysis for co-investors on adopting interventions. <i>Commercialising the predictive models</i> Develop and implement a strategy for taking the shelf-life prediction models to market or making them available to growers and exporters. <i>Communicate project learnings</i> Share risk profiles, trial results, model performance and decision aid tools at a post-season review workshop. <i>Complete final survey of growers and exporters</i> Survey collaborators and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity and confidence to better manage supply chain risks.

Mango program outline

Mango RD&E activities

DAF leads the AM21000 project and together with DITT will also manage the mango RD&E program. Mango project work will be focused on improving domestic and export supply chain performance and decision making with fruit sourced from the five main Australian production regions. The mango work program has three core RD&E components:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- a. Develop predictive time x temperature shelf life models for 'Honey Gold' mangoes using fruit from farms in the Northern Territory and Queensland production regions. The simulations would be designed to predict fruit quality and shelf life emerging from likely conditions in domestic road freight and export sea and airfreight consignments.
- b. Evaluate the influence of production (e.g. farm, block), harvest (e.g. fruit maturity) and postharvest (e.g. consolidation time, controlled atmosphere, surface coatings, irradiation) variables on fruit and model performance
- c. Develop interactive decision aid tools for growers/exporters and their supply chain partners to trial and view the impact of management and handling strategies on fruit quality and shelf life.

2. Monitoring and the surveyor network

- a. Monitor fruit outturn quality and handling conditions (about 20 consignments/year) to identify risks, validate models and provide reliable feedback on fruit quality to retailers and exporters
 - i. Source fruit from five production regions
 - ii. Track consignments to Melbourne and selected export markets (e.g. Singapore, Hong Kong) by mix of road, air and seafreight
- b. Create agreed fruit quality assessment procedures with a focus on objective measures
- c. Identify and train up professional produce surveyors (and potentially importers) in the three key markets to reliably assess fruit quality at outturn and ripe.

3. Capacity building and communication products

- a. Support grower and marketer confidence to diversify into exports
- b. Develop interactive decision aid tools and rules-of-thumb
- c. Scope potential to develop an online information portal to house project resources
- d. Deliver project information products via regular industry communication channels
- e. Coordinate with the mango industry association to share learnings at roadshows/conferences
- f. Update and complement existing best management practices resources
- g. Case study presentations with growers, marketer and retailer/importers.

Mango RD&E workplan

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2022	<i>Complete time x temperature storage trials</i> 'Honey Gold' mangoes will be sourced from farms near Darwin and Katherine in the Northern Territory and from Bowen, Mareeba and Bundaberg in Queensland. The fruit will be exposed to simulated domestic and export temperatures (e.g. 10-20°C) and times (e.g. 4-20 days). Project staff in the Northern Territory and Queensland will quantify the quality and shelf life response of fruit during simulated handling conditions, aligning observations to current industry quality standards. <i>Evaluate the influence of other variables</i> As part of the time x temperature storage trials, additional production (e.g. farm, block), harvest (e.g. fruit maturity, size) and postharvest (e.g. consolidation time) variables will be studied to evaluate their influence on fruit and model performance. The variables will be chosen in discussion with participating growers.	<i>Map mango supply chains</i> Map product flow from harvest to importers/wholesalers and quantify handling conditions (e.g. time, temperature) and fruit quality. <i>Create a fruit quality assessment procedure</i> In consultation with Piñata Farms, develop a simple 'Honey Gold' mango fruit quality assessment guide for use in domestic and export markets. Include objective measures (e.g. durometer) of quality. <i>Domestic fruit quality assessment</i> Identify a professional produce quality assessor in a key domestic (and export where feasible) market who has the capacity to independently assess 'Honey Gold' consignments. <i>Deliver training in fruit quality assessment</i> Deliver face-to-face training in fruit quality assessment to the third-party assessor to ensure reliable feedback. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 domestic (and export where demand exists) consignments from the five production regions. Quantify handling conditions. Rely on trained assessor to provide objective feedback on fruit quality and shelf life.	<i>Communicate preliminary project findings</i> Share preliminary results from trials with Piñata Farms and participating growers at post-season review meetings. <i>Identify collaborating growers/exporters</i> Attend 'Honey Gold' mango conference and together with Piñata Farms seek cooperation from growers in project work. <i>Establish project IP policy</i> Develop an information management policy with participating collaborators. <i>Complete initial survey of growers and exporters</i> Canvas views from the co-investor and collaborating growers on awareness of decision aid tools, the proposed online portal platform utility, and comments on project expectations, envisaged benefits and barriers.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2023	<i>Complete time x temperature storage trials</i> Repeat season 2022 storage trials that quantify fruit responses to time x temperature regimes, based on consignment monitoring conditions. Extend trials to evaluate impacts on different market access treatments (e.g. irradiation). <i>Evaluate the influence of other variables</i> Access historical records from growers, where available, to select production and postharvest factors that potentially contribute to product quality loss. Monitor potential production (e.g. blocks, nutrition, rainfall, spray history). and postharvest variables on fruit performance. Expand the trials to include evaluation of additional variables on fruit quality and shelf life. <i>Develop preliminary predictive shelf life models and decision aid tools</i> Databases will be established. Model development will involve determining best fits for postharvest time, temperature units with observed fruit quality and shelf life.	<i>Deliver follow-up training to assessors</i> Refine the standard quality assessment protocol and training materials for 'Honey Gold' mangoes. Provide refresher training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 domestic and export consignments from the five production regions to key markets via road, sea and/or airfreight.	<i>Support intervention</i> Support Piñata Farms to intervene and modify practices based on trial results. <i>Deliver information products</i> Develop information products that show how the co-investor use of the models helped to identify, assess and manage risks to product quality associated with production factors and/or export supply chain conditions. Promote guidelines or rules of thumb present in the modelling to the co-investor, collaborating growers and broader mango industry. <i>Communicate project findings</i> Share results from trials with Piñata Farms and participating growers at post-season review meetings. Engage with Australian Mango Industry Association to identify how generic data can be shared with the broader industry.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2024	<i>Evaluate the influence of other variables</i> Correlate production (e.g. blocks, farms, nutrition) and postharvest (e.g. ethylene, controlled atmosphere) factors or treatments with quality and shelf life responses. <i>Simulate variations in supply chains</i> Based on preliminary time x temperature storage responses of 'Honey Gold' mangoes, run computer simulations to predict outturn quality and remaining shelf life based on potential variations in production, harvest maturity, market access treatments and supply chain handling conditions to inform practices and freight decisions. <i>Deliver decision aid tools</i> Develop interactive decision aid tools for growers/exporters and their supply chain partners to trial and view the impact of management and handling strategies on fruit quality and shelf life. Develop guidelines or rules of thumb to maximise fruit quality for export vs domestic markets and minimise risks of quality loss. Update existing best practice resources.	<i>Promote assessor network</i> Review and provide follow-up training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback. Encourage Australian exporter participation in activity. <i>Validate accuracy of predictive models</i> Monitor at least three export shipments to quantify handling conditions, outturn quality and shelf life to verify reliability of models.	<i>Implementing project recommendations</i> Support growers and exporters to modify practices based on trial results. Complete benefit cost analysis for co-investors on adopting interventions. <i>Commercialising the predictive models</i> Implement a strategy for taking the shelf-life prediction models to market or making them available to 'Honey Gold' growers and exporters. <i>Communicate project learnings</i> Share risk profiles, trial results, model performance and decision aid tools at a post-season review workshop. Identify project outputs and learnings that can be shared with the broader mango industry. <i>Case study presentations</i> Develop videos and articles focused on case studies of co-investor use of the modelling, decision aid tools and online portal platforms. <i>Develop an online project information portal</i> Form a working group to commission gap analysis of portal needs. Evaluate expression of interest from software developers to establish and maintain the online project portal. <i>Complete final survey of growers and exporters</i> Survey the co-investor, collaborators and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity and confidence to manage supply chain risks.

Strawberry program outline

Strawberry RD&E activities

DAF leads the AM21000 project and the strawberry RD&E program. Strawberry project work will mostly focus on improving domestic supply chain performance with a view to enhancing practices, fruit quality and decision support for growers to engage in exporting. The strawberry program will run for 2.5 years and has three core components:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- Develop predictive time x temperature shelf life models for 'Red Rhapsody' and other sub-tropical/temperate strawberry cultivars that show export potential using fruit from farms in south-east Queensland production regions. The simulations would be designed to predict fruit quality and shelf life emerging from likely conditions in road and airfreight consignments.
- Evaluate the influence of production (e.g. field, tunnel, table), postharvest (e.g. pre-cooling time, relative humidity, pack in field vs shed) and phytosanitary treatments (e.g. MeBr, irradiation) on fruit performance.
- Validate shelf life prediction algorithms in domestic and/or export supply chains, relying on trained resources to provide feedback on product quality
- Align/complement work with other industry investments
 - MT20004 Export development

2. Monitoring and the surveyor network

- a. Monitor fruit outturn quality and handling conditions (about 20 consignments/year) to identify risks, validate models and provide reliable feedback on fruit quality to growers and exporters
 - i. Source fruit from two to three production regions (sub-tropical, temperate) with at least two different suppliers per region
 - ii. Track consignments within Australia, and to New Zealand, Hong Kong or Singapore (where feasible) by road and airfreight
- b. Create agreed fruit quality assessment procedures with a focus on objective measures
- c. Identify and train up professional produce surveyors (and potentially importers) in the four key markets to reliably assess fruit quality at outturn and at end of shelf life

3. Capacity building and communication products

- a. Support growers to improve domestic supply chain practices and fruit quality outcomes to build confidence to embrace exporting
- b. Develop predictive shelf life models and rules-of-thumb for those seeking different levels of decision support.
- c. Scope potential to develop an online information portal to house project resources
- d. Deliver project information products via regular industry communication channels
- e. Link in with strawberry industry regional and national forums to share learnings
- f. Develop best management practices resources
- g. Case study presentations with growers and exporters but also include importers/retailers

Strawberry RD&E workplan

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2023	<i>Complete time x temperature storage trials</i> Simulate different domestic and export handling practices and supply chain conditions in the laboratory, identified from the monitoring activity, from harvest to retail to quantify the relative impacts on fruit quality and shelf life. Work closely with one or two south-east Queensland growers who produce popular sub-tropical cultivars (e.g. Red Rhapsody), including those with export potential. Project staff will quantify the quality and shelf life response of fruit during simulated supply chain conditions, aligning observations to current industry quality standards. <i>Develop preliminary predictive shelf life models and decision aid tools</i> Databases will be established. Model development will involve determining best fits for postharvest time, temperature units and other variables with observed fruit quality and shelf life. <i>Align with other investments</i> Ensure project work aligns with other strawberry industry investments (e.g. export development; MT20004) by organising regular meetings to share learnings across projects.	<i>Document grower practice</i> Work with up to five Queensland growers to document handling practices from harvest to dispatch and identify risks to quality loss. <i>Create a fruit quality assessment procedure</i> In consultation with growers, develop a simple strawberry fruit quality assessment guide for use in domestic and export markets. <i>Domestic fruit quality assessment</i> Identify a professional produce quality assessor in a key domestic (and export where feasible) market who has the capacity to independently assess strawberry fruit quality. <i>Deliver training in fruit quality assessment</i> Deliver face-to-face training in fruit quality assessment to a domestic/export third-party assessor to ensure reliable feedback. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 domestic (and export where demand exists) consignments of sub-tropical cultivars from about five growers. Quantify handling conditions. Rely on trained assessor to provide objective feedback on fruit quality and shelf life.	<i>Identify collaborating growers/exporters</i> Assemble a strawberry industry working group to advise on potential collaborators, priority work areas and project communication channels. <i>Complete initial survey of growers and exporters</i> Canvas views from the co-investor and collaborating growers on awareness of decision aid tools, the proposed online portal platform utility, and comments on project expectations, envisaged benefits and barriers. <i>Establish project IP policy</i> Develop an information management policy with participating collaborators. <i>Communicate preliminary project findings</i> Share preliminary results from trials with participating growers at post-season review meetings or an industry-wide forum.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2024	<i>Complete time x temperature storage trials</i> Repeat season 2023 storage trials with a popular sub-tropical cultivar to quantify strawberry responses to time x temperature regimes, based on consignment monitoring conditions. <i>Evaluate the influence of other variables</i> Evaluate the influence of production (e.g. field, tunnel, table), postharvest (e.g. pack in field vs shed, pre-cooling time) and phytosanitary treatments (e.g. MeBr, irradiation) on fruit performance. The variables will be chosen in discussion with participating growers. <i>Simulate variations in supply chains</i> Based on preliminary time x temperature storage responses of strawberry fruit, run computer simulations to predict outturn quality and remaining shelf life based on potential variations in production, market access treatments and supply chain handling conditions to inform practices and freight decisions. <i>Align with other investments</i> Ensure project work aligns with other strawberry industry investments (e.g. export development; MT20004) by organising regular meetings to share learnings across projects.	<i>Deliver follow-up training to assessors</i> Refine the standard quality assessment protocol and training materials for strawberries. Provide refresher training in fruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback. <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 domestic and export strawberry consignments from sub-tropical and temperate regions (Queensland, Victoria/Tasmania) to key markets via road or airfreight. Quantify handling conditions and fruit outturn quality plus shelf life. Identify risks to quality loss. <i>Verify accuracy of predictive models</i> Monitor at least three shipments from harvest to domestic or export markets to verify accuracy of preliminary models.	<i>Review project learnings</i> Meet with participating growers to evaluate the economics of implementing improved practice, capacity and supply chain partnerships. <i>Quantifying improved practice</i> Travel to domestic and/or export markets with growers to identify supply chain issues and witness improved practice in action. <i>Develop an online project information portal</i> Form a working group to commission gap analysis of portal needs. Evaluate expression of interest from software developers to establish and maintain the online project portal. <i>Align with other industry investments</i> Align the work and recommendations for export preparedness with other industry export focused investments. <i>Commercialising the predictive models</i> Develop and implement a strategy for taking the shelf-life prediction models to market. <i>Communicate project findings</i> Share results from trials with participating growers at post-season review meetings or an industry-wide forum.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025	<i>Complete time x temperature storage trials</i> Repeat season 2024 storage trials that quantify strawberry responses to time x temperature regimes, based on consignment monitoring conditions. Extend trials to evaluate additional cultivars (e.g. Cabrillo, Albion) with export potential. <i>Evaluate the influence of other variables</i> Monitor potential production (e.g. field, tunnel or table), postharvest (e.g. pack in field vs shed, pre-cooling time, relative humidity) and phytosanitary treatments (e.g. MeBr, irradiation) and evaluate impacts on cultivar performance. <i>Develop predictive models and decision aid tools</i> Develop interactive decision aid tools for growers/exporters and their supply chain partners to trial and view the impact of management and handling strategies on fruit quality and shelf life. Produce updated handling guidelines, including rules of thumb advice for increasing consistency of quality, shelf life and value. <i>Align with other investments</i> Ensure project work aligns with other strawberry industry investments (e.g. export development; MT20004) by organising regular meetings to share learnings across projects.	<i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to 20 domestic and export strawberry consignments from sub-tropical and temperate regions to key markets via road or airfreight. Quantify handling conditions and fruit outturn quality plus shelf life. Identify risks to quality loss. <i>Validate accuracy of predictive models</i> Monitor at least three shipments from harvest to domestic or export markets to validate accuracy of preliminary models.	<i>Develop grower case studies</i> Develop case studies (e.g. videos, articles) that capture the different journeys of participating growers towards use of decision aid tools and implementation of improved practice. <i>Deliver information products</i> Develop and deliver information products to extend project learnings and recommendations to the wider industry, including aspiring exporters, through industry communication channels. Promote guidelines or rules of thumb present in the modelling to collaborating growers and broader strawberry industry. <i>Complete final survey of growers and exporters</i> Survey the collaborators and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity and confidence to better manage supply chain risks.

Summerfruit RD&E activities

DAF leads the AM21000 project and together with DEECA delivers the Summerfruit RD&E program. Summerfruit project work will focus on improving export supply chain performance with a view to enhancing practices, fruit quality and decision support for growers and exporters. The Summerfruit program will run for 3.5 years and has three core components:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- Develop predictive time x temperature shelf life models for 'Majestic Pearl', 'September Bright' and 'Flavour Pearl' nectarines that are currently exported using fruit from farms in Victorian production regions. The simulations would be designed to predict fruit quality and shelf life emerging from likely conditions in air and seafreight consignments.
- Evaluate the influence of production region, postharvest (e.g. modified/controlled atmospheres, stepwise cooling) on fruit performance and susceptibility to storage disorders.
- Validate shelf life prediction algorithms in export supply chains, relying on trained resources to provide feedback on product quality

2. Monitoring and the surveyor network

- a. Monitor fruit outturn quality and handling conditions (about 5-10 consignments/year) to identify risks, validate models and provide reliable feedback on fruit quality to growers and exporters
 - i. Source fruit from the main production regions in Victoria with at least two different suppliers per region
 - ii. Track consignments to China, Singapore, Malaysia and Vietnam (where feasible) by road, air and seafreight
- b. Create agreed fruit quality assessment procedures with a focus on objective measures
- c. Identify and train up professional produce surveyors in the four key markets to reliably assess fruit quality at outturn and at end of shelf life

3. Capacity building and communication products

- a. Support growers to identify cultivars that are suited to air (short) and sea (long) freight supply chains
- b. Develop predictive shelf life models and rules-of-thumb for those seeking different levels of decision support.
- c. Scope potential to develop an online information portal to house project resources
- d. Deliver project information products via regular industry communication channels
- e. Link in with Summerfruit industry regional and national forums to share learnings
- f. Develop best management practices resources
- g. Case study presentations with growers and exporters but also include importers/retailers

Summerfruit program outline

RD&E activities

While DAF leads the AM21000 project, DEECA (Agriculture Victoria) manages the Summerfruit RD&E program. The Summerfruit work program is based on a Victoria Government Food to Market grant. It is focused on delivering decision support tools for cultivar selection and enhancing export supply chain performance. The Summerfruit program has three core components:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- Develop predictive time x temperature shelf life models for several existing and/or emerging stone fruit cultivars with export potential using fruit from farms in Victorian production regions. The simulations would be designed to predict fruit quality and shelf life emerging from likely conditions in air and seafreight consignments.
- Evaluate the influence of other production (e.g. harvest maturity) and postharvest variables (e.g. modified atmosphere packaging, cooling) on fruit performance.
- Validate shelf life prediction algorithms in export supply chains, relying on trained resources to provide feedback on product quality.
- Align/complement work with other industry investments.

2. Monitoring and the surveyor network

- a. Monitor fruit outturn quality and handling conditions (about 5-10 consignments/year) to identify risks, validate models and provide reliable feedback on fruit quality to growers and exporters.
 - i. Source fruit from two to three grower-exporters.
 - ii. Track consignments from Australia to key export markets (e.g. Hong Kong/China, Singapore, Malaysia, Vietnam where feasible) by air and seafreight.
- b. Create agreed fruit quality assessment procedures with a focus on objective measures.
- c. Identify and train up professional produce surveyors (and potentially importers) in the key markets to reliably assess fruit quality at outturn and at end of shelf life.

3. Capacity building and communication products

- a. Support growers to improve export supply chain practices and fruit quality outcomes to build confidence.
- b. Develop predictive shelf life models and rules-of-thumb for those seeking different levels of decision support.
- c. Scope potential to develop an online information portal to house project resources.
- d. Deliver project information products via regular industry communication channels.
- e. Link in with Summerfruit industry regional and national forums to share learnings.
- f. Develop best management practices resources.
- g. Case study presentations with growers and exporters but also include importers/retailers.

Summerfruit RD&E workplan

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2022	<i>1. Conduct sea freight simulation trials</i> Simulate sea freight handling conditions to assess storage potential of Majestic Pearl and September Bright nectarines, building up additional data for shelf life models. <i>2. Evaluate the influence of other variables</i> Evaluate the influence of region, postharvest (e.g. modified atmosphere liners, stepwise cooling, dynamic controlled atmosphere) on fruit performance.	<i>1. Map export supply chains</i> Map product flow from harvest to importers and quantify handling conditions (e.g. time, temperature) and fruit quality. <i>2. Create a fruit quality assessment procedure</i> In consultation with growers, develop a simple nectarine/peach and plum fruit quality assessment guide for use in domestic and export markets. Include objective measures (e.g. brix) of quality. <i>3. Export fruit quality assessment</i> Identify a professional produce quality assessor in key export markets who has the capacity to independently assess Summerfruit consignments. <i>4. Monitor handling conditions</i> Using real-time loggers, monitor up to five export Summerfruit consignments from production regions. Quantify handling conditions.	<i>1. Identify collaborating growers/exporters</i> Seek cooperation from leading growers and exporters to advise on priority work areas and supply fruit for trial and monitoring activities. <i>2. Complete initial survey of growers and exporters</i> Canvas views from the co-investor and collaborating growers on awareness of decision aid tools, the proposed online portal platform utility, and comments on project expectations, envisaged benefits and barriers. <i>3. Communicate preliminary project findings</i> Share preliminary results from trials with participating growers at post-season review meetings or an industry-wide forum.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2023	<i>Conduct sea freight simulation trials</i> Conduct sea freight simulation trials to validate two shelf life prediction models for Majestic Pearl and September Bright nectarines, based on consignment monitoring conditions. <i>Simulate variations in supply chains</i> For two cultivars repeat 2022-23 integrated postharvest storage trials that include factors such as harvest maturity, packaging, cooling regimes and storage duration to understand the interaction between these factors in reducing chilling injury and extending shelf-life. <i>Incorporate other postharvest variables into shelf-life models</i> Modify existing preliminary models for at least two cultivars to allow for the effects of modified atmosphere packaging, harvest maturity and cooling regime after harvest.	<i>Deliver training to assessors</i> Develop a standard quality assessment protocol and training material for Summerfruit. Provide training in Summerfruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback (in collaboration with QDAF). <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to five export Summerfruit consignments from production regions to key markets via road, sea and/or airfreight.	<i>Support intervention</i> Support collaborating growers and exporters to intervene and modify practices based on trial results. <i>Deliver information products</i> Develop information products that show how the co-investor use of project recommendations helped to identify, assess and manage risks to product quality associated with production factors and/or export supply chain conditions. Promote guidelines or rules of thumb present in the modelling to the co-investor, collaborating growers and broader Summerfruit industry. <i>Communicate project findings</i> Share results from trials with participating growers at post-season review meetings, industry conference and workshops, industry articles etc. Engage with SAL to identify how generic data can be shared with the broader industry.

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2024	<i>Simulate variations in supply chains</i> For each cultivar repeat 2023-24 integrated postharvest storage trials that include factors such as harvest maturity, packaging, cooling regimes and storage duration to understand the interaction between these factors in reducing chilling injury and extending shelf-life. <i>Incorporate other postharvest variables into shelf-life models</i> Modify existing preliminary models for at least two cultivars to allow for the effects of MA packaging, harvest maturity and cooling regime after harvest. <i>Develop predictive models and decision aid tools</i> Develop interactive shelf-life prediction models for three cultivars (decision aid tools) for growers/exporters and their supply chain partners to trial and view the impact of management and handling strategies on fruit quality and shelf life.	<i>Deliver follow-up training to assessors</i> Refine the standard quality assessment protocol and training materials for Summerfruit. Provide refresher training in Summerfruit quality assessment to third-party assessors and/or importers in key markets to ensure reliable feedback (in collaboration with QDAF). <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor up to ten export Summerfruit consignments from production regions to key markets via road, sea and/or airfreight. <i>Validate accuracy of predictive models</i> Monitor or simulate at least two shipments from harvest to domestic or export markets to verify accuracy of shelf-life models.	<i>Deliver information products</i> Develop information products that show how the co-investor use of decision support tools helped to identify, assess and manage risks to product quality associated with production factors and/or export supply chain conditions. Promote guidelines or rules of thumb present in the modelling to the co-investor, collaborating growers and broader Summerfruit industry. <i>Case study presentations</i> Develop videos and articles focused on case studies of co-investor use of the modelling, decision aid tools and associated commercial and online portal platforms. <i>Communicate project findings</i> Share results from trials with participating growers at post-season review meetings, industry conference and workshops, industry articles etc. Engage with SAL to identify how generic data can be shared with the broader industry. <i>Complete final survey of growers and exporters</i> Survey the collaborators and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity and confidence to better manage supply chain risks.

Appendix 12

Updated RD&E workplans



Updated RD&E workplans for project extension

Andrew Macnish, Department of Primary Industries, Queensland

Project summary

AM21000 Serviced Supply Chains II is a 4-year (2022-2026) investment in providing Australian horticulture industries with the necessary decision support for managing export and domestic supply chain risks and delivering consistent fresh produce quality. It is funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levies, and contributions from the Australian Government. It includes co-investment from the Department of Primary Industries, Queensland (DPI), the Department of Agriculture and Fisheries, Northern Territory (DAF), the Department of Energy, Environment and Climate Action, Victoria (DEECA), the Department of Primary Industries and Regional Development, Western Australia (DPIRD), Pinata Farms Pty Ltd and Summerfruit Australia Ltd. The AM21000 project aims to extend the success of the initial AM15002 Serviced Supply Chains project to additional varieties, commodities and freight modes.

The deliverables for the AM21000 project are divided into the following three components:

Component 1: Develop Predict Models

- Develop predictive remaining shelf life models through laboratory trials for a variety of fresh produce, factoring in parameters applicable to real world variability in both pre- and postharvest conditions such as regional variability, harvest maturity, phytosanitary treatments, chilling procedures etc.

Component 2: Simulated Supply Chains

- Based on these models, develop decision aid tools that, with input from real-time remote data loggers, can inform commercial decisions when ideal supply chain conditions have not been met
- By application of these models, simulate a variety of cultivars through supply chain variation and disruption to develop decision aid tools assisting cultivar selection and freight options
- Apply the models to develop pre- and postharvest guidelines with a focus on quantifying critical control points to maximise outturn quality, consistency and value.

Component 3: Capacity building and communications

- Promote project communication products on peak industry websites to build grower and supply chain partner capacity and facilitate usability of the models and decision aid tools.

The project has a focus on avocado, mango, strawberry and Summerfruit.

Commodity RD&E workplans

The project was recently extended by 6-months to finish in April 2026. The extension will ensure that additional avocado and strawberry trial work plus an evaluation of commercial uptake of mango and Summerfruit shelf life prediction algorithms can be completed. The following RD&E workplans have been revised to prioritise remaining activities for each commodity from July 2025 to April 2026. Background information for each commodity program is included for context.

Acknowledgement

The Serviced Supply Chains II project (AM21000) is funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland (DPI), Department of Energy, Environment and Climate Action, Victoria (DEECA), Department of Agriculture and Fisheries, Northern Territory (DAF), Department of Primary Industries and Regional Development, Western Australia (DPIRD), Pinata Farms Pty Ltd and Summerfruit Australia Ltd. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.



RD&E activities

DPI leads the AM21000 project and works with DAF, DPIRD and DEECA to manage the avocado, mango, strawberry and Summerfruit RD&E programs. A key objective is to develop decision aid tools based on shelf life modelling to support growers and their supply chain partners to deliver more consistent fruit quality. This work is being delivered through the following RD&E activities:

1. Predictive models and simulations
2. Monitoring and the surveyor network
3. Capacity building and communication products

1. Predictive models and simulations

- Develop predictive time x temperature shelf life models for 'Hass' and 'Shepard' avocados, 'Honey Gold' mangoes, sub-tropical and temperate strawberries plus selected nectarine and plum cultivars using fruit from farms in the main production regions. The simulations are designed to predict fruit shelf life in response to likely conditions encountered in domestic and export supply chains
- Evaluate the influence of production (e.g. region, farm), harvest (e.g. fruit maturity, size) and postharvest (e.g. delayed cooling, controlled atmosphere, ethylene) variables on fruit and model performance
- Develop shelf life prediction algorithms and interactive decision aid tools for growers/exporters and their supply chain partners to trial and view the impact of management and handling strategies on fruit quality and shelf life.

2. Monitoring and the surveyor network

- Monitor fruit arrival quality and handling conditions to identify risks, validate models and provide reliable feedback on fruit quality to growers and their supply chain partners
 - Source fruit from major production regions with at least two different suppliers per region
 - Track consignments to domestic and export markets by road freight and air or seafreight
- Create agreed fruit quality assessment procedures with a focus on objective measures
- Identify and train up professional produce surveyors in the seven key markets to reliably assess fruit quality at arrival and ripe.

3. Capacity building and communication products

- Provide growers and their supply chain partners with tailored decision support tools that increases awareness, capacity and confidence to deliver more consistent product quality
- Support avocado and Summerfruit growers to improve practices to increase export volume and value
- Support mango and strawberry growers to improve domestic supply chain practices and encourage diversification into exports
- Develop interactive decision aid tools and rules-of-thumb guidelines
- Deliver project information products via regular industry communication channels, including hosting content on peak industry body websites
- Link in with industry regional, national and export forums to share learnings
- Update and complement existing best management practices resources
- Deliver case study presentations with growers, exporters, importers/retailers

The following RD&E workplan provides a summary of remaining tasks and deliverables in 2025/26.

Avocado RD&E workplan (updated July 2026)

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025/26	• <i>Complete time x temperature simulation trials</i> Complete three simulated storage trials with early, mid and late-season 'Hass' avocados from WA farms to quantify fruit quality responses (August 2025 to January 2026) and provide data for shelf life model development. • <i>Finalise data analysis and model development</i> Analyse 2025/26 simulation trial data to relate production (e.g. region, harvest time) and postharvest (e.g. controlled atmosphere) factors or treatments with WA 'Hass' fruit quality and shelf life. Finalise development of shelf life prediction models and algorithms for WA fruit (April 2026). • <i>Deliver decision aid tools</i> Finalise development of a shelf life prediction calculator for 'Hass' with an option for WA fruit on the DPI Fresh Intel dashboard. Ensure the AAL website can link to the calculator (April 2026). Host final versions of the shelf life prediction algorithms for 'Hass' and 'Shepard' fruit on the dashboard. Ensure that real-time predictions are available to Escavox via API calls to the dashboard (February 2026). Encourage and support growers and their supply chain partners to trial the decision aid tools. Refine algorithms and calculator as required.	• <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor 4-6 'Hass' avocado export consignments from WA to Asian markets via air or seafreight (August 2025 to January 2026). Utilise in-market assessors to quantify fruit arrival quality and validate accuracy of shelf life prediction models. • <i>Real-time testing of shelf life prediction algorithms</i> Evaluate performance of 'Shepard' and 'Hass' algorithms to predict shelf life in real-time during a commercial trial with Escavox and north Queensland growers (February to April 2026). Commit project resources to compare the predicted vs actual shelf life for 4-6 avocado consignments, utilising assessors in-market. • <i>Evaluate the performance of a shelf life prediction calculator to meet industry expectations</i> Monitor usage of the calculator and quantify the number of visits, typical scenarios tested and seek feedback from users through a short survey (February 2026 to April 2026).	• <i>Economic analysis case study</i> Complete economic analysis with collaborating growers on cost/benefit of implementing improved practice (October 2025). • <i>Commercialise the prediction algorithms</i> Finalise a licence agreement with Escavox to commercialise the algorithms (October 2025). • <i>Deliver project resources</i> Deliver two factsheets on the use of controlled atmosphere storage (October 2025) and predicting avocado shelf life (January 2026). Deliver three Talking Avocado articles on addressing nodule damage (October 2025), optimal 'Shepard' storage (December 2025) and using shelf life predictions (March 2026). Deliver one article (e.g. Fresh Plaza) or factsheet on the value of the surveyor network. Update export best practice guidelines (January 2026). Resources to be hosted on AAL website. • <i>Case study presentations</i> Deliver a presentation at two avocado industry forums (October 2025), Asia Fruit Logistica (September 2025) and one case study video with two growers that highlights project learnings and examples of practice change (December 2025). • <i>Complete final survey of growers and exporters</i> Survey collaborating growers and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity to manage supply chain risks (April 2026).

Mango RD&E workplan (updated July 2025)

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025/26	<i>Finalise data analysis and model development</i> Analyse 2024/25 simulation trial data to relate production (e.g. region, farm) and postharvest (e.g. ethylene, controlled atmosphere) factors or treatments with 'Honey Gold' fruit quality and shelf life. Finalise development of shelf life prediction models and algorithms (September 2025). <i>Deliver decision aid tools</i> Develop a shelf life prediction calculator for 'Honey Gold' (from project AM21000) plus 'Kensington Pride' and 'R2E2' (from project AM15002) mangoes on the DPI Fresh Intel dashboard. Ensure the AMIA website can link to the calculator (October 2025). Host final versions of the shelf life prediction algorithms for each cultivar on the dashboard. Ensure that real-time predictions are available to Escavox via API calls to the dashboard (October 2025). Encourage and support growers and their supply chain partners to trial the decision aid tools. Refine algorithms and calculator as required.	<i>Real-time testing of shelf life prediction algorithms</i> Evaluate performance of 'Honey Gold', 'Kensington Pride' and 'R2E2' algorithms to predict shelf life in real-time during a commercial trial with Escavox and growers (October 2025 to January 2026). Commit project resources to compare the predicted vs actual shelf life for 20-30 mango consignments, utilising assessors in market. <i>Evaluate the performance of a shelf life prediction calculator to meet industry expectations</i> Monitor usage of the calculator and quantify the number of visits, typical scenarios tested and seek feedback from users through a short survey (October 2025 to January 2026).	<i>Economic analysis case study</i> Complete economic analysis with the co-investor and growers on cost/benefit of implementing improved practice (October 2025). <i>Commercialise the prediction algorithms</i> Finalise a licence agreement with Escavox to commercialise the shelf-life prediction algorithms (October 2025). <i>Deliver project resources</i> Deliver two factsheets on the use of controlled atmosphere storage (October 2025) and predicting mango shelf life (December 2025). Deliver two Mango Matters articles on managing mango quality along supply chains (October 2025) and using shelf life prediction technology to inform decision making (March 2026). Update the mango industry quality assessment manual and the ripening manual (October 2025). Resources to be hosted on the AMIA website. <i>Case study presentations</i> Deliver a presentation at four mango industry roadshows (August/September 2025) and Asia Fruit Logistica (September 2025) that highlights project learnings and examples of practice change. <i>Complete final survey of growers and exporters</i> Survey the co-investor and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity to manage supply chain risks (October 2025).

Strawberry RD&E workplan (updated July 2025)

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025/26	• <i>Complete time x temperature storage trials</i> Complete three simulated storage trials with early, mid and late-winter season 'Red Rhapsody' strawberries from Qld farms to quantify fruit quality responses (July to October 2025). Complete two trials with temperate cultivars (e.g. 'Cabrillo', 'Albion') in the early and mid-summer season (November 2025 to January 2026). • <i>Evaluate the influence of other variables</i> Monitor the influence of potential production (e.g. rainfall) factors on shelf life. Complete three trials to evaluate the impact of time delays between harvest and pre-cooling at 2-3 farms with 'Red Rhapsody' and 'Cabrillo' / 'Albion' fruit. Evaluate phytosanitary treatment (e.g. MeBr, irradiation) impacts on cultivar performance (September 2025 to January 2026). • <i>Finalise data analysis and model development</i> Analyse 2025/26 simulation trial data to relate production and postharvest factors with 'Red Rhapsody' and 'Albion'/'Cabrillo' fruit quality and shelf life. Finalise development of shelf life prediction models and algorithms (March 2026). • <i>Deliver decision aid tools</i> Develop a preliminary shelf life prediction calculator for strawberries on the DPI Fresh Intel dashboard. Ensure the Berries Australia website can link to the calculator (March 2026). Ensure that real-time predictions are available to Escavox via API calls (March 2026). Encourage growers and their supply chain partners to trial the tools.	• <i>Monitor handling conditions and product quality</i> Using real-time loggers, monitor 4-6 domestic 'Red Rhapsody' strawberry consignments from Qld to a capital city market via road (July to October 2025). Monitor an export consignment where demands exists. Monitor 4-6 domestic 'Albion'/'Cabrillo' strawberry consignments to a capital city market (November 2025 to January 2026). Quantify handling conditions and fruit outturn quality plus validate accuracy of shelf life prediction models. Identify breaks in the cool-chain and risks to quality loss. • <i>Evaluate the performance of a shelf life prediction calculator to meet industry expectations</i> Encourage testing of the calculator and seek feedback from users through a short survey (March 2026).	• <i>Economic analysis case study</i> Complete economic analysis with collaborating and growers on the cost/benefit of implementing improved practice (October 2025). • <i>Commercialise the prediction algorithms</i> Finalise a licence agreement with Escavox to commercialise the shelf-life prediction algorithms (October 2025). • <i>Deliver project resources</i> Deliver three factsheets on consignment monitoring technology (October 2025), benefits of prompt pre-cooling (February 2026) and predicting strawberry shelf life (March 2026). Deliver two Australian Berry Journal articles on a grower case study implementing project learnings (October 2025) and prompt pre-cooling benefits (February 2026). Update the strawberry quality management guidelines on the Berries Australia website. Share project results with growers at one industry-wide forum (e.g. QSGA, February 2026). • <i>Case study presentations</i> Deliver one case study video with two strawberry growers that highlights project learnings and examples of practice change (October 2025). • <i>Complete final survey of growers and exporters</i> Survey collaborating growers and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity to manage supply chain risks (April 2026).

Summerfruit RD&E workplan (updated July 2025)

Year	Predictive models and simulations	Monitoring and the surveyor network	Capacity building and communication products
2025/26	<i>Deliver decision aid tools</i> Develop a shelf life prediction calculator for 'Diamond Pearl', 'Polar Zee' nectarine and 'Angeleno' and 'Black Ruby' plum (from project AM21000) plus 'Flavour Pearl', 'Majestic Pearl' and 'September Bright' nectarine (from project AM15002) on the DPI Fresh Intel dashboard. Ensure the SAL website can link to the calculator (October 2025). Host shelf life prediction algorithms for each cultivar on the dashboard. Ensure that real-time predictions are available to Escavox via API calls to the dashboard (October 2025). Encourage and support growers and their supply chain partners to trial the decision aid tools.	<i>Real-time testing of shelf life prediction algorithms</i> Evaluate performance of selected nectarine and plum algorithms to predict shelf life in real-time during a commercial trial with Escavox and growers (December 2025 to March 2026). Commit project resources to compare the predicted vs actual shelf life for 3-5 nectarine and plum consignments, utilising assessors in market. <i>Evaluate the performance of a shelf life prediction calculator to meet industry expectations</i> Monitor usage of the calculator and quantify the number of visits, typical scenarios tested and seek feedback from users through a short survey (December 2025 to March 2026).	<i>Economic analysis case study</i> Complete economic analysis with the co-investor and growers on cost/benefit of implementing improved practice (October 2025). <i>Commercialise the prediction algorithms</i> Finalise a licence agreement with Escavox to commercialise the shelf-life prediction algorithms and make available to growers and exporters (October 2025). <i>Deliver project resources</i> Deliver one factsheet on predicting stone fruit shelf life (October 2025). Deliver one Australian Tree Crop article on using shelf life prediction technology to inform decision making (October 2025). Update the Summerfruit industry export guidelines (October 2025). Resources to be hosted on the SAL website. <i>Case study presentations</i> Deliver a case study video with an exporter on the benefits of shelf life prediction (October 2025). <i>Complete final survey of growers and exporters</i> Survey the co-investor and broader industry to quantify if the project has increased awareness of decision aid tools and their capacity to manage supply chain risks (October 2025).

Appendix 13

Consignment monitoring report



AM21000 Monitoring Program

summary report

Saeedeh Taghadomi Saberi, Jodie Campbell and Andrew Macnish

Department of Primary Industries

Summary

This report summarises the AM21000 monitoring program (2022–25), which tracked domestic and export shipments of avocado (Hass and Shepard), Honey Gold mango and strawberries using real-time data loggers. Shipments were monitored for temperature, time, humidity and location, and fruit outturn quality and residual shelf life were assessed by trained assessors at destination markets in Australia and key export markets. The program also reviewed available real-time monitoring technologies and shared guidance with industry through factsheets and stakeholder engagement, supporting improved supply chain management and more consistent fresh produce quality.

Key outcomes of the monitoring program are:

- Industry learning and awareness
- Growing adoption and intent to adopt real-time monitoring
- Improved supply chain insight and decision-making
- Standardised quality assessment resources
- Greater confidence in delivering predictable quality
- Improved consistency in outturn assessment
- Expanded assessor capability and coverage
- Supporting extension and best-practice materials



1 Introduction

Australia produces large volumes of high-value fresh fruit that are distributed through long domestic and international supply chains. Mango, strawberry and avocado are among the country's most economically important horticultural crops. Australian mango production averages around 70,000–75,000 tonnes per year, with a farm-gate value of approximately \$180–200 million, and exports of several thousand tonnes annually, largely to Asian markets¹. Strawberries are a major domestic fresh fruit crop, with annual production of around 75,000–80,000 tonnes, supplying both domestic and export markets². Avocado production has grown substantially in recent years, reaching more than 150,000 tonnes in 2023/24 with a value close to \$600 million, and exports accounting for an increasing share of total production³.

Maintaining fruit quality through these supply chains is critical to protecting grower returns, market access and the reputation of Australian produce. Domestic supply chains for Honey Gold mango and strawberries, and international shipments of avocado and summerfruits from Australia, are sensitive to handling practices, temperature management and consistency of quality. Fruit quality and shelf life at destination are strongly influenced by quality at harvest and all subsequent handling and transport stages, with temperature recognised as one of the most critical factors affecting ripening rate, disorder development and marketable life.

The monitoring component of this project focuses on tracking commercial consignments through representative domestic and international supply chains to identify areas for improvement. Monitoring fruit performance and conditions from dispatch through to destination provides practical, real-world evidence of where quality losses occur. These data are used to support the development of standardised quality assessment resources, improve consistency in assessments, and inform targeted training of assessors in destination markets. Together, these activities aim to strengthen quality feedback across the supply chain and support measurable improvements in fruit quality outcomes.

2 Objectives

The objective of this project component was to deliver more consistent fruit quality and improve the profitability of Australian horticultural produce supplied to domestic and Asian markets through a dedicated supply chain monitoring program (2021-25). The monitoring component aimed to:

1. Develop a resource with a list of available real-time technologies for monitoring horticultural produce supply chain from farm to retail.

¹ [Hort Innovation | Australian Horticulture Statistics Handbook 2024/25](#)

² [WEB-181022-MASTER-Austrade-Industry-Capability-Reports-STR.pdf](#)

³ [Avocados Australia's latest industry figures out now! - Avocados Australia](#)



2. Measure storage and transport conditions, including temperature and time, and assess fruit performance during and after shipment, including outturn quality and residual shelf life.
3. Identify critical points in domestic and export supply chains where handling practices could be improved to reduce quality loss.
4. Support targeted interventions to improve handling practices and fresh produce quality.
5. Assess progress by supply chain partners in adopting improved procedures to minimise fruit quality loss.
6. Validate predictive models and decision-support tools or guidelines developed by the project AM21000 to assist growers and exporters in delivering more consistent fruit quality to domestic and export markets.
7. Provide training to supply chain businesses and project collaborators in fruit quality assessment protocols and best practice handling and cooling procedures.
8. Establish a network of trained fruit quality assessors in Australia and key export destinations to provide consistent and reliable feedback to Australian growers and exporters.

3 Materials and Methods

3.1 Real-time loggers

Desktop research was conducted to identify commercially available real-time loggers and assess their features for monitoring horticultural supply chains, based on online research and engagement with equipment providers.

3.2 Shipments tracking

Over 5 years (2021-25), project monitored road, air and sea freight shipments of

- 'Hass' and 'Shepard' avocados
- 'Honey Gold' mango
- 'Red Rhapsody', 'Scarlet Rose', 'PCT', 'Big Sur', 'Cabrillo' and 'Petaluma' strawberries
- 'Majestic Pearl', 'Flavour Pearl' and 'Polar Zee' nectarines

DPI project staff worked with 32 businesses to undertake this monitoring.

Consignments were tracked from growing regions to domestic and international markets using real-time loggers. One Tive real-time data logger, recording temperature, relative humidity and location, was placed in each monitored consignment. The activated logger was positioned in the centre of one tray, three layers from the top of the pallet. This tray, along with one tray above and one below, was labelled as sample fruit for retrieval and assessment after shipment (Figure 1).

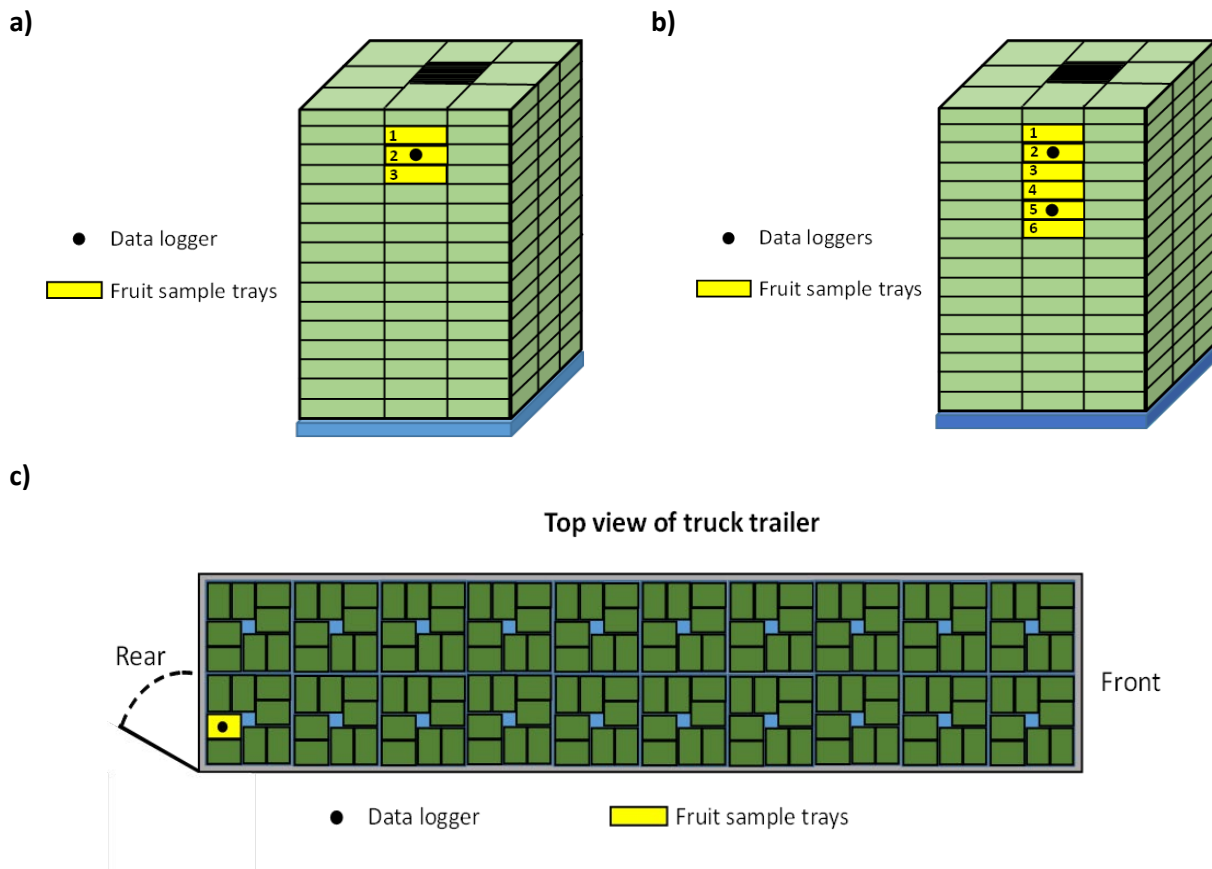


Figure 1. (a) and (b) the position of sample trays and data logger in the pallet of all consignments and (c) the position of pallet in trailer for mango consignments only.

Three trays of fruit from the same harvest batch were also retained as library samples for avocado and mango monitoring. A data logger was usually included in the library trays to track conditions during transport to the project laboratory.

Once in the laboratory, library fruit were handled as follows:

- Mango: held at 20 °C until individual fruit reached end of shelf life
- Avocado (air freight simulation): held at 7 °C for 7 days, then at 20 °C until end of shelf life
- Avocado (sea freight simulation): held at 5 °C for 20 days, then at 20 °C until end of shelf life

An additional tray of fruit from the same harvest batch was collected to measure dry matter content.



3.3 Outturn quality assessment

Outturn quality assessment was conducted using tagged sample trays collected by trained assessors at the destination market. Mango and strawberry consignments were assessed in Melbourne, Brisbane and Sydney, while avocado consignments were assessed in Asian markets. For monitored Honey Gold mango consignments, sample trays were collected either before or after ethylene ripening.

At destination, assessors evaluated external fruit quality on arrival, before storage at 20 °C. Individual fruit were then monitored over time, and the date at which each fruit reached end of shelf life was recorded. End of shelf life was determined based on loss of firmness, development of rots, or the presence of other major defects.

To support consistent quality assessment, the project established a network of assessors across Australia and key export markets. Assessors were trained using standardised, objective assessment procedures, reference image sets and a quality assessment app. This system enabled rapid and reliable quality reporting in both domestic and international markets. The quality assessment app was developed by Rudge Produce Systems. Further details on the assessor network are provided in the factsheet '[Quality assessor network](#)'.

Quality assessment results, along with minimum, maximum and average temperature data, were compiled into an individual report for each consignment and shared with participating businesses. Observed issues and recommendations for improved supply chain management were then communicated to businesses. Results from individual consignment monitoring were also compiled into a general report that included all consignments in a de-identified format. These summary reports were shared with industry through workshops, forums and Project Advisory and Reference Group meetings.

4 Results

The market offers a wide range of real-time trackers and loggers with different features. The desk-top research compiled a list of commonly used real-time trackers and loggers for monitoring fresh produce in the cold chain (Table 2). Costs vary depending on what the device measures, whether it is reusable, and its battery life. Typical prices range from AUD 20 to AUD 115, with bulk discounts often available.

The list was shared with industry through a factsheet in stakeholder engagement activities, including the Gatton AgTech Showcase, and was well received. For further information, refer to '[Selecting real-time shipment trackers and loggers](#)'.

Table 1. Tracker and logger options for monitoring horticultural produce supply chains.

Company	Model	Approving airlines ¹	Battery life (days) ²	Battery life (no. connection attempt) ³	Air temperature ⁴	Humidity	Light	Shock	Motion	GPS-enabled	Wi-Fi ⁵	Adjusting settings	Rechargeable	Multi-use ⁶	Alerts	CO ₂	Probe (Product Temperature)
Copeland	Go Real-Time 4G/5G	55	20	1600													
	Go Real-Time 4G/5G N	55	18	1440													
	Go Real-Time XL 4G/5G LT	55	60	1440													
	Go Real-Time Reusable 4G/5G LT	55	20	1600													
	Go Real-Time CO ₂	55	20	1600													
Elitech	RCW-800W-THE	-	35	1680													
	RCW-800W-TDE	-	35	1680													
	Glog5	16	40 -120	2880													
	LogEt 260-TH & THE	-	60	2880													
	RCW-360Plus-WG-DC	-	80	3840													
	RCW-360Pro-DC	-	60	2880													
	RCW-360Pro-SC	-	60	2880													
Escavox ⁷	Blue Box Tracker	14	150	7200													
Frigga	V5B 5G	64	120	1440													
	V5C 5G	64	120	1440													
	V5Y 5G	64	120	1440													
	V5H 5G	64	120	1440													
	V5-CO ₂	64	120	1440													
Sensitech	TempTale Geo Lte & Extended	-	30 / 90	480													
	TempTale Geo Ultra & Ultra Extended	78/51	30 / 120	480													
	TempTale Geo X & XE	77/71	60 / 120	480													
	TempTale GEO Dry Ice & Ultra Extended	73/51	60 / 120	480													
Sigmawit ⁸	GLogs1	-	260	6240													
	GLogsp1	-	260	6240													
	GLogm1	-	260	6240													
	GLogmp1	-	260	6240													
Tive	Solo 5G	170+/130+	22+/90+	528/2160													
	Solo Lite	170+/130+	30+/60+	720/1440													
	Solo Pro	182	110+	220-720													
Tzone ⁹	TT18-4G-S	-	60	2880													
	TT18-4G-M	-	100	4800													
	TT19	6	60	1440													
	TT19EX	-	60	1440													
	TT19SI	-	120	2880													
	TT19SE	-	120	2880													
Xsense	GPRS	-	50	1200													
	2G & Cat-M1(4G)	-	200	4800													

4.1 Shipments monitored

Figure 2 shows an example of an avocado shipment monitored from north Queensland to Malaysia. Stakeholders can track the shipment in real time using the technology provider's dashboard. The dashboard provides consignment reports with information on temperature, transit duration, and location, as well as alerts when conditions, such as temperature, move outside pre-set optimum ranges.

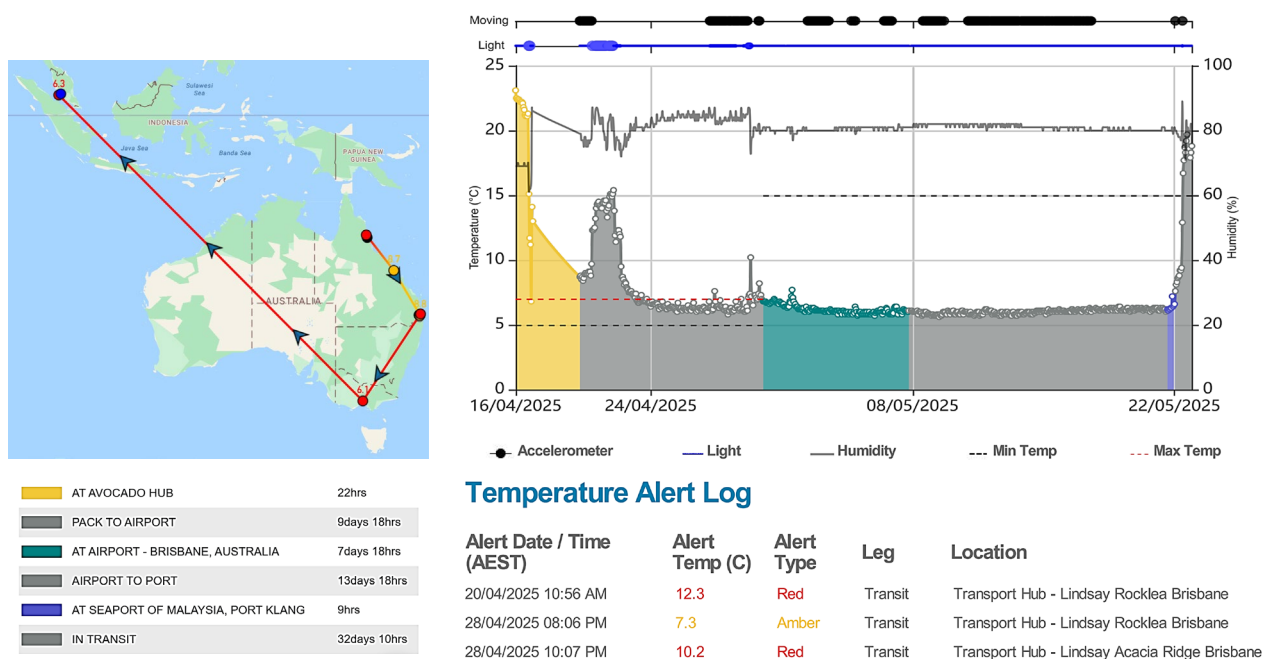


Figure 2. Real-time monitoring of an avocado shipment (Cairns → Brisbane → Melbourne → Port Klang, Malaysia) by sea freight. The consignment averaged 7.2 °C over 37 days, with alerts triggered along the way.

In the following section, commodity-specific results are presented.

4.1.1 Avocado

Over four seasons, SSC II successfully monitored 42 Hass and Shepard avocado consignments out of 63 consignments that were tagged and equipped with temperature loggers and shipped to Japan, Singapore, Hong Kong, Malaysia, and Thailand (Table 2).

Table 2. Success rate of sea and air freight avocado consignments across seasons.

	2022	2023	2024	2025	Total per mode
Sea Freight	3/3	6/10	9/15	8/10	26/38
Air Freight	-	6/7	6/9	4/9	16/25
Total per season	3/3	12/17	15/24	12/19	42/63

The majority of Hass consignments were transported by sea freight to Japan, Singapore, Hong Kong, Thailand, and Malaysia (Table 3). In contrast, most Shepard consignments were transported by air freight to Singapore,



Hong Kong, and Malaysia (Table 3). In general, air freight is more tightly controlled than sea freight, so it typically operates at higher average temperatures.

Table 3. Number of Hass and Shepard consignments monitored by SSC II, by shipment mode per season.

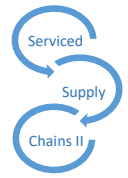
Season	Hass		Shepard	
	Sea Freight	Air Freight	Sea Freight	Air Freight
2022	3	-	-	-
2023	6	2	-	4
2024	7	1	2	5
2025	8	1	-	3
Total	24	4	2	12

Figure 3 summarises key environmental conditions across monitored sea freight consignments of Hass avocado, together with the percentage of fruit showing less than 10% damage. Across all seasons, average dry matter remained consistently within the recommended range, indicating good maturity management and no major seasonal variation in this parameter.

Supply chain temperature performance for the monitored Hass sea freight consignments improved over time, with the lowest and most consistent temperatures observed in 2025. Average supply chain temperature declined from around 7 °C in 2023 to approximately 5.5 °C in 2025, and average temperature variation between consignments was also reduced in this final season. Dispatch temperatures followed a similar trend. In 2023 and 2024, fruit was often dispatched well above the recommended 5 °C, typically around 10–11 °C. In 2025, dispatch temperatures moved closer to the target range, averaging around 7 °C, indicating improved temperature management at the start of the supply chain.

In contrast, the performance of arrival temperature for monitored Hass sea freight consignments was poorest in 2025. This included one consignment arriving at 23 °C, highlighting ongoing challenges in maintaining temperature control towards the end of long supply chains. These elevated arrival temperatures coincided with longer transport durations and likely contributed to poorer quality outcomes observed in this season.

Quality assessments showed a change in the main defect type over time in monitored Hass sea freight consignments. Rot became the dominant quality issue in 2025, while vascular browning and diffuse discolouration continued to decline. The higher incidence of rot in 2025 was largely associated with heavy rainfall earlier in the season. Results from simulation trials showed that controlled atmosphere (CA) storage



can reduce rot during long storage periods, but it does not always keep rot below the defect allowance. Overall, rot incidence is strongly influenced by preharvest weather conditions and packing practices.

Overall fruit condition improved between 2022 and 2024 in the monitored Hass sea freight consignments, with 2024 recording the highest proportion of fruit with less than 10% damage. However, quality outcomes declined in 2025, with an approximate 15% reduction in fruit meeting this threshold. This decline is likely linked to longer supply chain durations and higher arrival temperatures, reinforcing the importance of end-to-end temperature control for maintaining fruit quality.

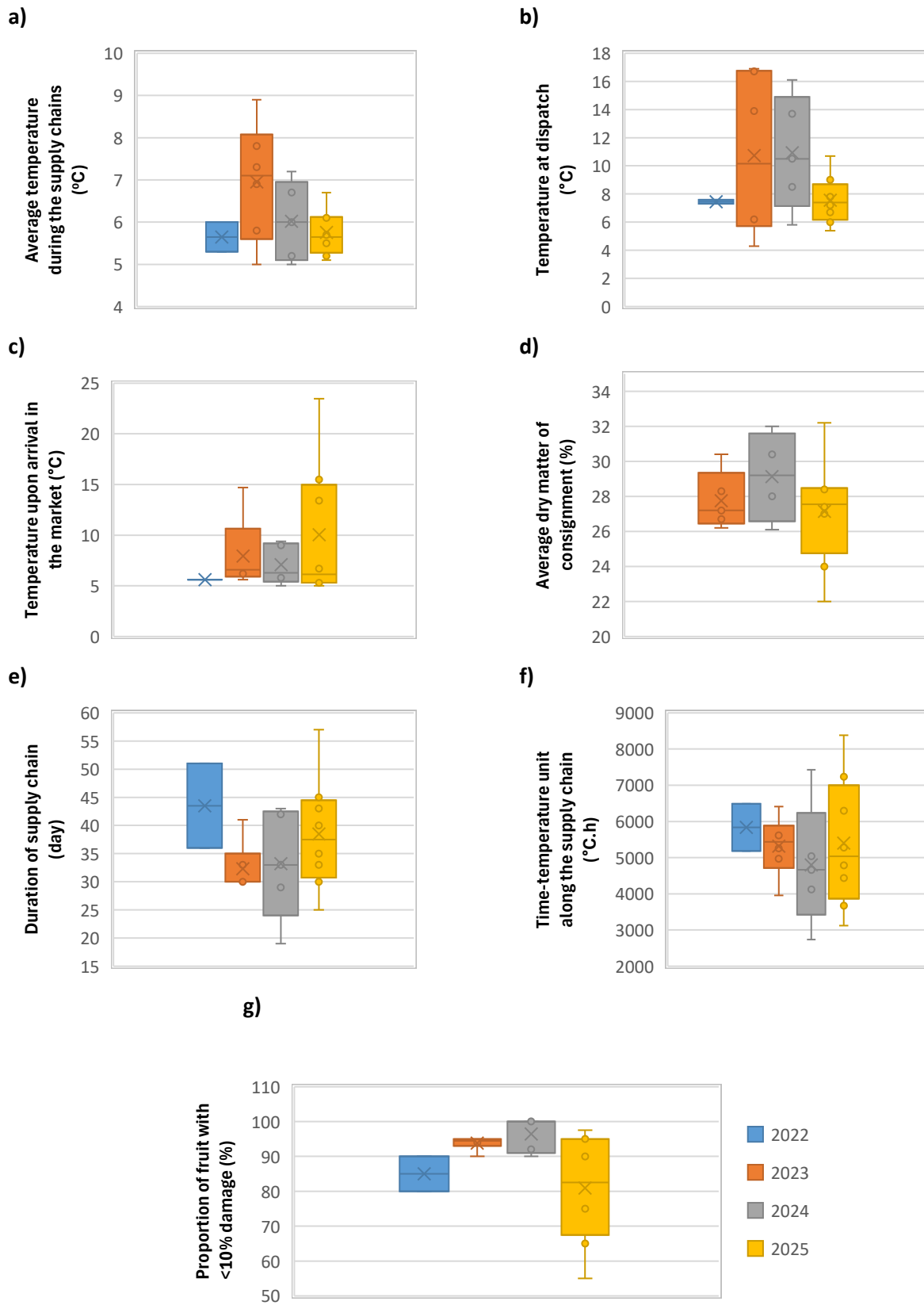


Figure 3. Changes in environmental conditions of sea freight consignments of Hass avocado, including (a) average temperature along the supply chain, (b) temperature at dispatch, (c) temperature on arrival, (d) average dry matter, (e) days in the supply chain, (f) time-temperature units, and (g) percentage of fruit with less than 10% defects.

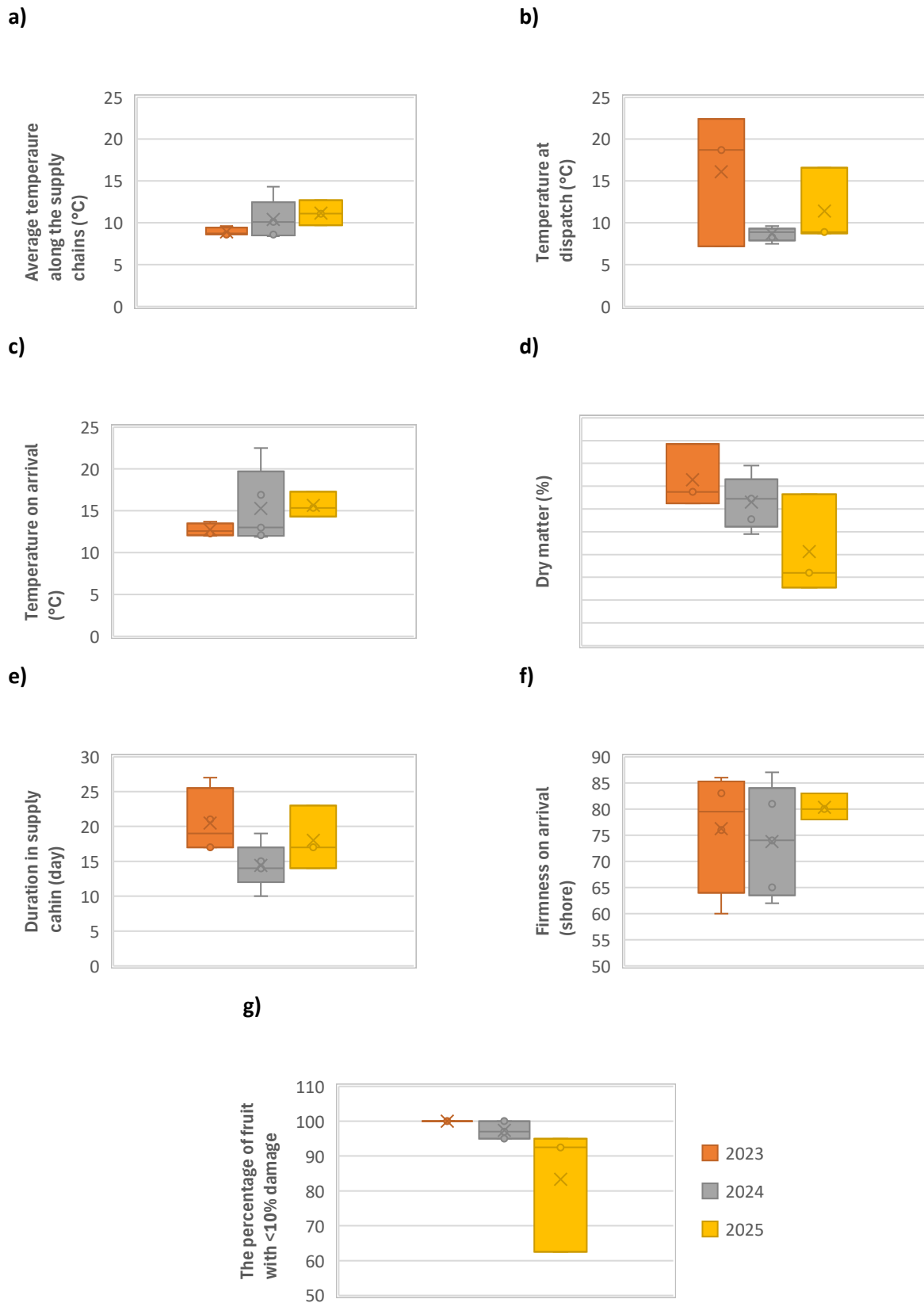


Figure 4. Changes in environmental conditions of air freight consignments of Shepard avocado, including (a) average temperature along the supply chain, (b) temperature at dispatch, (c) temperature on arrival, (d) average dry matter, (e) days in the supply chain, (f) firmness on arrival, and (g) percentage of fruit with less than 10% defects.



Average supply chain temperature for monitored airfreight shipments of Shepard avocado increased over the monitoring period, rising from around 9 °C to 11 °C. These higher temperatures largely reflect the use of airfreight, which typically operates at warmer conditions than sea freight. Dispatch temperature was better managed in 2024, remaining around 9 °C, but increased again in 2025. Arrival temperatures also increased over time and were consistently above the recommended target (Figure 4).

Average fruit dry matter declined across seasons in the monitored airfreight shipments of Shepard avocado, decreasing from 30 % in 2023 to 23 % in 2025. Supply chain duration shortened in 2024 but increased again in 2025, leading to greater variability in handling time (Figure 4).

Fruit quality declined over the same period in the monitored airfreight shipments of Shepard avocado. Consignments monitored in 2023 showed excellent quality, quality declined in 2024, and was lowest in 2025. This trend aligned with progressively poorer temperature management across the supply chain over time and, more importantly, the extremely wet weather conditions experienced in 2024 and 2025 (Figure 4).

4.1.2 Mango

Over three seasons, 59 domestic and two international consignments were monitored from packing sheds near Darwin, Katherine, the Atherton Tablelands, Bowen and Bundaberg to a ripener in Melbourne (Table 4).

Table 4. Success rate of Honey Gold mango consignments across seasons.

2022-23	2023-24	2024-25	Total
13/17	18/18	28/28	59/63

Figure 4 shows the changes in the condition and residual shelf life of HG mango consignments across seasons. Mango consignment monitoring showed clear improvements in temperature management over time, particularly in how average temperatures were controlled along the supply chain. Temperatures became more consistent across seasons, reflecting better overall handling and monitoring practices. This improvement was most evident in later seasons, where variability between consignments was reduced.

Dispatch temperature management improved steadily, with the lowest and most consistent dispatch temperatures recorded in the final season. Stricter dispatch practices were adopted, including one central Queensland business consistently dispatching fruit below 16 °C. Across the program, 75% of consignments in the final season were dispatched below 18 °C, around 3 °C cooler than in earlier seasons, indicating closer alignment with recommended dispatch targets.

Supply chain duration was also more actively managed over time. Consignment duration was most consistent in the 2023–24 season, when half of monitored shipments took between 3.5 and 5.5 days, with a median



duration of 4 days. Although consistency reduced slightly in 2024–25, the average and median duration remained the same.

End-to-end temperature control improved overall, with substantial gains seen by 2024–25. In this final season, 75% of consignments recorded an average supply chain temperature below 17 °C, compared with around 20 °C in 2022–23. Arrival temperatures improved in 2023–24, indicating better temperature control during transport, although this improvement was not fully maintained in 2024–25.

Changes in temperature and handling were reflected in shelf life outcomes. Remaining shelf life increased by around two days in the second year of monitoring but declined by approximately one day in the final year. This reduction is likely linked to higher average and median dry matter levels at dispatch, reinforcing the interaction between maturity, temperature management and postharvest performance.

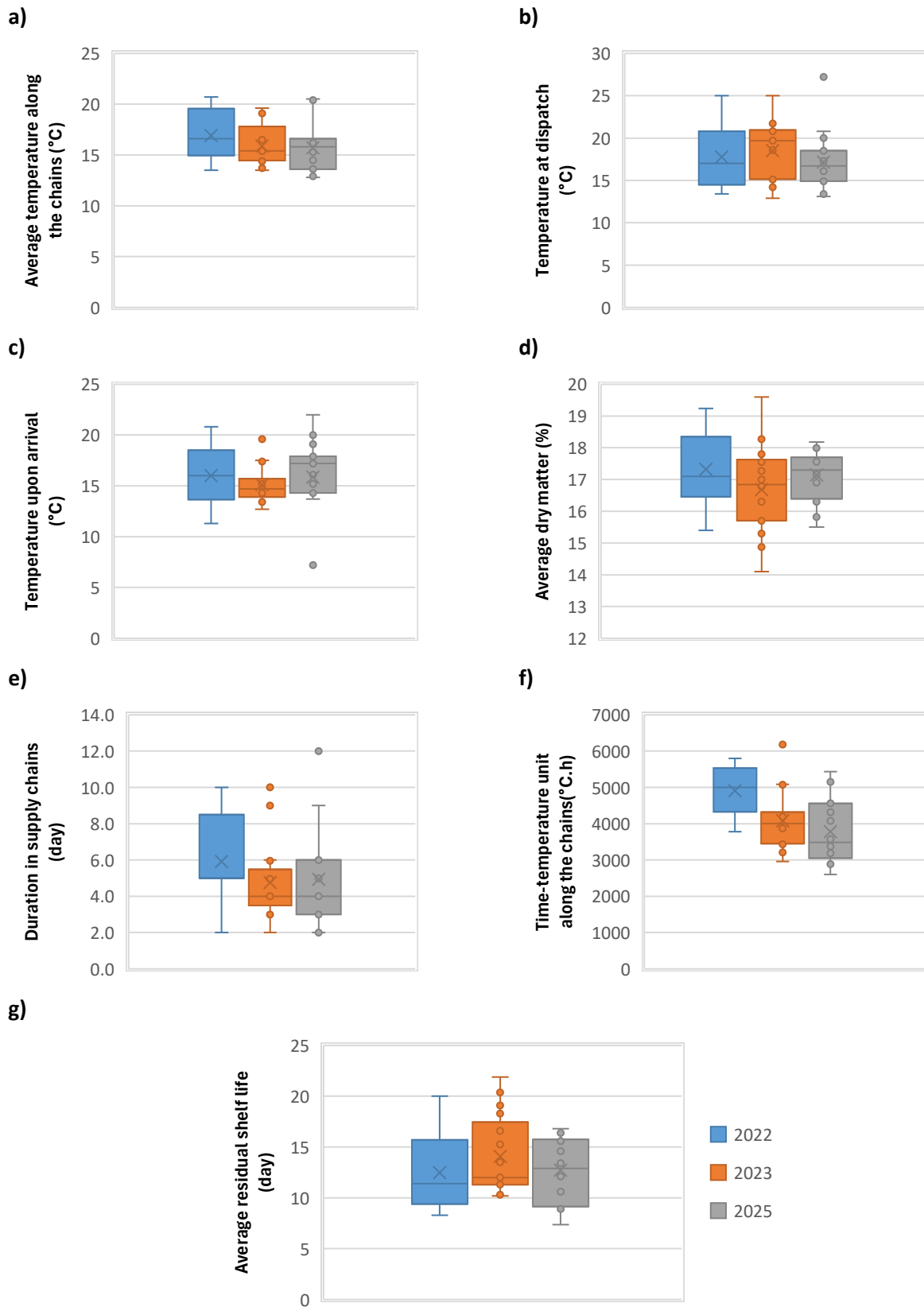


Figure 5. Changes in environmental conditions of Honey Gold mango consignments, including (a) average temperature along the supply chain, (b) temperature at dispatch, (c) temperature on arrival, (d) average dry matter, (e) days in the supply chain, (f) time-temperature units, and (g) percentage of fruit with less than 10% defects.



4.1.3 Strawberry

Over three seasons 32 domestic and one international consignment were monitored (Table 5).

Table 5. Success rate of strawberry consignments across seasons.

2022	2023	2024	2025	Total
0/2	7/8	15/15	10/13	32/35

Figure 5 shows a marked improvement in cold chain management over the project period. Average supply chain temperature was reduced from 7.5 °C in 2023 to 3.7 °C in 2025, bringing conditions into the optimal 0.5–4 °C range. This was supported by better pre-cooling at dispatch, with dispatch temperature dropping from 8.7 °C to 4.1 °C, and improved arrival temperature, which fell from 9.7 °C to 5.2 °C. Humidity control also improved, with average relative humidity increasing from 64 % to 83 % in 2025, approaching the recommended 90–95 % range. Fruit quality consistently improved as cold chain conditions improved, with acceptable fruit increasing from 96 % in 2023 to 98 % in 2024 under cooler and more humid conditions. However, in 2025 acceptable fruit declined to 76 %, despite optimal temperature and humidity. This indicates that factors other than temperature and humidity limited quality in the final season, including longer and more variable supply chain duration and a wider packing window, which increased variation in fruit maturity and dry matter. Overall, while temperature and humidity control improved substantially, supply chain duration and maturity management became the main constraints to quality in the final year.

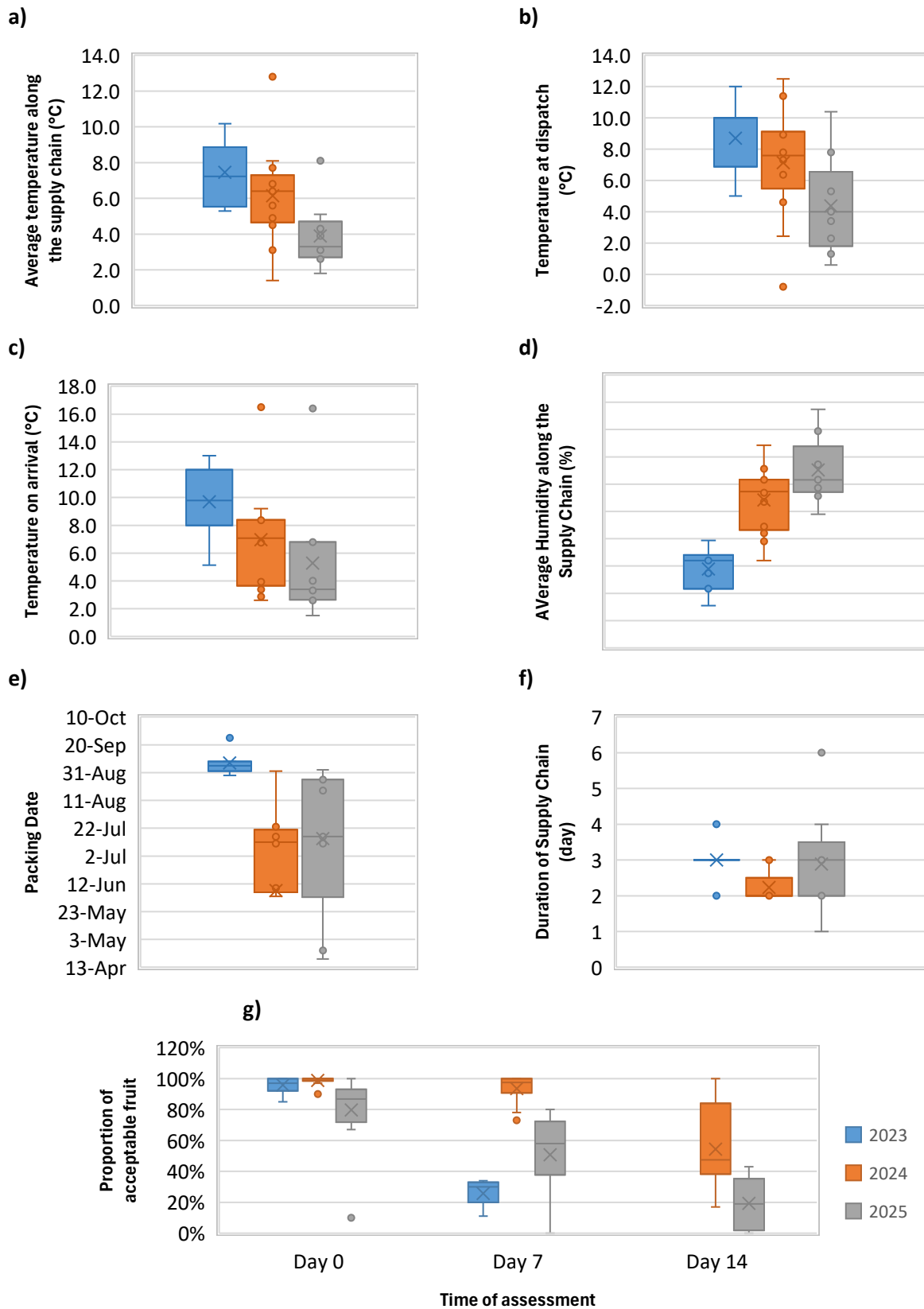


Figure 6. Changes in environmental conditions of strawberry consignments, including (a) average temperature along the supply chain, (b) temperature at dispatch, (c) temperature on arrival, (d) average humidity along the chains, (e) packing date, (f) days in the supply chain, (g) proportion of acceptable fruit.



4.1.4 Summerfruit / Nectarine

Four sea-freight nectarine consignments from Victoria to China and Vietnam were used to validate the summer fruit predictive models, with a summary shown in Table 6. These consignments had a duration of 22-35 days and the temperature was well managed with an average of 0.1 – 0.8°C.

Table 6. Four nectarine consignments were used for summerfruit model validations.

Variety	Pack Date	Destination	Initial Firmness (kg/cm ²)	Duration (day)	Shipment Ave Temp (°C)	Ripening
Polar Zee	10/12/2025	Guangzhou, China	4.7	26	0.1	4 days x 18°C
Majestic Pearl	14/01/2026	Guangzhou, China	8.45	22	0.8	4 days x 22°C
Flavour Pearl	3/01/2026	Hanoi, Vietnam	6.6	35	0.5	4 days x 18°C
Majestic Pearl	8/01/2026	Guangzhou, China	5.7	26	0.7	4 days x 18°C

4.2 Reports on Shipments

Businesses received post-assessment reports based on consignment monitoring data and findings from simulation trials. These reports informed changes to handling practices. An example report is shown in Figure 6. Each report included key shipment milestones, including packing, dispatch, arrival, sample collection and assessment dates. It also summarised average dry matter of the shipment, temperature management across the supply chain, and the type and incidence of major defects, reported as the percentage of fruit within industry tolerance levels.



Figure 7. Example report from consignment monitoring of a sample avocado shipment.

De-identified results from consignment monitoring were compiled into a general report covering all monitored consignments, including plots and summaries similar to those presented in 4.1. The report described how different transport modes were managed for each variety, including temperature management and, for strawberries, relative humidity. Changes in supply chain conditions over time and their effects on fruit quality were analysed. This information, together with findings from simulation trials, was used to identify common supply chain issues and to develop industry-level recommendations. The recommendations included:

- Pre-cool fruit to recommended/optimal temperatures immediately after harvest
 - 5°C, Hass avocado
 - 7°C, Shepard avocado
 - 12 - 16°C, Honey gold mango
 - 0.5 - 4°C, strawberry
- Work with your transport company to maintain an optimal temperature during transit
- Avoid mixing correctly pre-cooled fruit with poorly cooled fruit.
- Monitor fruit temperatures in transit, use logger alerts and act quickly if issues arise
- Communicate across the supply chain. Request fruit quality reports to help identify problems



- Use decision support tools such as Fresh INTEL to predict fruit quality and shelf life
- Be mindful of fruit dry matter content, higher levels are associated with shorter shelf life
- Plan for postharvest quality ahead of harvest with the right orchard and disease management.

Avocado only:

- Use CA:
 - To maintain firmness and shelf life
 - To reduce internal and skin defects
 - To maintain quality during long sea freight shipments > 20 days
 - For more even ripening
- Set the CA shipping container or storage room at 2% O₂ and 5% CO₂
- Avoid cool chain disruption to prevent ripening and resulting chilling damage
- Ensure CA containers and storage rooms are well-sealed
- Ensure thorough ventilation at removal before entering CA containers and storage rooms
- Monitor O₂ and CO₂ levels in transit using real-time loggers and act on alerts quickly

Hass only:

- Use smaller fruit for long supply chains to reduce internal defects
- Commence CA within 5 days for long supply chains, maintaining 5°C after harvest.

Mango only:

- Consider using ethylene for early-season or select-pick fruit to promote more uniform ripening

Strawberry only:

- Maintain relative humidity at >90%
- Pre-cool to <10°C within two hours after harvest

4.3 Practice changes

The project communication and recommendations resulted in measurable improvements in avocado, mango and strawberry industry practices and performance, including:

Sea freight avocado

- Improved supply chain temperature control, average temperature reduced from ~7 °C in 2023 to ~5.5 °C in 2025
- More consistent temperatures across consignments in 2025, reduced variability between shipments
- Lower dispatch temperatures in 2025, moving closer to recommended targets compared with 2023–2024
- Dry matter consistently managed within recommended ranges across all seasons



- Progressive reduction in fruit damage from 2022 to 2024, with 2024 achieving the highest proportion of fruit with less than 10% damage
- Reduced incidence of vascular browning and diffuse discolouration over time

Mango

- More consistent temperature control along the supply chain, especially average chain temperature
- Overall temperature performance improved, with 75% of consignments in 2024–25 averaging below 17 °C, compared with ~20 °C in 2022–23
- Lower and more consistent dispatch temperatures in the final season
- Stricter dispatch practices adopted, including one central Queensland business consistently dispatching fruit below 16 °C
- Improved dispatch consistency, with 75% of consignments in the final season dispatched below 18 °C, around 3 °C cooler than earlier seasons
- Supply chain duration more actively managed, with highest consistency achieved in 2023–24
- Improved arrival temperature control observed in 2023–24, indicating better in-transit temperature management

Strawberry

- Reduced average supply chain temperature into the optimal range, from 7.5 °C to 3.7 °C.
- Improved pre-cooling at dispatch, lowering fruit temperature from 8.7 °C to 4.1 °C.
- Lowered arrival temperature through tighter cold chain control, from 9.7 °C to 5.2 °C.
- Improved humidity management across the supply chain, increasing average humidity from 64 % to 83 %.
- Maintained more consistent cold chain conditions from dispatch through to arrival.
- Recognised the need to actively manage supply chain duration and packing windows, not only temperature and humidity.

4.4 Validation of predictive models

Results from consignment monitoring were used to validate the predictive models developed for each variety. The models are available through the Fresh Intel⁴ decision support tool, hosted on the relevant peak industry body websites. For Hass avocado, the models predicted the average time to firm-ripe and medium-ripe stages with an RMSE⁵ of ± 1.3 and ± 1.6 days, respectively. For Shepard avocado, prediction accuracy was ± 3.8 days for firm-ripe and ± 3.0 days for medium-ripe.

⁴ [Calculators | Fresh Intel](#)

⁵ Root Mean Squared Error



Honey Gold mango consignment monitoring data were also used to evaluate model performance. The models predicted average residual shelf life with an accuracy of ± 2.8 days. In addition, the project received temperature and quality assessment data for 19 commercial consignments of R2E2, Kensington Pride, Calypso and Honey Gold mangoes from industry partners.

For these consignments, the time–temperature unit models predicted average residual shelf life with an RMSE of ± 1.4 days for Honey Gold, ± 2.2 days for Kensington Pride, and ± 1.2 days for R2E2. The models developed for Honey Gold, Kensington Pride and R2E2 were also applied to Calypso mango, predicting average residual shelf life within ± 2.3 , ± 3.2 and ± 4.7 days, respectively.

For Red Rhapsody strawberry, the models predicted the average punnet shelf life and then it was transformed to the proportion (%) of fruit having > 7 days of shelf life in a punnet. The RMSE was $\pm 19.8\%$, this was $\pm 24.5\%$ for all three cultivars: Red Rhapsody, Albion and Cabrillo.

The summerfruit models predicted firmness with an RMSE of ± 1.6 at arrival and ± 1.8 after ripening for commercial nectarine consignments. Soluble solids content in the same shipments was predicted with an RMSE of ± 2.0 °Brix at arrival and ± 3.1 °Brix after ripening.

5 Outcome

The overarching aim of this program was to provide industry stakeholders with decision support tools, skills and confidence to better manage supply chain risks and deliver more consistent fresh produce quality. In addition to developing and promoting predictive models and decision aid tools, the program achieved the following outcomes:

- ***Strong industry learning and awareness:***

Endline survey results showed that 95 % of participating growers reported learning something new or improving their knowledge through the AM21000 program, including consignment monitoring. Around 90 % rated their awareness of the importance of real-time monitoring as improved compared with before their involvement in the project.

- ***Growing adoption and intent to adopt real-time monitoring:***

Around 50 % of surveyed growers had already made changes within their businesses, including routine use of real-time supply chain monitoring. Real-time monitoring was ranked as essential by 50 % of growers and important by a further 35 %, while 80 % indicated they were willing to adopt real-time monitoring services.

- ***Improved supply chain insight and decision-making:***

Increased industry awareness and use of real-time monitoring technologies enabled better identification of weaknesses and opportunities for improvement within supply chains.



- ***Standardised quality assessment resources:***

A comprehensive, standardised image library of key quality issues was developed for Hass and Shepard avocado, Honey Gold mango and strawberries. These resources will be made available through relevant peak industry body websites to support consistent quality assessment.

- ***Greater confidence in delivering predictable quality:***

Supply chain participants reported improved knowledge and confidence to deliver more predictable fruit quality to domestic and international markets, supporting stronger alignment with importer, retailer and consumer expectations and contributing to improved market performance.

- ***Improved consistency in outturn assessment:***

Standard outturn quality assessment procedures were established across commodities and markets, supporting more consistent and comparable quality evaluation.

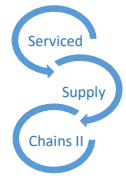
- ***Expanded assessor capability and coverage:***

A trained assessor network was established in Australia and key export markets, supported by fit-for-purpose training materials and tools. This increased industry confidence in independent quality assessment services.

- ***Supporting extension and best-practice materials:***

A series of supporting information products, including articles, factsheets and videos, was developed to communicate the benefits of real-time monitoring and predictive modelling across commodities, varieties and supply chains.

Key outputs from the AM21000 consignment monitoring program included best-practice guidelines, articles, factsheets, an assessor network, and a quality assessment resource kit. A detailed list of outputs and links to these resources is provided in appendices 7-13.



6 Acknowledgments

We thank all of the growers, marketers, wholesalers, exporters, freight forwarders, importers, and quality assessors for participating in and supporting the monitoring activities. This work was part of the broader Serviced Supply Chains II project (AM21000) that was funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland, Department of Energy, Environment and Climate Action, Victoria, Department of Agriculture and Fisheries, Northern Territory, Department of Primary Industries and Regional Development, Western Australia, Pinata Farms Pty Ltd and Summerfruit Australia Ltd.



Appendix 14

NQ 'Hass' avocado simulation trials report 2022

AM21000: Preliminary 2022 results from North Queensland Hass trials

John Archer and Minh Nguyen, Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Hass' avocados to quantify the fruit quality and shelf life response to a range of supply chain handling scenarios. The 2022 season objectives were to assess the storage response of 'Hass' avocado fruit grown in northern Queensland and develop shelf-life prediction models under varied supply chain conditions.

The following factors were investigated: Low temperature storage, storage durations, Controlled atmosphere (CA) storage, Fruit maturity (Dry matter content, DM), Low temperature preconditioning, total temperature units (TTU) and Different harvest times on the impact of shelf life. Key observations included:

Mid-season fruit (May)

- *The average DM was 25.7% standard deviation (SD) 1.7*
- *The remaining shelf life at 20°C varied from 5 to 15.5 days and was least for fruit held at higher storage temperature and/or longer durations.*
- *It was found that there is a relationship between TTU and end of shelf life (ESL)*
- *CA storage increased ESL and reduced chilling injury (CI) compared to non-CA treatments*
- *Storage at 5°C under CA extended shelf life by 1-2 days relative to non-CA treatments*

Late-season fruit (June)

- *The average DM was 26% standard deviation (SD) 1.6*
- *The remaining shelf life at 20°C varied from 0.9 to 9.4 days and was least for fruit held at higher storage temperature and/or longer durations.*
- *It was found that there is a relationship between TTU and end of shelf life (ESL)*
- *CA storage increased ESL and reduced chilling injury (CI) compared to non-CA treatments*
- *Storage at 5°C under CA extended shelf life by 1-2 days relative to non-CA treatments*

The data is being used to generate preliminary shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks. Rot severity and incidence will be compared at soft and firm ripe in future trials.

Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2022 avocado season. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Hass' avocados to various supply chain conditions. The trials also investigated a wide range of factors affecting fruit quality and shelf life, namely controlled atmosphere storage, fruit maturity (dry matter), fruit size and low temperature preconditioning. Data generated from the trials is being used to develop preliminary fruit quality and shelf life prediction models.

Methods

- Fruit were sourced from a grower near Tolga, Qld
- Mid-season and Late-season fruit were harvested in May and June, were count 20 in size and had been dipped in Graduate A.
- Fruit were treated at the Redden St. research station and shelf life was assessed.

All fruit were inspected at arrival for defects and firmness (Appendix 3). Each fruit was given a Serial number and tracked during the experiment. Firmness (via Bareiss) was determined on two marked sides of the fruit. DM was conducted on two sides of the fruit using a FELIX NIR and fruit were divided into treatment groups with matching DM. 'Hass' avocado fruit was subjected to a time x temperature matrix that represented air and sea freight conditions see Appendix 2.

Temperature was monitored from packing to the end of the trial. While fruit were held at 20°C, Hand firmness and rots were checked every 2 days (Hand firmness rating scale Appendix 3). We recorded the date when fruit reached soft ripe stages. Once fruit were soft ripe (Bareiss reading <40), or external rots above 10%, they were end of shelf life (ESL). Fruit were cut in half or quarters to evaluate for colour (1-6) body rot (1-5), stem-end rot (1-5), instances of CI and CI(1-5) see Appendix 1 for photos.

Total temperature units (TTU) combine storage temperature and time into a single value. Fruit stored at higher temperatures accumulate TTU more rapidly than fruit stored at lower temperatures over the same duration.

Unacceptable fruit were fruit where defects were >10%.

Results

- Fruit harvested in May had a DM mean 25.7% SD 1.7. Fruit harvested in June had a DM mean 26% SD 1.6.
- The trial showed good correlation between shelf life and TTU, with May harvest R^2 0.7 and June harvest fitting a linear regression with R^2 0.6. It was found that CA treatment had a different slope showing an increase in ESL compared to non-CA treatment. (Appendix 4 and Appendix 8)

May Harvest

- The longer fruit were kept in storage at cold temperature, the shorter the shelf life at 20°C. (Appendix 5).
- Storage at 5°C under CA extended shelf life by 1-2 days relative to non-CA treatments (Appendix 5).
- The CA treatment was also shown to have reduced CI compared to non-CA treatments (Appendix 11).
- Rots, both stem and body did not seem to be affected by storage duration or temperature. Vascular browning was only detected in low levels (Appendix 5).

June Harvest

- CI was also found to fit with TTU having an R^2 0.74 (Appendix 8).
- It was also found that CA treatment did not fit as they had less CI (Appendix 8).
- Fruit was found to have high levels of CI compared with May harvest.

Conclusion

- The trial demonstrated a relationship between shelf-life and TTU for both harvest dates. This allows for the development of shelf-life tools.
- Controlled atmosphere storage was found to improve shelf life and reduce CI.
- Low temperature preconditioning was found to have minimal benefit in improving CI and reducing unacceptable fruit.

Appendix

Appendix 1 Hass avocado defects

Body rots (1-5)

0% of flesh volume	2% of flesh volume	5% of flesh volume	10% of flesh volume	25%+ of flesh volume
1 	2 	3 	4 	5 
DAF	DAF	DAF	DAF	DAF

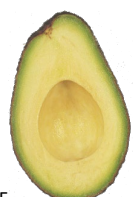
Stem end rots (1-5)

0% of flesh volume	2% of flesh volume	5% of flesh volume	10% of flesh volume	25%+ of flesh volume
1 	2 	3 	4 	5 
DAF	DAF	DAF	DAF	DAF

Chilling injury (1-5)

0% of flesh volume	2% of flesh volume	5% of flesh volume	10% of flesh volume	25%+ of flesh volume
1 	2 	3 	4 	5 
DAF	DAF	DAF	DAF	DAF

Vascular browning (1-5)

0% of flesh volume	2% of flesh volume	5% of flesh volume	10% of flesh volume	25%+ of flesh volume
1 	2 	3 	4 	5 
DAF	DAF	DAF	DAF	DAF

Appendix 2 'Hass' avocado fruit time x temperature matrix that represents air and sea freight conditions

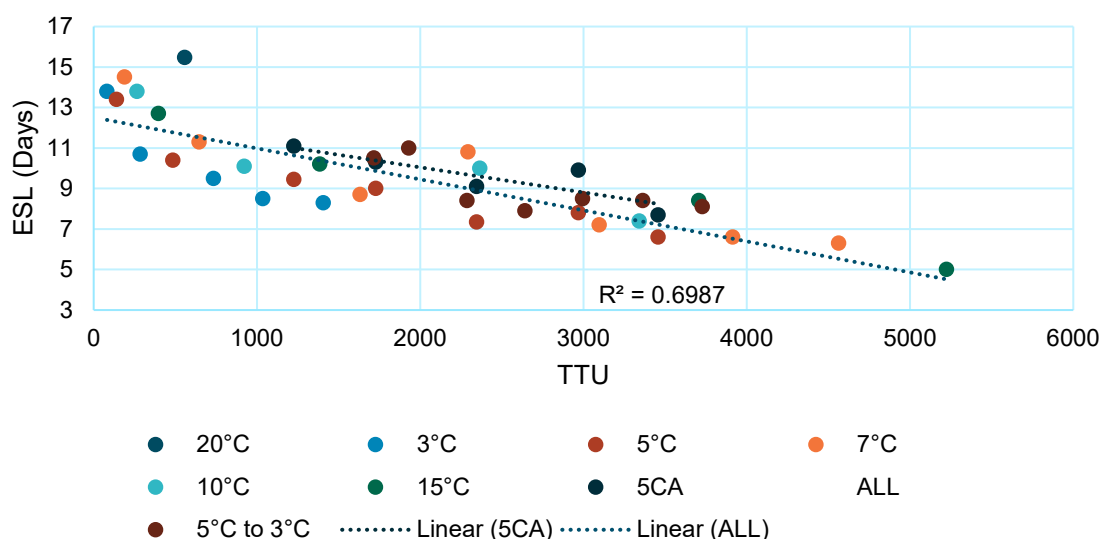
Temp (°C)	Removal time (days) to ongoing 20°C storage						
3	2	5	10	15	20		
5 + 3*	2	5	10	15	20	25	30
5	2	5	10	15	20	25	30
CA5**			10	15	20	25	30
7	2	5	10	15	20	25	30
10	2	5	10	15			
15	2	5	10	15			
20							

* Fruit were preconditioned at 5°C for 5 days and stored at 3°C for the storage time
 ** CA is controlled atmosphere with 2% O₂ and 5 % CO₂
 Relative humidity was maintained at 80 to 90%RH in all temperatures except 20°C which was maintained at 65%

Appendix 3 Relationship between fruit firmness rating, Bareiss number and description

Rating	Bareiss	Description
1	>80	Hard, no 'give' in the fruit with strong thumb pressure
2	70-79	Rubbery (pre-conditioned), slight 'give' with strong thumb pressure
3	50-69	Softening (breaking), flesh deforms 2-3 mm with moderate thumb pressure
4	40-49	Firm ripe, flesh deforms 2-3 mm with slight thumb pressure
5	39 or less	Soft ripe, deforms easily with gently hand pressure

Appendix 4 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures and end of shelf life (ESL) in May harvest 'Hass' avocados



As TTU increase ESL reduces.

Appendix 5 May Harvest “Hass’ avocados end of shelf-life assessments for Weight loss (%), Body rots, Stem End rot, Vascular browning, Chilling Injury, Incidence of Chilling Injury (%) assessed at ESL and ESL (days).

Temperature	duration (days)	Weight loss (%)	Body rots (1-5)	Stem End rot (1-5)	Vascular browning (1-5)	chilling injury (1-5)	Incidence of chilling injury* (%)	*ESL (days)
3°C	2	5.49%	2.9	2.2	1.3	1.0	0%	13.8
	5	5.34%	2.1	1.9	1.0	1.0	0%	10.7
	11	6.74%	1.9	1.1	1.0	1.0	0%	9.5
	15	6.71%	1.6	1.0	1.0	1.9	50%	8.5
	20	6.94%	1.0	1.0	1.0	2.3	60%	8.3
5°C	2	4.77%	1.8	2.0	1.0	1.0	0%	13.4
	5	4.77%	1.6	1.2	1.1	1.0	0%	10.4
	11	7.31%	1.2	1.2	1.0	1.0	0%	9.45
	15	6.94%	1.4	1.3	1.1	1.0	0%	9
	20	6.76%	1.3	1.1	1.2	1.0	0%	7.35
	25	7.32%	1.2	1.1	1.0	1.1	5%	7.8
	30	7.52%	1.6	1.1	1.1	1.5	10%	6.6
5°C CA	11	8.14%	1.9	1.9	1.0	1.0	0%	11.1
	15	7.70%	1.6	1.1	1.0	1.0	0%	10.3
	20	6.67%	1.6	1.2	1.0	1.0	0%	9.1
	25	6.92%	2.1	1.2	1.0	1.0	0%	9.9
	30	6.68%	1.4	1.4	1.0	1.0	0%	7.7
Preconditioning 5°C + 3°C	5+2	5.83%	1.4	1.8	1.0	1.0	0%	10.5
	5+5	7.21%	1.1	1.0	1.0	1.0	0%	11
	5+10	6.05%	1.0	1.0	1.0	1.1	10%	8.4
	5+15	6.53%	1.0	1.1	1.0	1.7	50%	7.9
	5+20	8.20%	1.8	1.0	1.0	1.5	30%	8.5
	5+25	7.58%	1.8	1.1	1.1	1.3	20%	8.4
	5+30	8.10%	1.7	1.1	1.0	2.4	70%	8.1
7°C	2	5.67%	2.5	2.2	1.1	1.0	0%	14.5
	5	5.55%	1.7	1.5	1.0	1.0	0%	11.3
	11	7.11%	1.1	1.0	1.1	1.0	0%	8.7
	15	6.90%	1.3	1.0	1.0	1.0	0%	10.8
	20	6.86%	1.0	1.0	1.0	1.0	0%	7.2
	25	6.89%	1.9	1.1	1.0	1.0	0%	6.6
	30	7.10%	2.2	1.0	1.2	1.0	0%	6.3
10°C	2	5.38%	2.3	2.4	1.0	1.0	0%	13.8
	5	4.92%	1.7	1.7	1.0	1.0	0%	10.1
	11	7.77%	1.5	1.2	1.1	1.0	0%	10
	15	7.17%	1.8	1.2	1.0	1.0	0%	7.4
15°C	2	5.72%	2.6	2.2	1.2	1.0	0%	12.7
	5	5.90%	1.9	2.0	1.1	1.0	0%	10.2
	11	7.99%	2.1	1.6	1.1	1.0	0%	8.4
	15	9.18%	2.8	2.3	1.0	1.0	0%	5
20°C	0	6.84%	2.4	2.4	1.3	1.0	0%	15.5

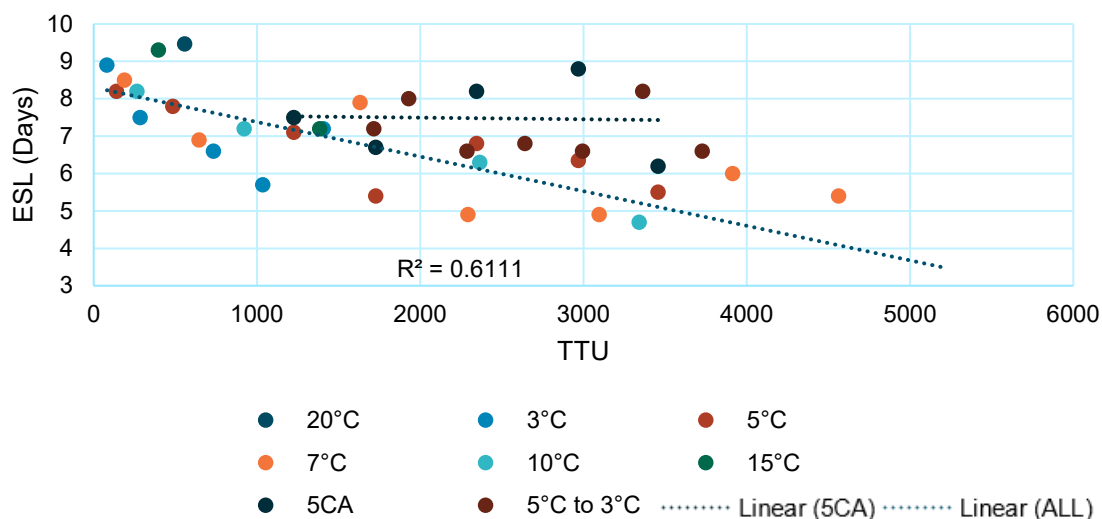
*ESL (days) days after treatment to end of shelf life

Appendix 6 May Harvest days to ESL, Incidence of chilling injury and Incidence Unacceptable fruit

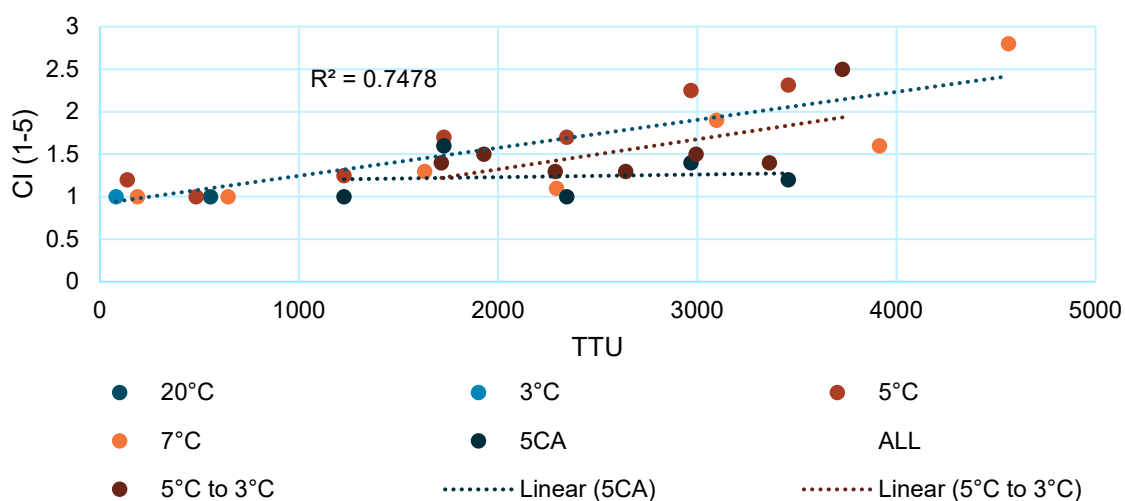
Temperature	Duration (days)	Incidence of chilling injury* (%)	*Unacceptable fruit (%)	**ESL (days)
3°C	2	0%	40%	13.8
	5	0%	20%	10.7
	11	0%	10%	9.5
	15	50%	20%	8.5
	20	60%	0%	8.3
5°C	2	0%	10%	13.4
	5	0%	0%	10.4
	11	0%	0%	9.45
	15	0%	0%	9
	20	0%	0%	7.35
	25	5%	0%	7.8
	30	10%	5%	6.6
5°C CA	11	0%	20%	11.1
	15	0%	0%	10.3
	20	0%	0%	9.1
	25	0%	0%	9.9
	30	0%	0%	7.7
Preconditioning 5°C + 3°C	5+2	0%	0%	10.5
	5+5	0%	0%	11
	5+10	10%	0%	8.4
	5+15	50%	0%	7.9
	5+20	30%	0%	8.5
	5+25	20%	10%	8.4
	5+30	70%	20%	8.1
7°C	2	0%	40%	14.5
	5	0%	10%	11.3
	11	0%	0%	8.7
	15	0%	0%	10.8
	20	0%	0%	7.2
	25	0%	10%	6.6
	30	0%	30%	6.3
10°C	2	0%	20%	13.8
	5	0%	10%	10.1
	11	0%	0%	10
	15	0%	0%	7.4
15°C	2	0%	20%	12.7
	5	0%	20%	10.2
	11	0%	10%	8.4
	15	0%	30%	5
20°C	0	0%	18%	15.475

*Unacceptable fruit were fruit where defects were >10%, ** ESL (days) days after treatment to end of shelf life.

Appendix 7 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures and end of shelf life (ESL) in June Harvest “Hass’ avocados



Appendix 8 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures and chilling injury (CI) in June Harvest “Hass’ avocados



Appendix 9 June Harvest “Hass’ avocados end of shelf life assessments for Weight loss, Body rots, Stem End rot, Vascular browning, Chilling Injury, Incidence of Chilling Injury and ESL

Temperature	Duration (days)	Weight loss (%)	Body rots (1-5)	Stem End rot (1-5)	Vascular browning (1-5)	chilling injury (1-5)	Incidence of chilling injury* (%)	*ESL (days)
3°C	2	6.17%	2.1	1.2	1.0	1.0	0%	8.9
	5	5.70%	2.0	1.0	1.0	1.0	10%	7.5
	11	6.22%	2.8	1.4	1.2	1.0	10%	6.6
	15	6.03%	1.0	1.0	1.1	1.4	30%	5.7
	20	6.56%	1.8	1.2	1.4	1.4	10%	7.2
5°C	2	5.61%	2.0	1.2	1.0	1.2	10%	8.2
	5	6.56%	1.3	1.4	1.2	1.0	0%	7.8
	11	4.12%	2.1	1.8	1.3	1.3	15%	7.1
	15	4.52%	1.6	1.2	1.2	1.7	30%	5.4
	20	4.54%	2.6	2.2	1.1	1.7	25%	6.8
	25	5.25%	2.6	1.7	1.1	2.3	50%	6.35
	30	5.53%	3.4	1.8	1.3	2.3	60%	5.5
5°C CA	11	6.22%	1.7	1.6	1.0	1.0	0%	7.5
	15	6.58%	1.8	1.7	1.0	1.6	20%	6.7
	20	8.01%	2.4	2.2	1.0	1.0	0%	8.2
	25	8.63%	4.3	3.0	1.0	1.4	10%	8.8
	30	7.30%	2.5	2.0	1.0	1.2	10%	6.2
Preconditioning 5°C to 3°C	5+2	6.21%	2.4	1.4	1.1	1.4	10%	7.2
	5+5	6.20%	1.9	1.8	1.5	1.5	40%	8
	5+10	6.95%	1.7	1.4	1.0	1.3	20%	6.6
	5+15	7.74%	1.3	1.2	1.0	1.3	20%	6.8
	5+20	7.43%	1.1	1.1	1.2	1.5	20%	6.6
	5+25	9.12%	1.8	1.2	1.3	1.4	40%	8.2
	5+30	10.44%	3.3	1.4	1.1	2.5	60%	6.6
7°C	2	6.69%	2.1	1.5	1.1	1.0	0%	8.5
	5	6.19%	1.2	1.1	1.0	1.0	0%	6.9
	10	6.64%	1.8	1.7	1.4	1.3	10%	7.9
	15	7.45%	1.4	1.2	1.0	1.1	10%	4.9
	20	7.60%	2.6	1.2	1.8	1.9	50%	4.9
	25	8.48%	2.6	1.4	1.4	1.6	40%	6
	30	10.12%	4.1	1.4	2.6	2.8	70%	5.4
10°C	2	6.47%	2.5	1.2	1.0	1.0	0%	8.2
	5	5.62%	2.2	1.3	1.0	1.0	0%	7.2
	11	8.74%	3.9	2.2	1.7	1.8	40%	6.3
	15	7.76%	2.7	2.1	1.4	1.0	0%	4.7
15°C	2	6.34%	1.8	1.6	1.3	1.0	0%	9.3
	5	6.72%	2.7	1.2	1.0	1.0	0%	7.2
	10	5.62%	2.9	1.8	1.0	1.0	0%	2.5
	15	5.66%	2.4	2.1	1.4	1.3	20%	0.9
20°C	0	6.66%	2.6	1.7	1.0	1.0	0%	9.4

• * ESL (days) days after treatment to end of shelf life.

Appendix 10 June Incidence of chilling injury, unacceptable fruit ESL

Temperature	duration (days)	Incidence of chilling injury* (%)	*Unacceptable fruit (%)	**ESL (Days)
3°C	2	0%	10%	8.9
	5	10%	0%	7.5
	11	10%	30%	6.6
	15	30%	0%	5.7
	20	10%	20%	7.2
5°C	2	10%	10%	8.2
	5	0%	0%	7.8
	11	15%	20%	7.1
	15	30%	15%	5.4
	20	25%	35%	6.8
	25	50%	50%	6.35
	30	60%	55%	5.5
5°C CA	11	0%	10%	7.5
	15	20%	20%	6.7
	20	0%	30%	8.2
	25	10%	90%	8.8
	30	10%	30%	6.2
Preconditioning 5°C to 3°C	5+2	10%	30%	7.2
	5+5	40%	40%	8
	5+10	20%	10%	6.6
	5+15	20%	0%	6.8
	5+20	20%	10%	6.6
	5+25	40%	0%	8.2
	5+30	60%	50%	6.6
7°C	2	0%	10%	8.5
	5	0%	0%	6.9
	10	10%	20%	7.9
	15	10%	0%	4.9
	20	50%	40%	4.9
	25	40%	50%	6
	30	70%	80%	5.4
10°C	2	0%	20%	8.2
	5	0%	10%	7.2
	11	40%	70%	6.3
	15	0%	30%	4.7
15°C	2	0%	20%	9.3
	5	0%	20%	7.2
	10	0%	30%	2.5
	15	20%	30%	0.9
20°C	0	0%	20%	9.4

*Unacceptable fruit were fruit where defects were >10%, ** ESL (days) days after treatment to end of shelf life.

Appendix 11 Incidence of chilling injury, unacceptable fruit at ESL for CA May Harvest

Temperature	Duration (days)	Incidence of chilling injury* (%)	Unacceptable fruit (%)	Days after Treatment
5C	11	0%	0%	9.45
	15	0%	0%	9
	20	0%	0%	7.35
	25	5%	0%	7.8
	30	10%	5%	6.6
5C + CA	11	0%	20%	11.1
	15	0%	0%	10.3
	20	0%	0%	9.1
	25	0%	0%	9.9
	30	0%	0%	7.7

Appendix 12 Incidence of chilling injury, unacceptable fruit at ESL for CA June Harvest

Temperature	Duration (days)	Incidence of chilling injury* (%)	Unacceptable fruit (%)	ESL Days after Treatment
5°C	11	15%	20%	7.1
	15	30%	15%	5.4
	20	25%	35%	6.8
	25	50%	50%	6.35
	30	60%	55%	5.5
5°C + CA	11	0%	10%	7.5
	15	20%	20%	6.7
	20	0%	30%	8.2
	25	10%	90%	8.8
	30	10%	30%	6.2

Appendix 15

CQ 'Hass' avocado simulation trials report 2022a

Predicting fruit quality and shelf life for 'Hass' avocado

A 2022 season Central Queensland grower report

Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish, Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Hass' avocados to quantify the fruit quality and shelf life response to a range of supply chain handling (i.e. 3, 5, 7, 10, 15°C x 5, 10, 15, 20, 25, 30 days) scenarios. Commercially mature fruit of different size were harvested during the mid- and late-season from a farm near Childers, Queensland in 2022. The influence of controlled atmosphere (CA) storage and low temperature pre-conditioning treatments on fruit quality were also evaluated. Key observations included:

Mid-season fruit

- The average dry matter content of mid-season large and small fruit was 27.4% and 29%, respectively.
- The firmness of fruit stored at 10°C or less remained largely unchanged for 20 days.
- The remaining shelf life at 20°C varied from 4.7 to 11.4 days and was least for fruit held at higher storage temperature and/or longer durations.
- Body rot and stem-end rot were evident in fruit flesh when evaluated at the soft ripe stage.
- Body rot severity in small fruit was similar to that of large fruit, but its incidence was somewhat lower.
- Minor chilling injury was detected in fruit stored at 5°C and 7°C after 20 days of storage.
- The incidence of fruit with more than 10% combined flesh volume affected by defects (e.g. body rot, stem-end rot, chilling injury) was 25.4% for large and 18.6% for small avocados.
- CA storage reduced fruit weight loss, rot development and chilling injury as compared to ambient air storage but was only consistently extended fruit shelf life when the storage exceeded 25 days.

Late-season fruit

- Fruit picked at the late harvest had an average dry matter content of 31.6%.
- The remaining shelf life at 20°C varied between 2.0 and 9.3 days, depending on the preceding storage temperature and duration.
- Chilling injury was prevalent on fruit stored at 5°C after just 15 days of storage.
- Body rot and stem-end rot were still a big issue for late-harvest fruit with the infected volume of body rot varying from 1.4% to 26.5% while rot incidence ranged from 30% to 100% at soft ripe.
- The incidence of fruit with >10% combined internal defects at the soft ripe stage was lower in CA (20%) versus air (78%) stored samples.
- Fruit at the firm ripe stage plus 2 days exhibited lower severity and incidence of both body rot and stem-end rot as compared to those examined at soft ripe.

The data is being used to generate preliminary shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks. Rot severity and incidence will be compared at soft and firm ripe in future trials.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2022 avocado season with a Central Queensland (CQ) farm. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Hass' avocados to various supply chain conditions. The trials also investigated a wide range of factors affecting fruit quality and shelf life, namely controlled atmosphere storage, fruit maturity (dry matter), fruit size and low temperature preconditioning. Data generated from the trials is being used to develop preliminary fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature (e.g. dry matter $\approx 27\text{--}31\%$) 'Hass' avocado fruit were sourced for trials during the 2022 season. Mid-season fruit were picked on 28 June while late-season fruit were harvested from a different block on 9 August at farms near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby pack shed on the same day. On the following day, they were treated with a fungicide, sorted by size and quality, and packed into cardboard trays. For the mid-season harvest, large (size 20) and small (size 30) fruit were collected while only large fruit were sourced for the late harvest. Packed fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car at ca. $22\text{--}25^\circ\text{C}$ within 3 hours and kept overnight at 20°C .

At the laboratory, the dry matter (DM) content was determined for individual fruit using near-infrared spectroscopy (NIR) via a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. A sticky label with NIR readings was temporally attached to each fruit and the fruit were grouped into DM categories that differed by 1% DM. The categorised fruit were then assigned randomly and evenly to treatment trays, each consisting of ten fruit. This was to make sure that every tray contains a normal distribution of the DMs in the population supplied. A small sub-set of fruit were also assessed for DM using the traditional oven drying method.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and seafreight conditions as shown in **Table 1**. A set of fruit were preconditioned at 5°C for 5 days and then shifted to 3°C for up to 30 days. In addition, other fruit were stored under controlled atmosphere (CA) with 2% O_2 and 5% CO_2 at 5°C for 30 days. Two trays of fruit were kept at 20°C as a control. Actual removal times may differ from those specified in Table 1 due to avoiding weekend work.

The air temperature adjacent to fruit was monitored from the time of collection from the pack shed to removal from the storage temperatures to calculate time x temperature unit (TTU) for predicting remaining shelf life at 20°C . Relative humidity (RH) inside cold rooms was maintained at 90% so that only temperature and time affected the shelf life. RH was held at 65% in a 20°C room to mimic retail conditions.

Fruit weight and firmness were measured at the beginning, removal from storage and end of shelf life (ESL) using a balance and fruit firmness durometer (Bareiss), respectively. A hand firmness rating scale was also used to determine when fruit reached firm ripe or soft ripe. The fruit were not treated with ethylene to ripen. Fruit quality (i.e. fruit firmness, rots and defects) was checked every 2 or 3 days. The fruit was considered to reach ESL when it was either at soft ripe (Bareiss reading <40) or developed rots with more than 10% surface areas. Once the fruit reached ESL, it was cut in half, the seed and skin were removed and the severity of body rot, stem-end rot and chilling injury was assessed and expressed in percentage of affected area. In late harvest fruit, an additional set of fruit was used to cut in half at firm ripe stage to compare the extent of rot development with those examined at soft ripe.

Table 1. Time x temperature matrix used to simulate supply chain handling of 'Hass' avocado fruit.

Storage temperature (°C)	Removal time (days) to ongoing 20°C storage					
3	5	10	15	20		
5 + 3*	5	10	15	20	25	30
5	5	10	15	20	25	30
CA5**		10	15	20	25	30
7	5	10	15	20	25	30
10	5	10	15			
15	5	10	15			
20						

* Fruit were preconditioned at 5°C for 5 days and stored at 3°C

** CA is controlled atmosphere with 2% O₂ and 5% CO₂

3. Results

3.1 Mid harvest fruit

Fruit firmness

Fruit picked at mid harvest had an average oven DM of 27.4% and 29% for large and small fruit, respectively. NIR predicted DM was 28.1% for the large fruit and 29.2% for small avocado. There was a good relationship between oven DM and NIR predicted DM ($R^2=0.76$, data not shown).

Changes in fruit firmness during storage at different temperature is presented in **Figure 1**. The firmness of fruit stored at 10°C or below remained unchanged after 20 days. Thereafter, it dropped slightly and stayed at the rubbery stage until the end of cold storage. The firmness of fruit stored at 15°C declined dramatically with an increase in storage duration.

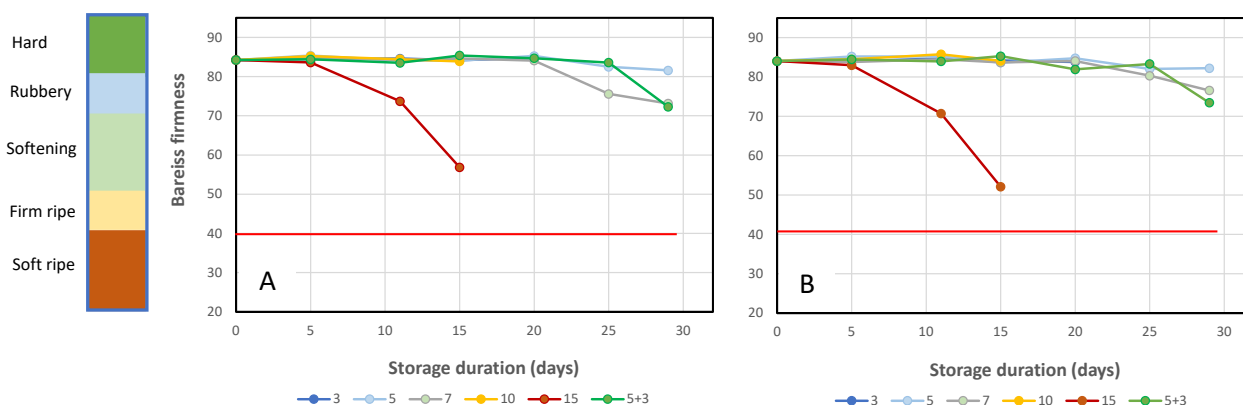


Figure 1. Changes in fruit firmness of large size (A) and small (B) avocado during storage at various temperatures

Weight loss and remaining shelf life

Fruit weight loss at cold removal increased with storage time and temperature, ranging from 0.6% to 4.3% (**Table 2**). There was no difference in weight loss at cold removal between the large and small fruit. Fruit weight loss continued when held at 20°C. The fruit lost between 6.5% and 9.4% of initial weight by the end of shelf life. Upon transfer to 20°C, fruit reached firm ripe in 0.8 to 6.3 days. The remaining shelf life of fruit at 20°C varied from 4.7 to 11.4 days, depending on the storage temperature and duration. As a rule, remaining shelf life was reduced for fruit held at higher storage temperature and longer durations. For example, fruit stored at 15°C for 15 days only displayed 1 day of shelf life at 20°C.

Rot development and chilling injury

Body rot and stem-end rot were the main diseases found in avocado flesh. There was no clear temperature effect on rot development. The infected volume of body rot in large fruit varied from 0.8% to 28.5% (6.5% on average) whereas rot incidence was from 10% to 100% (**Table 3**). The severity of body rot in small fruit was similar to that of large fruit, but its incidence was somewhat lower. The affected area and incidence of stem-end rot in both fruit sizes was greatly lower than body rot. Minor chilling injury was detected on the fruit stored at 5°C and 7°C after 20 days of storage, especially with large fruit. It is possible that small fruit was more tolerant to chilling injury than large fruit. The incidence of fruit with more than 10% combined flesh volume affected by defects (e.g. body rot, stem-end rot, chilling injury) was 25.4% for large and 18.6% for small avocados (**Table 3**).

Fruit quality under ambient air versus controlled atmosphere (CA)

Fruit quality of avocado stored under ambient air and CA at 5°C is shown in **Table 4**. CA storage helped reduce fruit weight loss by 0.5% as compared to ambient storage. CA storage was only beneficial in consistently extending fruit shelf life when the storage exceeded 25 days. CA also prevented rot development and chilling injury. The incidence of fruit with more than 10% combined defects was reduced by CA storage from 34% and 38% in ambient air to 22% and 20% in small and large avocados, respectively (**Table 5**).

Table 2. Weight loss of ‘Hass’ avocado evaluated at cold removal, at the end of shelf life and remaining shelf life at 20°C under varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Wt loss at removal (%)		Wt loss at ESL (%)		Days to firm ripe		Remaining shelf life at 20°C (day)	
		L size	S size	L size	S size	L size	S size	L size	S size
3	5	0.6	0.5	7.0	7.2	5.7	6.2	9.0	9.8
	11	1.1	0.9	7.7	8.3	4.3	4.9	9.2	10.4
	15	1.3	1.2	7.5	8.8	5.4	6.1	9.1	11.4
	20	1.6	1.7	7.2	8.7	4.7	4.6	9.0	9.1
5 + 3	11	1.1	1.1	7.3	8.5	4.8	4.8	8.4	9.5
	15	1.3	1.3	7.8	8.5	5.0	4.6	9.7	10.9
	20	1.5	1.7	7.5	8.0	4.8	4.3	9.6	8.4
	25	1.9	2.0	7.5	7.7	3.9	3.4	7.8	7.2
	29	2.1	2.3	7.2	7.7	4.7	4.1	8.0	6.7
	35	2.8	2.8	8.9	9.1	3.4	3.0	7.1	6.8
5	5	0.6	0.6	7.4	7.8	5.6	5.1	9.0	9.1
	11	1.3	1.1	7.5	8.8	3.7	4.1	9.1	10.7
	15	1.6	1.5	7.5	9.0	4.2	4.2	8.9	10.5
	20	1.7	1.7	7.6	8.5	4.3	4.2	8.6	9.8
	25	2.2	2.2	8.4	9.4	3.5	4.4	8.4	8.6
	29	2.4	2.3	7.0	8.3	3.4	4.5	6.6	8.3
7	5	0.7	0.7	7.3	7.6	6.3	5.7	10.0	10.2
	11	1.2	1.3	7.1	8.3	4.2	4.8	9.0	10.2
	15	1.5	1.7	6.7	7.6	4.6	4.0	9.1	8.2
	20	2.1	1.8	7.7	7.9	3.8	4.2	7.6	9.0
	25	2.5	2.3	7.8	7.8	2.5	4.0	7.3	7.7
	29	2.7	2.7	6.6	7.7	3.2	4.0	5.7	6.7
10	5	0.7	0.7	6.6	8.3	5.7	6.5	9.2	10.9
	11	1.4	1.3	7.7	8.3	4.8	5.0	9.0	10.4
	15	1.8	1.8	7.2	8.2	3.8	4.7	7.9	9.5
15	5	1.2	1.2	6.5	8.0	4.1	4.8	8.5	10.1
	11	2.8	2.9	6.6	8.7	1.8	2.1	6.6	8.2
	15	4.1	4.3	7.8	7.8	1.1	0.8	5.2	4.7
AVE		1.7	1.7	7.4	8.2	4.2	4.4	8.3	9.0
20		N/A	N/A	7.5	8.2	6.4	6.5	11.1	10.6

Table 3. Severity and incidence of body rot, stem-end rot and chilling injury from ‘Hass’ mid-harvested avocado evaluated at the end of shelf life after exposure to varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Body rot				Stem-end rot				Chilling injury				Incidence of fruit with >10% combined defect	
		Affected volume (%)		Incidence (%)		Affected volume (%)		Incidence (%)		Affected volume (%)		Incidence (%)			
		L size	S size	L size	S size	L size	S size	L size	S size	L size	S size	L size	S size	L size	S size
3	5	4.4	1.5	40	10	0.2	0.0	20	0	0.0	0.0	0.0	0	20.0	10.0
	11	2.3	2.7	50	30	0.3	0.0	10	0	0.0	0.0	0.0	0	10.0	10.0
	15	2.8	7.3	50	70	0.0	1.8	0	40	0.0	0.0	0.0	0	0.0	30.0
	20	1.2	2.0	60	30	0.1	1.2	10	20	0.0	0.2	0.0	10	0	10
5 + 3	11	1.7	1.0	30	30	0.0	3.0	0	10	0.0	0.0	0	0	0	10
	15	6.9	5.5	50	60	0.4	3.6	20	30	0.0	0.0	0	0	30	20
	20	4.3	3.3	70	40	1.9	0.0	20	0	0.2	0.0	10	0	30	10
	25	2.3	0.7	50	20	0.2	0.0	10	0	0.4	0.8	10	10	0	0
	29	1.6	1.4	40	40	0.4	0.0	10	0	0.7	1.0	20	10	10	0
	35	6.1	1.0	80	40	0.1	1.0	10	10	5.5	0.8	20	10	20	10
5	5	4.6	7.7	40	20	0.0	0.6	0	20	0.0	0.0	0	0	20	10
	11	2.9	2.5	50	40	0.7	1.9	10	30	0.0	0.0	0	0	10	20
	15	3.2	5.8	50	60	1.3	1.3	40	30	0.0	0.0	0	0	10	20
	20	14.2	14.2	60	70	3.9	3.0	40	30	3.0	0.1	40	10	60	40
	25	20.4	12.7	80	70	3.3	5.2	60	60	4.8	1.0	50	40	70	50
	29	9.2	12.2	90	70	0.0	2.4	0	40	12.7	1.7	50	20	40	40
7	5	3.7	1.0	60	30	0.8	0.1	20	10	0.0	0.0	0	0	10	0
	11	5.4	1.4	50	40	0.6	1.9	20	30	0.0	0.0	0	0	30	10
	15	4.0	8.1	70	40	2.1	2.5	30	20	0.0	1.5	0	10	20	20
	20	8.1	0.8	60	30	0.9	0.0	20	0	4.5	0.0	20	0	30	0
	25	26.1	0.4	70	20	2.5	0.0	30	0	12.9	0.8	70	10	70	10
	29	4.9	6.5	60	30	0.0	1.0	0	10	4.9	3.0	40	10	40	30
10	5	1.9	0.8	50	20	0.0	0.0	0	0	0.0	0.0	0	0	0	0
	11	4.5	7.2	70	50	0.4	2.2	10	30	0.0	0.0	0	0	10	30
	15	5.9	5.9	80	60	0.5	0.0	10	0	2.2	0.0	30	0	40	10
15	5	2.8	14.7	60	80	0.0	1.2	0	20	0.0	0.0	0	0	10	30
	11	5.9	21.7	70	100	1.3	5.4	20	60	0.0	0.0	0	0	30	50
	15	28.5	21.5	100	80	1.7	3.3	40	50	2.7	5.4	30	40	90	40
AVE		6.8	6.1	60.4	45.7	0.8	1.5	16.4	19.6	1.9	0.6	13.9	6.4	25.4	18.6
20		5.7	2.7	70	65	0.6	0.5	25	10	0.0	0.0	0	0	10	10

Table 4. Comparison of “Hass” avocado quality under ambient air and controlled atmosphere storage at 5°C for 29 days.

Storage duration (day)	Wt loss at removal (%)				Shelf life from intake (day)			
	L size		S size		L size		S size	
	Air	CA	Air	CA	Air	CA	Air	CA
11	1.3	1.0	1.1	0.8	9.1	10.6	10.7	10.4
15	1.6	1.2	1.5	1.0	8.9	9.5	10.5	10.8
20	1.7	1.4	1.7	1.4	8.6	9.0	9.8	10.0
25	2.2	1.6	2.2	1.5	8.4	7.5	8.6	9.8
29	2.4	1.7	2.3	1.7	6.6	9.1	8.3	9.6
AVE	1.9	1.4	1.8	1.3	8.3	9.1	9.6	10.1

Shelf-life models

The mid-season ‘Hass’ avocado time x temperature trial captured data that clearly showed how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) for the mid harvest fruit showed an acceptable linear regression ($R^{21}=0.77$ for large fruit and 0.53 for small fruit, **Figure 2**) although shelf life prediction accuracy for small varied with temperature (e.g. at 5+3°C and 15°C). The trial needs to be repeated to confirm the model accuracy. In predicting shelf life, we considered DM as another independent factor which influences fruit shelf life; the higher DM, the shorter the shelf life. However, it was not the case in this trial. As illustrated in **Figure 2**, the small fruit having a DM of 29% had a longer shelf life (0.8 day) in comparison with large fruit which had a DM of 27.4%.

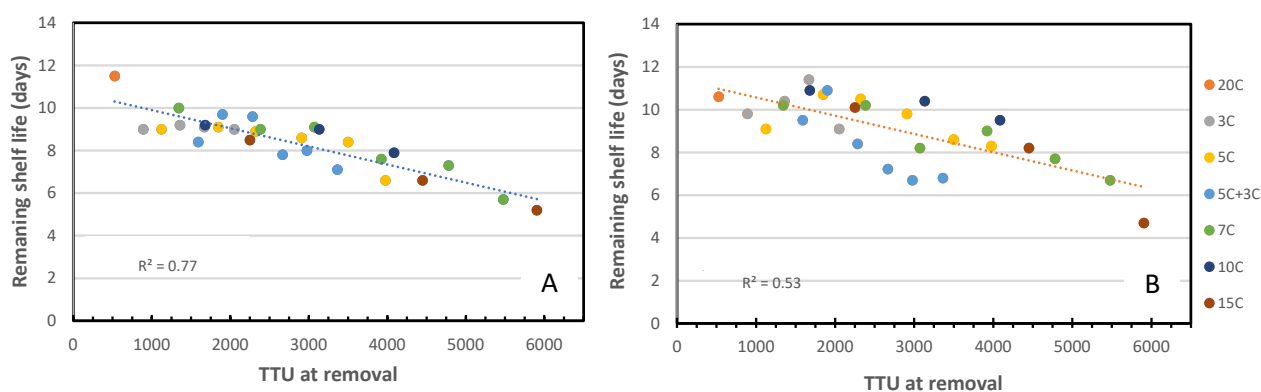


Figure 2. Relationship between temperature time units (TTUs) from picking time at pack shed to the cold removal at various temperatures and remaining shelf life (tray averages) of large (A) and small (B) ‘Hass’ fruit at mid harvest.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

Table 5. Severity and incidence of body rot, stem-end rot and chilling injury from 'Hass' mid-harvested avocado under ambient air and controlled atmosphere storage at 5°C for 29 days.

Large fruit

Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)		
11.0	2.9	50	5.7	70	0.7	10	0.5	20	0	0	0	0	10	40
15.0	3.2	50	5.6	40	1.3	40	0	0	0	0	0	0	10	20
20.0	14.2	60	1.4	50	3.9	40	0	0	3	40	0	0	60	0
25.0	20.4	80	3.6	40	3.3	60	0.2	10	4.8	50	0	0	70	10
29.0	9.2	90	6.6	60	0.0	0	1.0	10	12.7	50	0.3	10	40	30
AVE	10.0	66	4.6	52	1.8	30	0.3	8	4.1	28	0.1	2	38	20

Small fruit

Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)	Affected volume (%)	Incidence of fruit with any affected (%)		
11.0	2.5	40	4.2	30	2	30	0.8	20	0	0	0	0	20	30
15.0	5.8	60	12.1	70	1	30	3.2	40	0	0	0	0	20	50
20.0	14.2	70	1.5	40	3	30	1.8	20	0	10	0	0	40	20
25.0	12.7	70	1.0	40	5	60	0	0	1	40	0	0	50	0
29.0	12.2	70	1.4	30	2	40	0.4	10	2	20	0	0	40	10
AVE	9.5	62	4.0	42	2.8	38	1.2	18	0.6	14	0	0	34	22

3.2 Late harvest fruit

Fruit firmness

Fruit picked at the late harvest had an average oven DM of 31.6% while the NIR predicted DM of 30.7%.

Changes in fruit firmness under various storage temperature is presented in **Figure 3**. The firmness of fruit stored at 10°C or below remained unchanged after 20 days and then dropped slightly by the end of cold storage, except for those maintained at 3°C and 5+3°C. Fruit stored at 15°C reached the end of shelf life after 15 days of storage.

Weight loss, days to firm ripe and remaining shelf life

Weight loss of fruit at cold removal increased with storage time and temperature, ranging from 0.5% to 4.3% (**Table 6**). Weight loss accelerated when fruit were transferred to 20°C. The fruit lost between 6% and 9.5% of initial weight by the end of shelf life. It took between 1.7 and 5.5 days for fruit to reach firm ripe once removed from cold storage, except for those stored at 15°C for longer than 5 days. The remaining shelf life at 20°C varied between 2 to 9.3 days, depending on the preceding storage temperature and duration. As a rule, shelf life at 20°C was reduced in association with higher temperature and longer storage duration. For example, fruit stored at 15°C for 15 days had a two-day shelf life at 20°C.

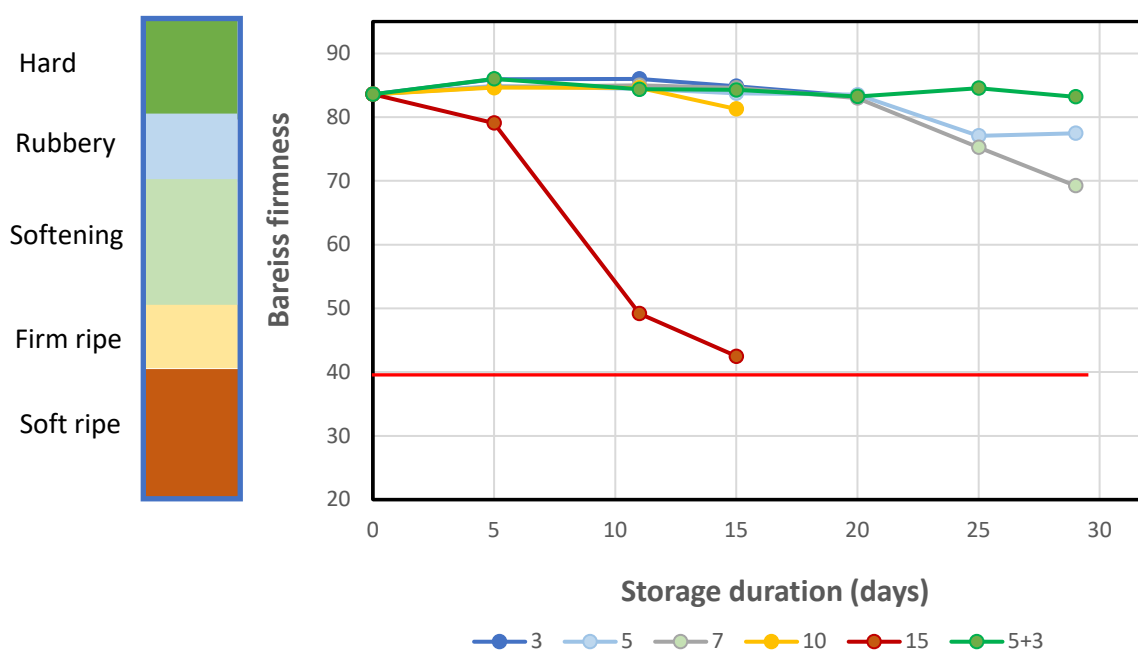


Figure 3. Changes in fruit firmness of 'Hass' avocado picked at late harvest during storage at various temperatures

Rot development and chilling injury

Body rot and stem-end rot were still a big issue for late-harvest fruit. There was no clear temperature effect on rot development. The rot was likely present as a latent infection inside the fruit before harvest. The infected volume of body rot varied from 1.4% to 26.5% (9.7 % average) whereas rot incidence was from 30% to 100% (80.7% average, **Table 7**). The affected area and incidence of stem-end rot was significantly smaller than body rot. Chilling injury was prevalent on the fruit stored at 5°C after 15 days of storage.

*Fruit quality under ambient air versus controlled atmosphere (CA)*

Fruit quality of 'Hass' avocado stored under ambient air and CA at 5°C is illustrated in **Table 8**. CA storage had only benefit in extending fruit shelf life after 25 days as compared to ambient storage. CA also prevented body rot development and chilling injury. The incidence of fruit with >10% combined internal defects at the soft ripe stage was lower in CA (20%) versus air (78%).

Rot severity and incidence of the fruit examined at firm rip stage + 2 days versus at soft ripe

The fruit at firm ripe stage plus 2 days had a lower severity and incidence of both body rot and stem-end rot as compared to those examined at soft ripe stage (**Table 9**). Also, the incidence of fruit with >10% combined defects when examined at firm ripe plus 2 days was less than when checked at soft ripe.

Table 6. Weight loss of ‘Hass’ avocado evaluated at cold removal, at the end of shelf life and remaining shelf life at 20°C under varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Wt loss at removal (%)	Wt loss at ESL (%)	Days to firm ripe at 20°C	Remaining shelf life at 20°C (day)
3	5	0.6	7.3	5.0	8.3
	11	1.1	7.5	5.1	8.2
	15	1.5	7.7	4.0	8.0
	20	1.7	7.1	4.0	6.8
5 + 3	11	1.1	8.6	4.8	9.3
	15	1.4	7.2	3.7	7.8
	20	1.9	8.6	3.9	8.0
	25	2.3	8.7	3.4	8.0
	29	2.7	8.9	3.0	7.7
	35	3.4	9.5	3.3	7.5
5	5	0.7	8.5	5.5	9.0
	11	1.5	8.5	4.1	8.9
	15	1.8	8.8	3.3	8.4
	20	2.3	8.7	3.9	8.1
	25	2.7	8.8	3.5	8.5
	29	3.1	8.0	2.4	5.9
7	5	0.6	6.8	5.2	8.7
	11	1.3	7.6	4.6	7.7
	15	1.6	7.7	3.8	7.8
	20	2.1	9.0	4.0	8.6
	25	2.6	7.9	3.0	6.5
	29	2.7	7.3	1.7	6.0
10	5	0.7	7.0	5.2	8.7
	11	1.3	7.3	4.3	7.6
	15	1.9	7.7	3.1	7.4
15	5	1.6	7.1	3.3	6.7
	11	3.4	6.3	0.2	3.7
	15	4.3	6.0	0.0	2.0
AVE		1.9	7.9	3.6	7.5
20		N/A	7.9	6.3	9.4

Table 7. Severity and incidence of body rot, stem-end rot and chilling injury from ‘Hass’ late-harvested avocado evaluated at the end of shelf life after exposed to varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Body rot		Stem-end rot		Chilling injury		Incidence of fruit with >10% combined defect
		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	
3	5	3.4	60	0	0	0	0	20
	11	9.7	70	0	0	0	0	30
	15	3.3	90	0	0	0	0	10
	20	1.4	60	0	0	6	10	10
5 + 3	11	18.4	100	0.2	10	0	0	40
	15	4.6	90	0.5	10	1.8	20	30
	20	6.3	90	0.5	30	0	0	20
	25	10.3	100	0.5	30	0.4	20	50
	29	6.2	90	0	0	1.5	20	20
	35	5.7	50	0	0	1.2	40	20
5	5	4.6	70	0	0	0	0	10
	11	19.3	90	0.9	20	2.5	30	70
	15	17.0	80	1.1	30	2.2	20	70
	20	12.5	100	0.4	30	2.0	40	60
	25	26.4	100	0.9	40	13.9	50	90
	29	22.2	100	7.1	30	16.7	60	100
7	5	1.4	50	0	0	0	0	0
	11	4.8	60	0	0	0	0	30
	15	5.4	100	0.9	30	0	0	30
	20	19.2	100	0.8	50	0	0	60
	25	12.5	90	0	0	10.2	30	50
	29	16.4	100	1.0	30	13.2	40	50
10	5	1.4	60	0	10	0	0	0
	11	10.4	70	0	20	0	0	50
	15	6.3	100	0	10	1.3	30	30
15	5	1.3	30	0.2	10	0	0	0
	11	5.9	70	0.1	10	0	0	20
	15	14.3	90	1.1	30	0	0	50
AVE		9.7	80.7	0.6	15.4	2.6	14.6	36.4
20		2.1	40	0	0	0	0	5

Table 8. Comparison of ‘Hass’ avocado quality under ambient air and controlled atmosphere storage at 5°C for 29 days.

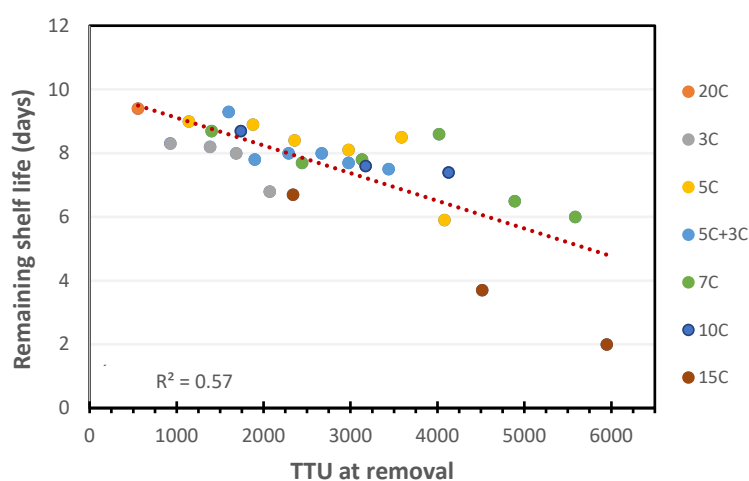
Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		
11.0	19.3	90	5.0	90.0	0.9	20	0.3	20	2.5	30	0.0	0	70	20
15.0	17.0	80	12.7	90.0	1.1	30	0.1	10	2.2	20	0.0	0	70	30
20.0	12.5	100	13.1	100.0	0.4	30	1.0	30	2.0	40	0.0	0	60	40
25.0	26.4	100	1.8	70.0	0.9	40	0.1	10	13.9	50	0.0	0	90	0
29.0	22.2	100	3.3	90.0	7.1	30	0.0	0	16.7	60	0.8	10	100	10
AVE	19.5	94.0	7.2	88.0	2.1	30.0	0.3	14.0	7.5	0.2	0.2	2.0	78.0	20.0

Table 9. Comparison of rot development on ‘Hass’ avocado at two different firmness stages.

Storage temperature (°C)	Storage duration (day)	Firm ripe + 2 days					Soft ripe				
		Body rot		Stem-end rot		>10% combined defect	Body rot		Stem-end rot		>10% combined defect
		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	
5	20	5.8	100	0.2	20	20	10.9	100	1.1	50	70
7	20	7.1	100	0.2	20	20	7.9	100	0.4	40	20
10	15	3.4	100	0.3	30	0	5.6	100	0.3	20	20
15	11	5.0	70	0.7	20	20.0	9.3	90	1.5	70	40
AVE		5.3	92.5	0.4	22.5	15.0	8.4	97.5	0.8	45.0	37.5

Shelf-life models

The late harvested ‘Hass’ avocado time x temperature trial captured good quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) for late harvest fruit showed an acceptable linear regression ($R^2 = 0.56$ ², **Figure 4**) although shelf life prediction accuracy varied with temperature (e.g. at 15°C). In predicting shelf life, we have considered DM as another independent factor which influence fruit shelf life, the higher DM, the shorter the shelf life. Late fruit had about 4% higher DM than mid harvest fruit. This resulted in a shorter shelf life (1.7 days at 20°C).

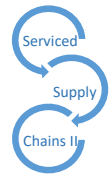
Figure 4. Relationship between temperature time units (TTUs) from picking time at pack shed to the cold removal at various temperatures and remaining shelf life of ‘Hass’ fruit at late harvest.

4. Summaries and recommendations

The results from these two trials demonstrated that fruit body rot was a big issue for both harvests. Small fruit seemed to be a longer shelf life and more tolerant to chilling injury compared to large fruit. When holding fruit at 20°C, DM affected the shelf life. Late harvest fruit had a 1.7-day shorter than those pick at mid harvest. The effect of dry matter content on fruit shelf life when kept at cold temperature was not identified. Controlled atmosphere storage helped to extend fruit shelf life only after 20 or 25 days of storage, reduce rot development and chilling injury. The shelf- life prediction accuracy varied with storage temperature.

Further work needs to be investigated the effect of lower DM on extending shelf life for export, the extending of duration at low temperature, fruit variation between batches and blocks, fruit size etc. Rot

² R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.



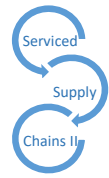
severity and incidence will be checked when avocado fruit are at firm soft and firm ripe to see rot variation between two firmness stages.

5. Acknowledgments

We thank the farm team and grower for supplying fruit for trials and for their technical advice and support.

Appendix 16

CQ 'Hass' avocado simulation trials report 2022b



Predicting fruit quality and shelf life for 'Hass' avocado

A 2022 season Central Queensland farm report

Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish, Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Hass' avocados to quantify the fruit quality and shelf life response to a range of supply chain handling (i.e. 3, 5, 7, 10, 15°C x 5, 10, 15, 20, 25, 30 days) scenarios. Commercially mature fruit of different size were harvested during the mid- and late-season from a farm near Childers, Queensland in 2022. The influence of controlled atmosphere (CA) storage and low temperature pre-conditioning treatments on fruit quality were also evaluated. Key observations included:

Mid-season fruit

- The average dry matter content of mid-season large and small fruit was 30.9% and 33.5%, respectively.
- The firmness of fruit stored at less than 10°C remained largely unchanged for 20 days.
- The remaining shelf life at 20°C varied from 0.7 to 11.3 days and was least for fruit held at higher storage temperature and/or longer durations.
- Body rot and stem-end rot were evident in fruit flesh when evaluated at the soft ripe stage.
- Body rot severity in small fruit was similar to that of large fruit, but its incidence was somewhat lower.
- Minor chilling injury was detected in fruit stored at 3°C, 5°C and 7°C after 20 days of storage.
- The average incidence of fruit with more than 10% combined flesh volume affected by defects (e.g. body rot, stem-end rot, chilling injury) was 44.3% for large and 31.1% for small avocados.
- CA storage reduced fruit weight loss, rot development and chilling injury as compared to ambient air storage and extended fruit shelf life, particularly when the storage exceeded 25 days.

Late-season fruit

- Fruit picked at the late harvest had an average dry matter content of 32.6%.
- The remaining shelf life at 20°C varied between 0.2 and 7.1 days, depending on the preceding storage temperature and duration.
- Chilling injury was prevalent on fruit held at 5°C for 11-15 days of storage.
- Body rot and stem-end rot were still a big issue for late-harvest fruit with the infected volume of body rot varying from 1.3% to 20.6% while rot incidence ranged from 40% to 100% at soft ripe.
- The incidence of fruit with >10% combined internal defects at the soft ripe stage was lower in CA (14%) versus air (60%) stored samples.
- Fruit at the firm ripe stage plus 2 days exhibited lower severity and incidence of both body rot and stem-end rot as compared to those examined at soft ripe.

The data is being used to generate preliminary shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks. Rot severity and incidence will be compared at soft and firm ripe in future trials.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2022 avocado season with fruit from a farm located near Childers, Central Queensland (CQ). The main objective of the trials was to generate preliminary data sets to develop fruit shelf life prediction models for 'Hass' avocado under varied supply chain conditions. The trials also investigated a wide range of factors affecting fruit shelf life, namely controlled atmosphere storage, fruit maturity (dry matter), fruit size and low temperature preconditioning.

2. Materials and methods

Commercially mature (e.g. dry matter $\approx$ 30-34%) 'Hass' avocado fruit were sourced for trials during the 2022 season. The fruit were picked on 14 June for mid harvest and 17 August for late harvest from a farm located near Childers, CQ. The fruit were placed into field bins and transferred to a nearby pack shed on the same day. On the following day, they were treated with a fungicide, sorted by size and quality, and packed into cardboard trays. For mid harvest, large size (20s) and small (30s) fruit were collected while only large size fruit were sourced for late harvest. They were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car at ca. 22-25°C within 3 hours and kept overnight at 20°C.

At the laboratory, near-infrared spectroscopy (NIR) was taken on all trial and dry matter (DM) fruit as an index of dry matter content. NIR predicted DM was measured using a Felix F-750 Quality Meter, based on a general avocado dry matter model. NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. A sticky label with NIR readings was temporally attached to each fruit and the fruit were grouped into DM categories that differed by 1% DM eg 25.0 - 25.9%, 30.0 - 30.9%, 35.0 - 35.9% etc. These categorised fruit were then assigned randomly and evenly to treatment trays, each consisting of ten fruit. This is to make sure that every tray contains a normal distribution of the DMs in the population supplied. Thereafter treatment trays were assigned to different storage temperature as shown in **Table 1**. A set of fruit were preconditioned at 5°C for 5 days and then shifted to 3°C for up to 30 days. In addition, the fruit were stored under controlled atmosphere with 2% O₂ and 5% CO₂ at 5°C for 30 days. Two trays of fruit were kept at 20°C as a control. It is noted that actual removal time may be different due to avoiding weekend work.

The air temperature adjacent to fruit was monitored from the time of picking fruit at pack shed to the cold removal to calculate time x temperature unit (TTU) for predicting the remaining fruit shelf life at 20°C. Relative humidity (RH) inside cold rooms was maintained at 90% so that only temperature and time affected the shelf life. RH was held at 65% in a 20°C room to mimic the retail condition. Fruit weight and firmness were measured at the beginning, at cold removal and at the end of shelf life (ESL) using a balance and fruit firmness durometer (Bareiss), respectively. A hand firmness rating scale was also used to determine when fruit reached firm ripe or soft ripe. Having removed from different storage temperatures, the fruit were kept at 20°C until they reached ESL. The fruit were not treated with ethylene to ripen. Fruit quality (i.e. fruit firmness, rots and defects) was checked every 2 or 3 days. The fruit was considered to reach ESL when it was either at soft ripe (Bareiss reading <40) or developed rots with more than 10% surface areas. Once the fruit reached ESL, it was cut in half, the seed and skin were removed; then severity of body rot, stem-end rot and

chilling injury was assessed and expressed in percentage of affected area. In late harvest fruit, an additional set of fruit was used to cut in half at firm ripe stage to compare the extent of rot development with those examined at soft ripe.

Table 1. Time x temperature matrix used to simulate supply chain handling of 'Hass' avocado fruit.

Storage temperature (°C)	Removal time (days) to ongoing 20°C storage					
3	5	10	15	20		
5 + 3*	5	10	15	20	25	30
5	5	10	15	20	25	30
CA5**		10	15	20	25	30
7	5	10	15	20	25	30
10	5	10	15			
15	5	10	15			
20						

* Fruit were preconditioned at 5°C for 5 days and stored at 3°C

** CA is controlled atmosphere with 2% O₂ and 5% CO₂

3. Results

3.1 Mid harvest fruit

Fruit firmness

Fruit picked at mid harvest had an average oven dry matter (DM) of 30.9% and 33.5% for large and small fruit, respectively. NIR predicted DM was 28.5% for the large whilst it was 30.7% for small avocado. There was a good relationship between oven DM and NIR predicted DM ($R^2=0.7$, data not shown).

Changes in fruit firmness during storage at different temperature is presented in **Figure 1**. As can be seen that fruit firmness dropped significantly with an increase in storage temperature and duration, except for those stored at 3°C and 5+3°C. Small size fruit had a tendency to be slightly harder than the large size fruit when stored at 7, 10 and 15°C. It is obvious that large fruit stored at 15°C reached the end of shelf life after 14 days of storage.

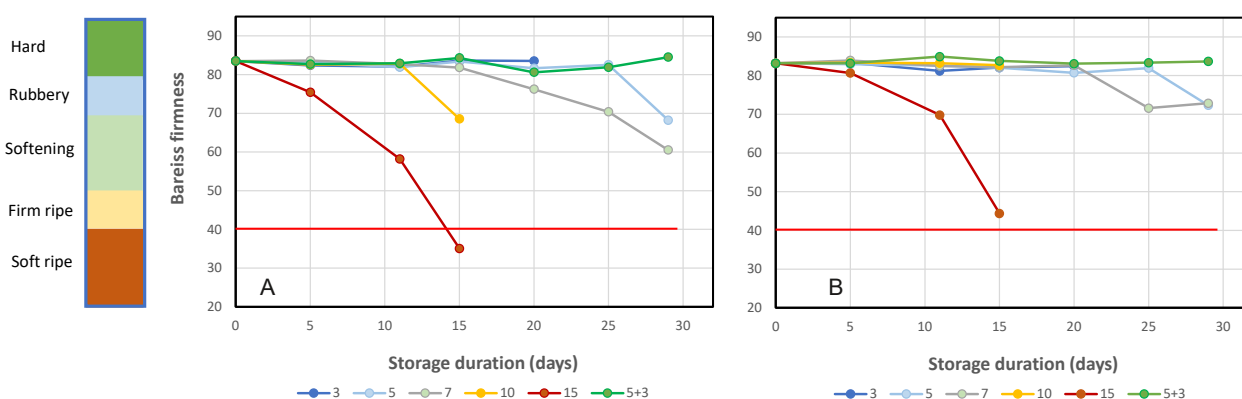


Figure 1. Changes in fruit firmness of large size (A) and small (B) avocado during storage at various temperatures



Weight loss and remaining shelf life

Weight loss of fruit at cold removal rose with an increase in storage time and temperature, ranging from 0.5% to 4.3% (**Table 2**). There was no difference in weight loss at cold removal between the large and small fruit. Fruit kept losing its weight when held at 20°C. The fruit lost between 3.9% and 9.8% its initial weight when they reached the end of shelf life. The small size fruit seemed to lose more its weight than the large ones. The remaining shelf life of fruit at 20°C varied depending on temperature and duration. As a rule, the higher temperature and longer duration the fruit were kept, the shorter the shelf life remained at 20°C. The fruit stored at 15°C for 15 days had only 2.2 days of shelf life at 20°C. It is likely that small fruit had a two-day longer shelf life than large ones.

Rot development and chilling injury

Body rot and stem-end rot were the main diseases found in avocado flesh. There was no clear temperature effect on rot development. The infected volume of body rot in the large fruit varied from 0.7% to 30% (10.1% average) whereas rot incidence was from 40% to 100% (**Table 3**). The severity of body rot in small fruit was similar to that of large fruit, but its incidence was somewhat lower. The affected area and incidence of stem-end rot in both fruit sizes was smaller than body rot. Minor chilling injury was detected on the fruit stored at 5°C and 7°C after 15 days of storage, especially with large fruit. It is possible that small fruit was more tolerant to chilling injury than large fruit. Looking at incidence of fruit with more than 10% combined affected volume (body rot, stem-end rot and chilling injury), 44.3% of large size fruit was rejected based on avocado industry standard and incidence of rejected fruit was lower with small size fruit (**Table 3**).

Fruit quality under ambient air versus controlled atmosphere

Fruit quality of avocado stored under ambient air and controlled atmosphere at 5°C is shown in **Table 4**. Controlled atmosphere storage helped reduce fruit weight loss (0.5%-0.7%) as compared to ambient storage. CA storage had only benefit in extending fruit shelf life after 25 days. CA also prevented rot development and chilling injury. Incidence of fruit with more than 10% combined defects was much lower (10% for large fruit-16% for small fruit) in CA stored fruit as compared to air stored ones (48% for large fruit-60% for small fruit) (**Table 5**).

Table 2. Weight loss of “Hass” avocado evaluated at cold removal, at the end of shelf life and remaining shelf life at 20°C under varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Wt loss at removal (%)		Wt loss at ESL (%)		Remaining shelf life at 20°C (day)	
		L size	S size	L size	S size	L size	S size
3	5	0.8	0.8	6.1	9.8	7.8	10.3
	11	1.1	1.1	5.5	7.1	6.4	7.9
	15	1.4	1.4	5.5	7.1	6.1	8.7
	20	1.6	1.5	5.8	7.0	6.8	8.0
5 + 3	11	0.9	0.9	5.1	6.0	5.8	8.1
	15	1.1	1.2	4.3	6.2	5.6	7.9
	20	1.3	1.5	5.5	7.2	7.0	8.4
	25	1.7	2.0	6.9	8.0	7.3	8.3
	29	2.0	2.1	6.4	8.2	7.2	8.9
	35	2.2	2.8	6.9	9.8	8.1	9.0
5	5	0.5	0.6	4.1	8.8	7.4	11.3
	11	1.0	1.3	5.0	9.3	6.2	9.8
	15	1.4	1.5	4.7	7.6	5.3	8.3
	20	2.0	2.1	5.6	8.3	4.9	8.7
	25	1.9	2.1	6.6	8.4	7.4	9.3
	29	2.5	2.7	6.5	8.3	5.2	6.7
7	5	0.6	0.6	6.9	7.6	8.8	9.2
	11	1.0	1.0	4.6	6.3	5.8	7.4
	15	1.5	1.5	5.1	6.6	6.2	7.8
	20	1.6	1.9	4.6	7.0	5.4	6.6
	25	2.0	2.6	4.4	7.6	4.0	6.2
	29	2.4	2.5	5.6	7.1	3.6	6.3
10	5	0.6	0.6	5.1	7.9	7.4	10.2
	11	1.1	1.2	4.9	7.3	6.0	8.9
	15	1.5	1.6	4.4	6.5	4.3	7.1
15	5	1.2	1.4	6.7	8.1	7.4	9.1
	11	2.3	2.9	4.4	6.4	3.3	5.2
	15	3.7	4.1	3.9	5.4	0.7	2.2
AVE		1.5	1.7	5.4	7.5	6.0	8.1
20		N/A	N/A	6.1	6.2	11.4	10.6

Table 3. Severity and incidence of body rot, stem-end rot and chilling injury from “Hass” mid-harvested avocado evaluated at the end of shelf life after exposed to varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Body rot				Stem-end rot				Chilling injury				Incidence of fruit with >10% combined defect	
		Affected volume (%)		Incidence (%)		Affected volume (%)		Incidence (%)		Affected volume (%)		Incidence (%)			
		L size	S size	L size	S size	L size	S size	L size	S size	L size	S size	L size	S size	L size	S size
3	5	11.8	8.7	90	60	2.0	7.3	50	80	0	0	0	0	50	60
	11	8.0	5.7	90	40	1.3	1.5	30	50	0.2	0	10	0	30	30
	15	2.5	7.6	40	50	0.3	2.3	20	30	0	0	0	0	10	30
	20	4.1	3.1	50	30	2.1	0.8	20	20	7.0	0	10	0	30	10
5 + 3	11	2.7	1.0	70	10	0.8	1.3	40	20	0.2	0	10	0	0	10
	15	1.7	6.0	70	30	0.5	1.2	20	20	0.6	0	10	0	0	10
	20	3.1	1.2	60	40	0.8	3.7	40	60	0	0	0	0	20	20
	25	16.8	8.4	60	60	9.7	4.0	50	40	0.8	0	20	0	50	30
	29	3.9	20.8	90	50	1.5	1.3	30	20	3.2	0.8	50	20	30	50
	35	13.4	12.5	100	40	2.9	4.7	60	30	5.9	0.9	100	30	80	50
5	5	8.3	12.1	90	70	5.0	6.5	50	40	0	0	0	0	50	30
	11	2.9	10.6	50	50	0.6	5.4	30	70	0	0	0	0	10	50
	15	6.4	15.3	60	80	0.6	8.0	30	80	0	2.5	0	10	20	60
	20	11.1	21.5	80	90	0.9	3.5	20	50	4.2	2.0	50	10	50	40
	25	18.0	15.0	80	60	1.8	6.6	30	60	4.2	0.0	40	0	70	50
	29	23.7	30.2	100	100	1.2	2.7	40	30	11.3	5.2	70	70	90	100
7	5	19.1	8.0	100	60	3.6	3.7	60	50	0	0	0	0	70	30
	11	2.5	1.8	60	60	1.7	1.1	30	40	0	0	0	0	10	10
	15	4.6	0.7	50	20	1.2	0.4	40	20	0.6	0	20	0	20	0
	20	5.2	0.0	70	0	0.4	0.2	20	20	3.8	0	20	0	20	0
	25	11.6	29.8	70	70	0.5	2.5	30	20	1.7	0.4	20	20	50	40
	29	12.2	15.7	100	30	1.8	3.4	40	30	10.5	0.5	80	10	70	30
10	5	9.8	1.8	90	40	4.4	3.3	70	60	0	0	0	0	70	0
	11	11.6	3.9	100	40	0.5	5.2	40	60	0	0	0	0	40	30
	15	15.7	6.5	80	30	2.1	1.6	50	20	0.6	3.3	10	10	60	10
15	5	22.9	7.6	90	70	5.5	5.7	70	70	0	0	0	0	80	50
	11	12.3	4.6	100	60	3.0	2.7	40	80	0	0	0	0	90	20
	15	18.0	4.9	90	60	4.9	2.5	80	40	0	0	0	0	70	20
AVE		10.1	9.5	77.9	50.0	2.2	3.3	40.4	43.2	2.0	0.6	18.6	6.4	44.3	31.1
20		17.1	6.4	80	85	3.6	4.8	55	55	0.0	0.0	0	0	35	45

Table 4. Comparison of “Hass” avocado quality under ambient air and controlled atmosphere storage at 5°C for 29 days.

Storage duration (day)	Wt loss at removal (%)				Remaining shelf life at 20°C			
	L size		S size		L size		S size	
	Air	CA	Air	CA	Air	CA	Air	CA
11.0	1.0	0.8	1.3	0.8	6.2	6.2	9.8	7.7
15.0	1.4	1.3	1.5	1.3	5.3	7.9	8.3	9.0
20.0	2.0	1.2	2.1	1.2	4.9	7.1	8.7	8.8
25.0	1.9	1.3	2.1	1.4	7.4	7.2	9.3	9.2
29.0	2.5	1.4	2.7	1.5	5.2	7.2	6.7	8.0
AVE	1.7	1.2	1.9	1.2	5.8	7.1	8.6	8.5

Shelf-life models

Mid harvested ‘Hass’ avocado time x temperature trial captured acceptable quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) for mid harvest fruit showed an acceptable linear regression ($R^2 = 0.6$ for large fruit and 0.65 for small fruit, **Figure 2**) although shelf life prediction accuracy varied with temperature e.g at 5+3°C and 15°C. The trial needs to be repeated to confirm the model accuracy. In predicting shelf life, we have considered DM as another independent factor which influences fruit shelf life, the higher DM, the shorter the shelf life. However, it was not the case in this trial. As illustrated in **Figure 2**, the small fruit having a DM of 33.5% had a longer shelf life in comparison with large fruit which had a DM of 30.9%.

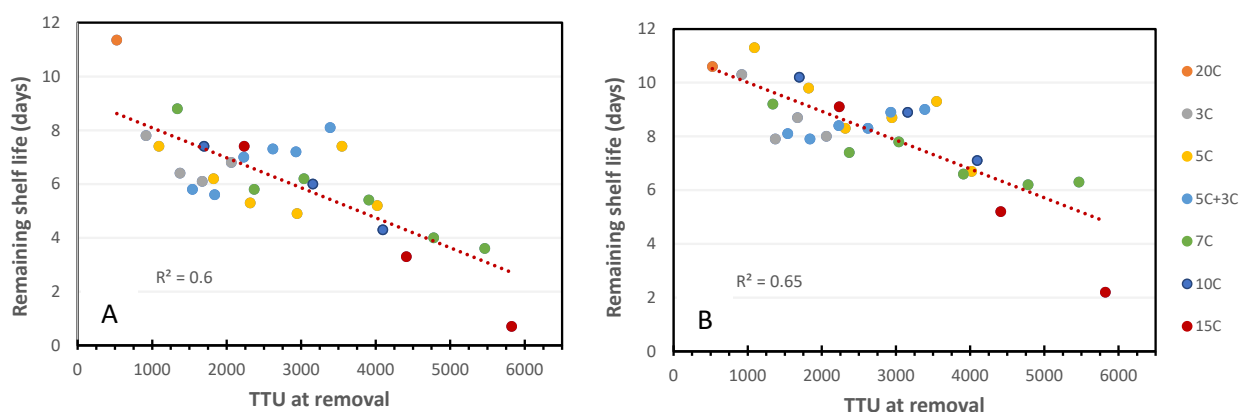


Figure 2. Relationship between temperature time units (TTUs) from picking time at pack shed to the cold removal at various temperatures and remaining shelf life (tray averages) of large (A) and small (B) ‘Hass’ fruit at mid harvest.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

Table 5. Severity and incidence of body rot, stem-end rot and chilling injury from “Hass” mid-harvested avocado under ambient air and controlled atmosphere storage at 5°C for 29 days.

Large fruit

Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		
11.0	2.9	50	3.9	60	0.6	30	0.5	10	0	0	0	0	10	10
15.0	6.4	60	0.8	60	0.6	30	0.5	20	0	0	0	0	20	0
20.0	11.1	80	3.2	70	0.9	20	1.0	30	4.2	50	0	0	50	20
25.0	18.0	80	3.1	60	1.8	30	0.7	20	4.2	40	0	0	70	10
29.0	23.7	100	3.5	50	1.2	40	0.6	20	11.3	70	0	0	90	10
AVE	12.4	74.0	2.9	60.0	1.0	30.0	0.7	20.0	3.9	32.0	0	0	48.0	10.0

Small fruit

Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		
11.0	10.6	50	0.8	20	5.4	70	0.8	30	0	0	0	0	50	0
15.0	15.3	80	8.7	50	8.0	80	2.5	30	2.5	10	0	0	60	10
20.0	21.5	90	2.0	30	3.5	50	2.5	50	2.0	10	0	0	40	20
25.0	15.0	60	10.6	70	6.6	60	6.8	60	0	0	1.5	10	50	40
29.0	30.2	100	5.5	20	2.7	30	2.3	30	5.2	70	0	0	100	10
AVE	18.5	76.0	5.5	38.0	5.2	58.0	3.0	40.0	1.9	18.0	0.3	2.0	60.0	16.0

3.2 Late harvest fruit

Fruit firmness

Fruit picked at late harvest had an average oven dry matter (DM) of 32.6% and NIR predicted DM of 34.1%. Changes in fruit firmness under various storage temperature is presented in **Figure 3**. It can be seen that fruit firmness dropped significantly with an increase in storage temperature and duration, except for those stored at 3°C and 5+3°C. It is clear that the fruit stored at 15°C reached the end of shelf life after 12.5 days of storage.

Weight loss, days to firm ripe and remaining shelf life

Weight loss of fruit measured at cold removal rose with an increase in storage time and temperature, ranging from 0.5% to 3.6% (**Table 6**). Fruit kept losing its weight when held at 20°C. The fruit lost between 3.4% and 6.4% its initial weight when they reached the end of shelf life. It took between 1.1 days and 4.3 days for fruit to reach firm ripe once removed from the cold storage, except for those stored at 15°C for longer than 5 days. The remaining shelf life at 20°C varied depending on temperature and duration. As a rule, the higher temperature and longer duration the fruit were kept, the shorter shelf life remained at 20°C. The fruit stored at 15°C for 15 days had nearly no shelf life at 20°C.

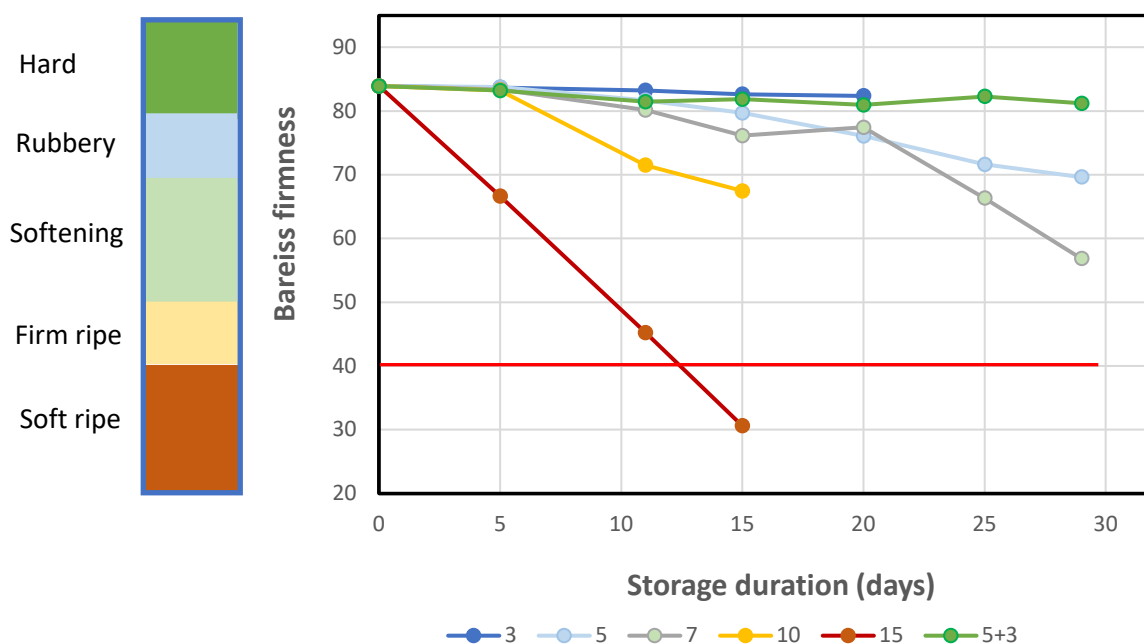


Figure 3. Changes in fruit firmness of “Hass” avocado picked at late harvest during storage at various temperatures

Rot development and chilling injury

Body rot and stem-end rot were still a big issue for late harvest fruit. There was no clear temperature effect on rot development. The rot was thought to be present inside the fruit before harvest. The infected volume of body rot varied from 1.3% to 20.6% (7.6 % average) whereas rot incidence was from 40% to 100% (88.6% average, **Table 7**). The affected area and incidence of stem-end rot was significantly smaller than body rot. Chilling injury was prevalent on the fruit stored at 5°C after 20 days of storage. Taking the incidence of fruit with >10% combined defects into account, the percentage of fruit rejected was 34.3% on average (**Table 7**)

Fruit quality under ambient air versus controlled atmosphere

There was no significant weight loss between air and CA storage, and CA storage had only benefit in extending fruit shelf life after 20 or 25 days as compared to ambient storage (data not shown). Rot development and chilling injury of avocado stored under ambient air and controlled atmosphere at 5°C is illustrated in **Table 8**. It can be seen that CA also prevented body rot development and chilling injury. Especially, the incidence of fruit with >10% combined defects in CA was lower (14%) versus air (60%).

Rot severity and incidence of the fruit examined at firm rip stage + 2 days versus at soft ripe

The fruit at firm ripe stage plus 2 days had a lower severity and incidence of both body rot and stem-end rot as compared to those examined at soft ripe stage (**Table 9**). Also the incidence of fruit with >10% combined defects when examined at firm ripe plus 2 days was smaller than when checked at soft ripe.

Table 6. Weight loss of “Hass” avocado evaluated at cold removal, at the end of shelf life and remaining shelf life at 20°C under varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Wt loss at removal (%)	Wt loss at ESL (%)	Days to firm ripe	Remaining shelf life at 20°C (day)
3	5	0.5	5.5	4.2	6.8
	11	1.0	5.7	3.5	6.4
	15	1.2	6.1	3.7	6.3
	20	1.4	5.8	3.3	5.8
5 + 3	11	0.8	6.2	3.2	7.1
	15	1.1	5.6	2.9	6.3
	20	1.4	5.7	2.9	5.9
	25	1.8	6.0	2.7	5.8
	29	1.9	6.1	2.8	5.7
	35	2.4	6.4	2.3	5.0
5	5	0.5	5.8	3.9	7.0
	11	1.1	5.4	2.8	5.7
	15	1.3	5.6	2.3	5.7
	20	1.5	6.2	2.7	6.3
	25	2.2	5.5	1.8	4.5
	29	2.1	5.5	2.0	4.5
7	5	0.7	6.0	3.8	6.8
	11	1.3	5.8	2.6	5.6
	15	1.4	6.1	2.2	4.7
	20	1.5	4.8	1.9	4.8
	25	2.0	5.2	1.2	4.3
	29	2.2	5.7	1.2	4.3
10	5	0.7	6.1	4.1	6.7
	11	1.2	4.8	1.8	4.6
	15	1.4	4.2	1.4	3.6
15	5	1.2	4.7	1.1	4.1
	11	2.6	4.7	0.4	2.8
	15	3.4	3.6	*	0.2
AVE		1.5	5.5	2.5	5.3
20		N/A	5.8	4.8	8.0

* Fruit already passed firmsoft at the removal date

Table 7. Severity and incidence of body rot, stem-end rot and chilling injury from “Hass” late-harvested avocado evaluated at the end of shelf life after exposed to varied duration and temperatures.

Storage temperature (°C)	Storage duration (day)	Body rot		Stem-end rot		Chilling injury		Incidence of fruit with >10% combined defect
		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	
3	5	2.4	50	0.6	20	0	0	10
	11	6.6	100	0.2	20	0.4	10	20
	15	3.1	100	0.1	10	0	0	0
	20	2.5	90	0.5	50	1.2	10	10
5 + 3	11	3.2	70	0.8	60	0	0	10
	15	3.9	100	0.2	20	0	0	20
	20	2.7	90	1.0	60	0	0	0
	25	4.4	80	0.2	20	11.9	30	30
	29	8.6	90	0.3	20	6.3	60	50
	35	1.3	40	0.3	20	1.6	40	10
5	5	8.8	70	0.2	10	0	0	20
	11	7.7	90	0.1	10	0.8	10	40
	15	5.3	100	0.3	20	2.1	20	20
	20	10.9	100	1.1	50	14.6	50	70
	25	8.5	100	0.1	10	11.9	100	70
	29	20.6	100	0.6	40	23.9	100	100
7	5	7.3	90	0.9	30	0	0	30
	11	10.8	90	1.5	50	0.5	10	60
	15	5.6	100	0.3	30	1.8	20	30
	20	7.9	100	0.4	40	0.5	10	20
	25	16.5	100	0.8	30	0.9	30	50
	29	19.7	100	7.3	70	3.7	50	90
10	5	7.0	90	0.9	20	0	0	40
	11	6.2	90	0.9	50	0	0	20
	15	5.6	100	0.3	20	1.4	20	20
15	5	10.0	70	1.9	40	0	0	60
	11	9.3	90	1.5	70	0	0	40
	15	6.2	90	1.5	70	0	0	20
AVE		7.6	88.6	0.9	34.3	3.0	20.4	34.3
20		1.8	45	1.1	35	0	0	10

Table 8. Comparison of “Hass” avocado quality under ambient air and controlled atmosphere storage at 5°C for 29 days.

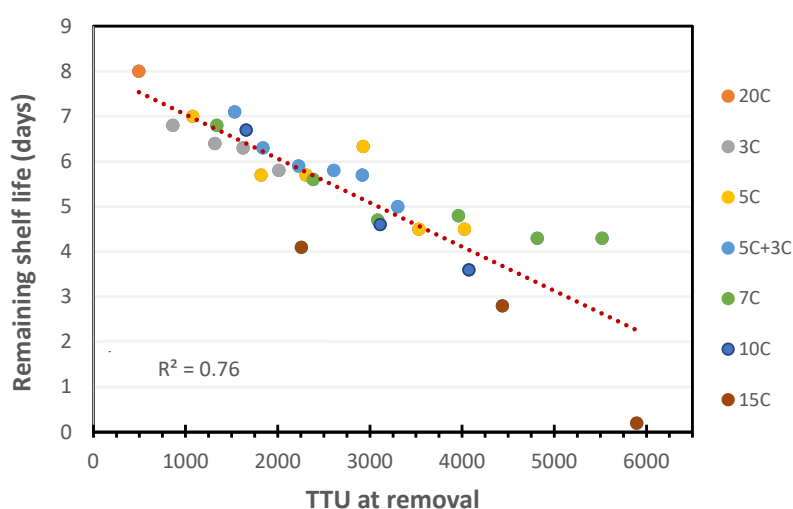
Storage duration (day)	Body rot (% v/v)				Stem-end rot (% v/v)				Chilling injury (% v/v)				Incidence of fruit with >10% combined defect	
	Air		CA		Air		CA		Air		CA		Air	CA
	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		
11.0	7.7	90	3.6	70.0	0.1	10	0.4	30	0.8	10	0.0	0	40	10
15.0	5.3	100	3.8	100.0	0.3	20	0.4	40	2.1	20	1.2	10	20	20
20.0	10.9	100	3.4	80.0	1.1	50	0.8	40	14.6	50	0.3	10	70	10
25.0	8.5	100	2.5	90.0	0.1	10	0.3	30	11.9	100	2.0	10	70	10
29.0	20.6	100	7.0	90.0	0.6	40	1.6	60	23.9	100	5.5	20	100	20
AVE	10.6	98.0	4.1	26.0	0.4	26.0	0.7	40.0	10.7	1.8	1.8	10.0	60.0	14.0

Table 9. Comparison of rot development on “Hass” avocado at two different firmness stages.

Storage temperature (°C)	Storage duration (day)	Firm ripe + 2 days					Soft ripe				
		Body rot		Stem-end rot		>10% combined defect	Body rot		Stem-end rot		>10% combined defect
		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)		Affected volume (%)	Incidence (%)	Affected volume (%)	Incidence (%)	
5	20	5.8	100	0.2	20	20	10.9	100	1.1	50	70
7	20	7.1	100	0.2	20	20	7.9	100	0.4	40	20
10	15	3.4	100	0.3	30	0	5.6	100	0.3	20	20
15	11	5.0	70	0.7	20	20.0	9.3	90	1.5	70	40
AVE		5.3	92.5	0.4	22.5	15.0	8.4	97.5	0.8	45.0	37.5

Shelf-life models

Late harvested ‘Hass’ avocado time x temperature trial captured good quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) for late harvest fruit showed an acceptable linear regression ($R^2 = 0.76$ ², **Figure 4**) although shelf life prediction accuracy varied with temperature e.g at 7°C and 15°C. In predicting shelf life, we have considered DM as another independent factor which influence fruit shelf life, the higher DM, the shorter the shelf life. Late fruit had about 2% higher DM than mid harvest fruit. This resulted in a shorter shelf life (3.4 days at 20°C).

**Figure 4.** Relationship between temperature time units (TTUs) from picking time at pack shed to the cold removal at various temperatures and remaining shelf life of ‘Hass’ fruit at late harvest.

4. Summaries and recommendations

The results from these two trials demonstrated that fruit body rot was a big issue for both harvests. Small fruit seemed to be a longer shelf life and more tolerant to chilling injury compared to large fruit. When holding fruit at 20°C, DM affected the shelf life. Late harvest fruit had a three-day shorter than those pick at mid harvest. The effect of dry matter content on fruit shelf life when kept at cold temperature was not identified. Controlled atmosphere storage helped to extend fruit shelf life only after 20 or 25 days of storage, reduce rot development and chilling injury. The shelf- life prediction accuracy varied with storage temperature.

² R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.



Further work needs to be investigated the effect of lower DM on extending shelf life for export, the extending of duration at low temperature, fruit variation between batches and blocks, fruit size etc. Rot severity and incidence will be checked when avocado fruit are at firm soft and firm ripe to see rot variation between two firmness stages.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support. We acknowledge Andy Mead and Lawrence Smith from the Queensland Department of Agriculture and Fisheries for assistance in managing trials and data collection.

Appendix 17

NQ 'Hass' avocado simulation trials report 2023

Predicting fruit quality and shelf life for ‘Hass’ avocado

John Archer and Minh Nguyen, Department of Agriculture and Fisheries

Summary

An export simulation trial was conducted with ‘Hass’ avocados to assess the impact of different supply chain handling and storage conditions on fruit quality and shelf life. The trial involved commercially mature fruit of size 20 and 30 harvested from a North Queensland (NQ) farm in 2023.

The avocados were stored at 3, 5, 7, 10 and 15°C, with 90% relative humidity (RH) for 5 to 40 days to replicate conditions observed in monitored air and seafreight supply chains. Sub-samples of fruit were periodically removed from storage and held at 20°C and 65% RH to assess their remaining shelf life.

Key observations from the trials included:

- **Chilling Injury Onset:** Noticeable chilling injury developed after about 17 days at 3 °C and 20 days at 5 °C, highlighting the risk of extended cold storage for susceptible fruit.
- **Shelf Life Decline:** Overall shelf life tended to decrease as treatment duration increased, with higher storage temperatures causing a more rapid decline in post-storage life.

The data gathered from these trials will be used to develop and update best practice handling guidelines and decision aid tools based on predictive models for avocado shelf life and fruit quality. Future work will focus on exploring the relationship between fruit dry matter content and shelf life, extending the potential for low-temperature shipping durations, and examining the variation in fruit quality across different batches and blocks.

Introduction

The Serviced Supply Chains II project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters—whether aspiring, emerging, or established, helping them maximize product value, reduce claims, and expand trade volume. The primary objectives of the project are:

- Develop predictive shelf-life models for a wide range of fresh horticultural produce.
- Apply these models to create decision aid tools and update handling guidelines for improved quality and consistency.

This report focuses on the export simulation trial work conducted during the 2023 ‘Hass’ avocado season on fruit grown in North Queensland. The central objective of these trials was to assess the fruit quality and shelf-life response of ‘Hass’ avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, such as CA storage and fruit maturity (dry matter content). The data generated from these trials will contribute to the development of accurate predictive models for avocado quality and shelf life, enhancing decision-making for exporters and stakeholders

Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Hass' avocado fruit, with a target dry matter (DM) content of >23%, were selected for the trials during the 2023 season. The fruit were harvested by a commercial picking crew on 8/05/2023 and 13/6/2023 from a NQ farm and transported to a nearby packing house. The harvested fruit were transferred within 24 hours.

Post-Harvest Treatment and Packing

Upon arrival at the packing house, the avocados were treated with a fungicide, sorted by size and quality, and then packed into cardboard trays. The packed fruit of size 20 (Large) and 30 (Small) were transported in an air-conditioned vehicle to the Cairns Research Facility within 3 hours, maintaining a temperature of 22-25°C. The fruit was kept overnight at 20°C to stabilize before further processing.

Dry Matter Content Measurement

At the laboratory, the dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values, and then sorted by DM content. Fruit was assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of fruits per size category were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

The fruit were assigned to different storage temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. Each treatment was applied to a tray(s) of fruit. A subset of fruit stored at 5°C was held under CA conditions at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

At the conclusion of each treatment storage period, the fruit were moved to 20°C for further assessment of their remaining shelf life. The air temperature adjacent to the fruit was monitored from the time of collection at the packing shed through to removal from the cold storage treatments. This allowed for the calculation of time × temperature units (TTU), which helped quantify the effects of storage duration and temperature.

Table 1 Number of treated fruit at each treatment temperature.

Fruit size	Treatment Temperature (°C)	Controlled Atmosphere	Treatment Duration (Days)							
			0	5	9/10	15	20	25	30	45
Trial 1										
20	5	FALSE			20		20		20	20
20	20	FALSE	20	20						
30	3	FALSE		20	20		20		20	20
30	5 to 3*	FALSE		20	20		20		20	20
30	5	FALSE		20	20		20	20	20	20
30	7	FALSE		20	20		20		20	
30	10	FALSE		20	20	20	20			
30	15	FALSE		20	20	20				
30	20	FALSE	20	20						
Trial 2										
20	5	FALSE			20				20	20
20	20	FALSE	20	20						
30	3	FALSE		20	20		20		20	
30	5 to 3*	FALSE		20	20		20		20	
30	5	FALSE		20	40	20	30		20	20
30	7	FALSE		20	20		20	20	20	
30	10	FALSE		20	20	20	20	20	20	
30	15	FALSE		20	20					
30	20	FALSE		72	20					
*5 to 3: fruit that is preconditioned by undergoing an initial treatment at 5°C for 5 days before being transferred to 3°C, where it remains for the duration of the treatment										

Humidity Control

Relative humidity (RH) inside the cold storage rooms was maintained at approximately 90% to simulate typical cold storage conditions. Once removed from storage, the fruit were placed in a controlled environment at 20°C, with the RH held at 65% to replicate retail conditions.

Bareiss Firmness Measurement

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit. A firmness value of 54 was defined as the threshold for firm soft (FS), while the end of shelf life (ESL) was determined when firmness reached 39. These benchmarks provided consistent criteria for assessing ripeness and the remaining usability of the fruit during the trials.

Results

Dry matter

Table 2 Dry Matter Content Analysis

Trial	Fruit Size	Average DM (%)	Maximum DM (%)	Minimum DM (%)	Standard deviation (%)
1	20	31.0	38.3	25.2	1.7
1	30	30.4	34.1	27.1	1.4
2	20	29.1	29.9	28.4	0.3
2	30	30.5	32.1	29.0	0.4

Impact of Storage Duration on Fruit Defects

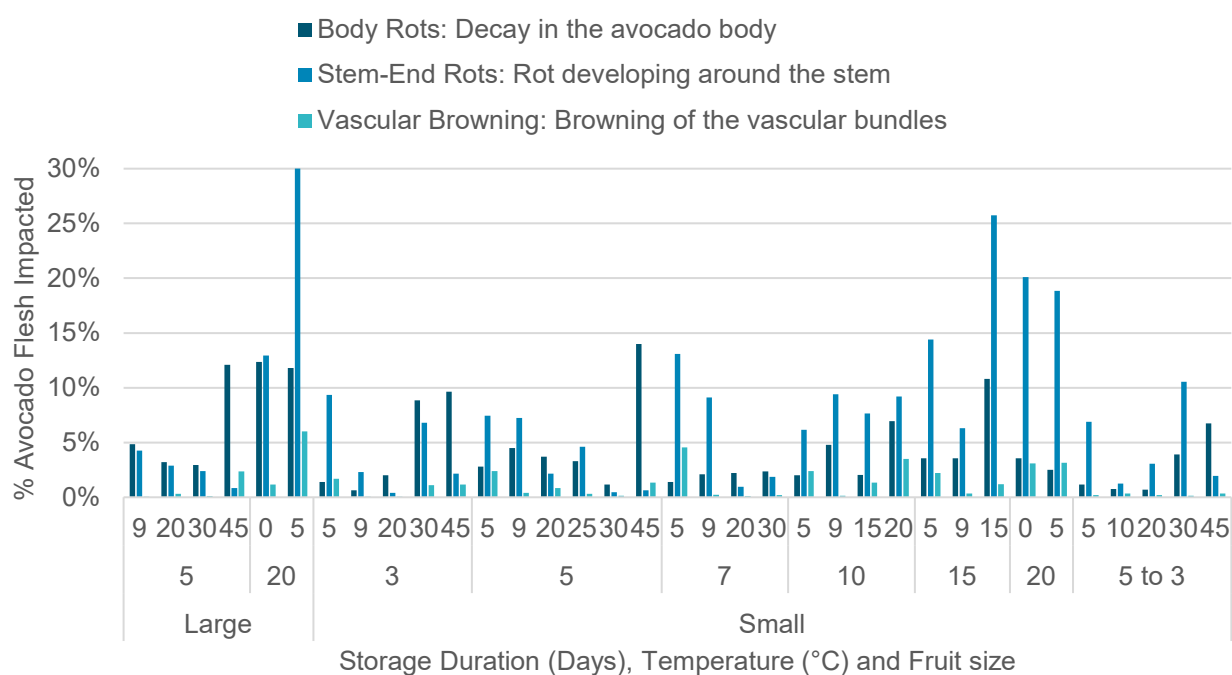


Figure 1 Trial 1 Impact of storage duration, temperature and fruit size on avocado quality defects.

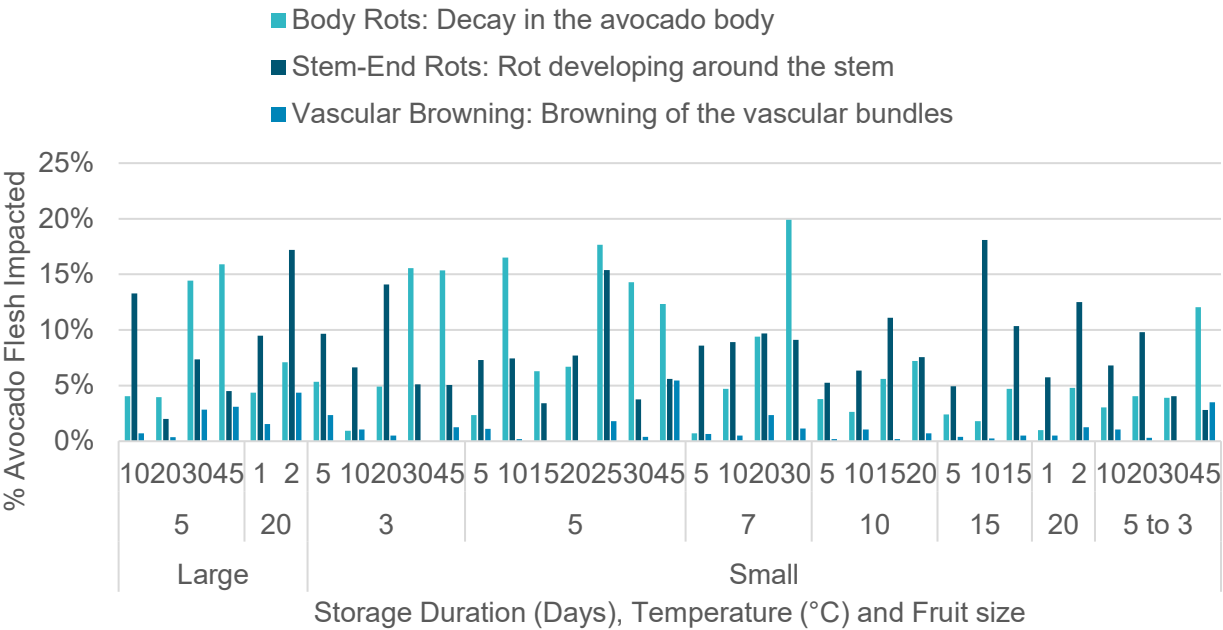


Figure 2 Trial 2 Impact of storage duration, temperature and fruit size on avocado quality defects.

As shown in Figure 1 and Figure 2, the percentage of avocado flesh affected by body rots, stem-end rots, and vascular browning varies with storage duration, temperature, and fruit size. Notably, body rot incidence increases at longer storage times, while stem-end rots and vascular browning also rise under certain conditions.

Internal chilling injury

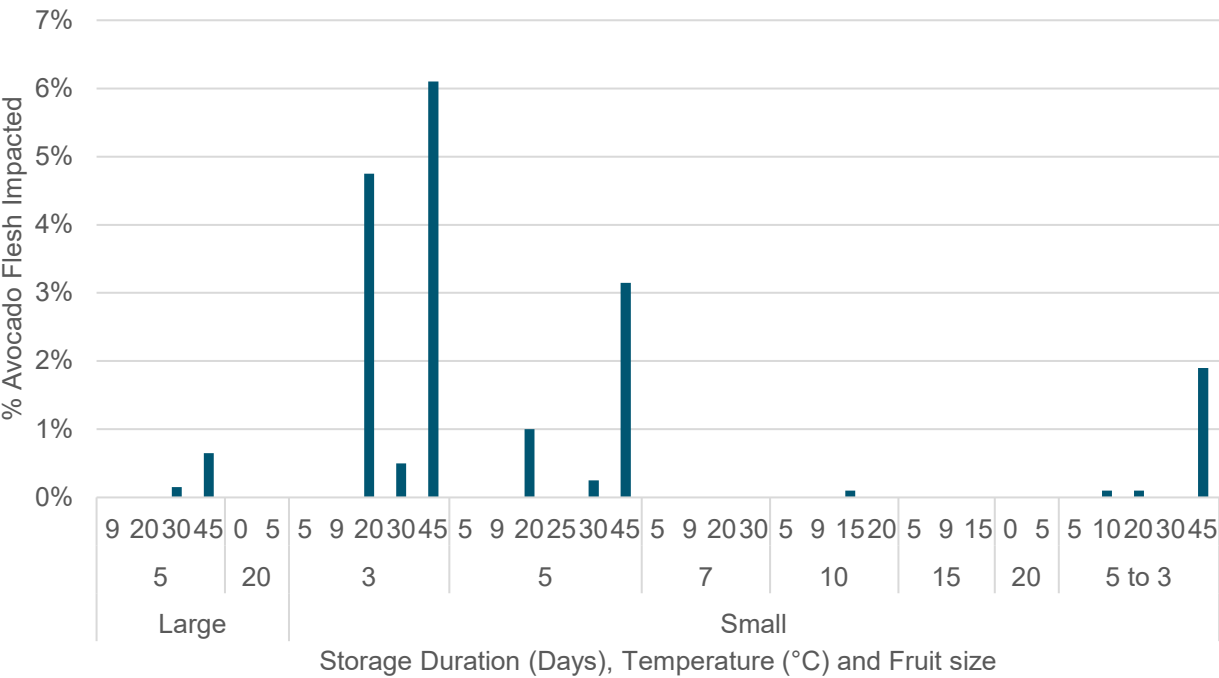


Figure 3 Trial 1 Incidence of diffuse discoloration (chilling injury) in avocados under different storage conditions.

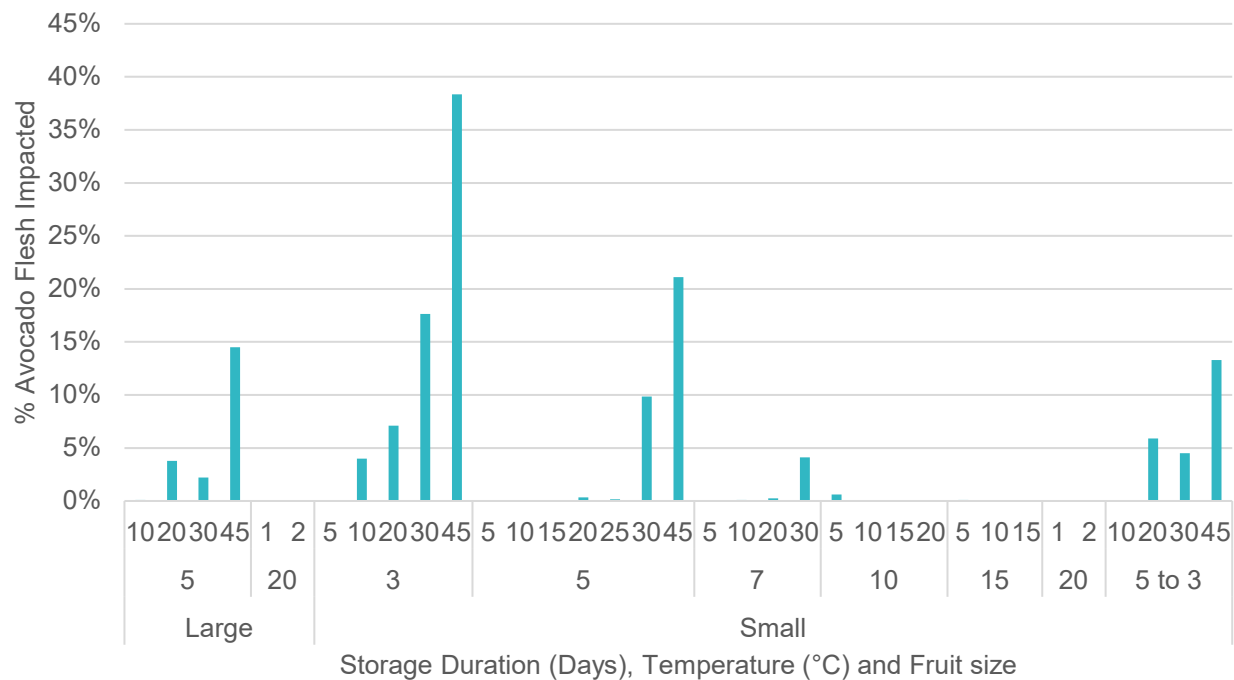
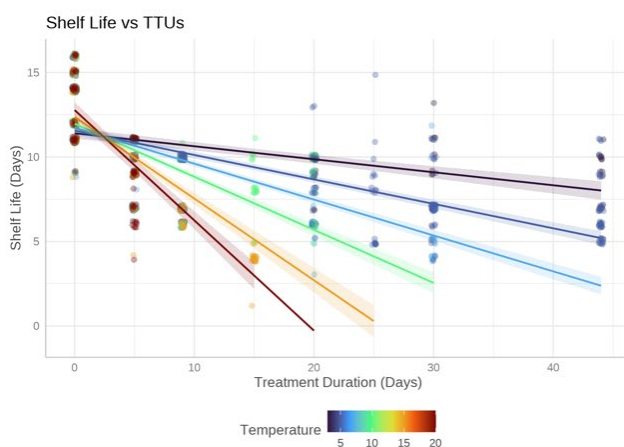


Figure 4 Trial 2 Incidence of diffuse discoloration (chilling injury) in avocados under different storage conditions.

As shown in Figure 3 and Figure 4, the extent of chilling injury in avocados can range from negligible levels up to nearly 40% of the flesh impacted, depending on storage temperature, duration, and fruit size. Large fruit stored at lower temperatures for longer periods showed the highest susceptibility, while shorter storage times and slightly warmer temperatures tended to minimize chilling injury.

Shelf Life



Characteristic	Beta	95% CI [†]	p-value
tmt_duration	0.02	0.00, 0.05	0.065
tmt_temp	0.08	0.04, 0.12	<0.001
tmt_duration * tmt_temp	-0.03	-0.04, -0.03	<0.001

[†] CI = Confidence Interval

Figure 5 Trial 1 Relationship between shelf life, treatment duration, and temperature.

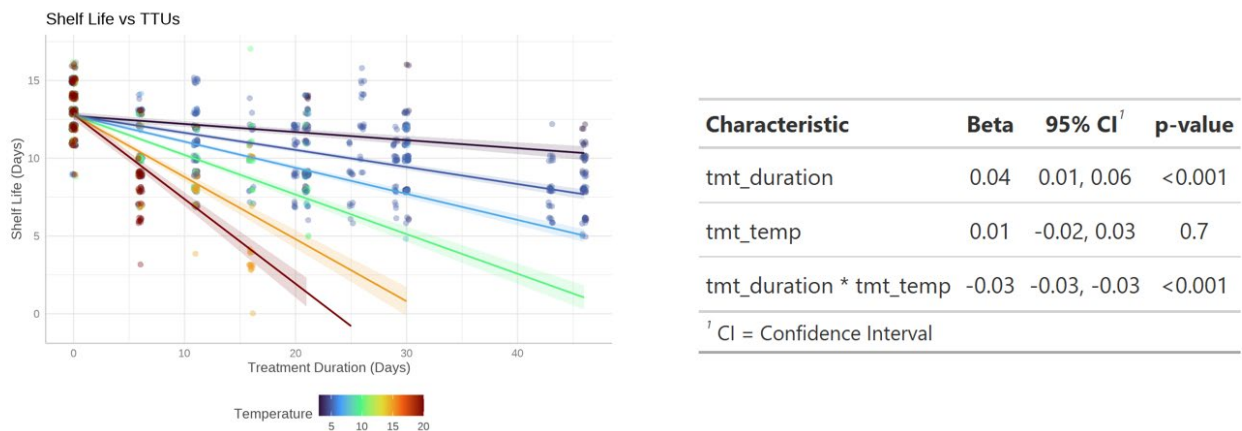


Figure 6 Trial 2 Relationship between shelf life, treatment duration, and temperature.

Figure 5 and Figure 6 show how the shelf life of fruit decreases as the treatment duration increases, with higher temperatures causing a faster decline. The lines represent different temperatures, with cooler colours (blue) for lower temperatures and warmer colours (red) for higher ones. The dots represent measured values, while the shaded areas indicate the confidence interval for predictions.

Summary

Time and temperature strongly influenced the shelf life and quality of 'Hass' avocados. Extended cold storage increased the risk of chilling injury and disease incidence, particularly in larger fruit. These findings will guide the refinement of handling guidelines and predictive models for avocado exporters.

Appendix 18

CQ 'Hass' avocado simulation trials report 2023a

Predicting fruit quality and shelf life for 'Hass' avocado

2023 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish

Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Hass' avocados to quantify fruit quality and shelf life response to a range of supply chain handling scenarios. Commercially mature fruit of 2 different sizes were harvested from a farm located near Childers, Queensland in June and August 2023. The fruit were stored at 3, 5, 7, 10 and 15°C and 90% relative humidity (RH) for up to 45 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. The influence of controlled atmosphere (CA) storage and pre-conditioning treatments on fruit quality were also evaluated. Key observations included:

- Firmness changes in 'Hass' avocados were strongly affected by storage temperature, with cooler storage temperatures delaying fruit softening.
- A substantial increase in rate of softening occurred between 10 and 15°C.
- Following storage for 20 to 30 days at 3 to 7°C, fruit typically took around 3 days at 20°C to ripen to firm soft and another 3 days to reach medium soft.
- Acceptable internal fruit quality remained at 80% or higher for up to 25 days in air, with a slight decline in quality after 30 days.
- After 45 days considerable quality issues were encountered in air stored fruit, including skin and flesh chilling damage.
- Green-black skin colour development occurred more commonly after 30 days or longer in cool storage, and at warm storage temperatures (15-20°C).
- CA storage showed strong benefits in:
 - retaining fruit firmness
 - reducing moisture loss
 - reducing green-black colour development, rots and chilling damage
 - improving internal quality
- After 45 days storage, 20-30% of air stored fruit had acceptable internal quality, while 90% of CA stored fruit were acceptable.
- A delay between harvest and packing of 3 days, with fruit re-warming prior to cool storage had strong impacts on fruit quality.
- Ripening during cool storage was associated with much higher severity of internal chilling damage, particularly in fruit with durometer firmness 65 or softer at removal.

Data from these trials will be used to generate shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, and impacts of delays and temperature fluctuations.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2023 'Hass' avocado season using fruit from a CQ farm. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Hass' avocados to various supply chain conditions. The trials also investigated a wide range of factors affecting fruit quality and shelf life, including controlled atmosphere storage, fruit maturity (dry matter) and fruit size. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Hass' avocado fruit (targeting dry matter >23%) were sourced for trials during the 2023 season from a farm located near Childers, Queensland. Fruit were sampled at 3 different times within the harvest period; 2-5 June (Mid 1), 19 June (Mid 2) and 1 August (Late). Fruit were commercially harvested, placed into field bins and transferred to the nearby packing shed. The Mid 1 trial included small fruit of a mixed batch picked on 2 June and held at 8°C prior to packing on 6 June. The large fruit in this trial were harvested on 5 June and packed the following day. In other trials fruit were packed the day following harvest.

At the pack shed, fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Large (count 20) and small (count 28) fruit were used in the trials. Packed fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car for 3 hours at approx. 22-25°C and then kept overnight at approx. 20°C. The Mid 2 trial commenced the day after packing, while the other trials commenced 2 days after packing.

At the laboratory, the dry matter (DM) content was estimated for each individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of approximately 15 large and 15 small fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. All treatments were applied to a single tray of 15 small (count 28) fruit. Selected treatments were also applied to a tray of 15 large (count 20) fruit. A subset group at 5°C was stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Additional treatments tested the effect of preconditioning at 5°C for 5 days prior to 3°C storage. Fruit within these trials were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored during storage to calculate time x temperature units (TTU). Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Hass’ avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
3	5	10		20	30	45
5+3		10		20	30	45
5	5	10 ^L	15	20 ^L	25	30 ^L 45 ^L
5+CA				20 ^L	25	30 ^L 45 ^L
7	5	10		20	30	
10	5	10	15	20		
15	5	10	15			
20	0 ^L	5 ^L				

^L Indicates treatments were applied to trays of small and large fruit, while other treatment were applied only to small fruit
 5+3 treatments were pre-conditioned at 5°C for 5 days before being shifted to 3°C for the remainder of the storage period
 5+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂
 Planned treatment durations were followed where possible, but in some cases durations were adjusted by up to +/- 2 days

At trial commencement all fruit were weighed. In addition, skin colour score and firmness were recorded for 15 large and 15 small fruit. Skin colour score was recorded according to the scale below:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx. 25% colour development
- 4 = Approx. 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, skin colour score, weight and firmness were recorded for all fruit. Skin chilling injury, which typically appeared as discrete dark patches, was recorded according to the scale below:

Skin chilling injury rating scale

- 0 = None
- 1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.
- 2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.
- 3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.
- 4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.
- 5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After storage treatment, fruit were shifted to 20°C for ongoing shelf life assessment, with fruit quality monitored at least every 2 days. The date at which each fruit reached firm soft (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium soft (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury, the incidence of severe shrivel, and percentage surface area (SA) of skin darkening. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including

body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Trial fruit had an average oven DM of 27.5%. Small fruit DM remained similar over the 2 mid-season trials, becoming slightly higher in the late trial (Table 2). Large fruit DM increased across the 3 trials. The relationships between NIR predicted DM and oven DM were generally good, but in the late data set no significant relationships were shown.

Table 2. Dry matter content in 2023 'Hass' trials

Trial	Harvest date	Small fruit DM	Large fruit DM
Mid 1	2 June (S) / 5 June (L)	27.2	23.7
Mid 2	19 June	26.7	26.1
Late	1 August	29.7	31.7

Weight loss

Fruit weight loss at cold removal tended to increase with storage time and temperature. For all treatments weight loss remained less than 7% (data not shown). Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Small fruit lost an average 5% of their weight after 5 days at 20°C and 65% RH. At 5°C and 90% RH, it took around 30 days for fruit to lose this amount of weight.

Firmness changes in storage treatments

Changes in small fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to firm ripe stage within around 6 to 8 days. Storage at cooler temperatures progressively slowed ripening. At 3 to 7°C, firmness change was minimal, with fruit showing very gradual softening over long storage periods. Storage at 10°C slowed fruit softening over short durations, but rapid softening was observed after 15 days. The strongest temperature effect was shown in the difference between 10 and 15°C. Fruit stored at 15°C softened much more rapidly than those kept at 10°C.

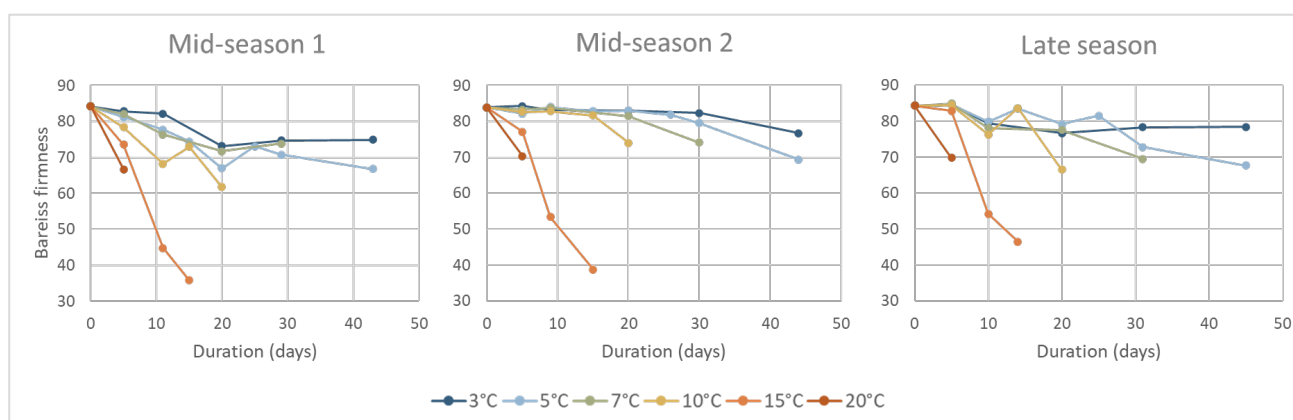


Figure 1. Changes in mean fruit firmness of small (count 28) 'Hass' avocados during storage at various temperatures

The patterns shown in firmness change were generally similar across the 3 harvest timings. Small fruit in the Mid 1 trial had a delay between harvest and packing (stored at approx. 8°C for an additional 3 days prior to packing). The fruit were then exposed to warmer temperatures during packing and trial set up before being cooled back down for treatment. This was the likely cause of the slightly more rapid softening shown in the Mid 1 trial.

In large fruit, firmness changes recorded at 5 and 20°C generally followed similar trends to those shown in small fruit (data not shown). However, in the Mid 1 trial, small fruit softened much more rapidly than large fruit. The delay between harvest date and packing for small fruit in the Mid 1 trial may have contributed to this difference. In addition, the small fruit in this trial had a higher DM content than the large fruit, suggesting they were slightly more mature. This may also have contributed to more rapid softening.

Firmness changes during shelf life assessment

Small fruit kept constantly at 20°C reached firm soft stage after an average 7 days (Table 3). The days taken to reach firm soft reflected a similar pattern to those seen in firmness values. Longer durations of storage and warmer storage temperatures tended to hasten subsequent softening to firm soft after fruit were transferred to 20°C. However, differences between 3 to 10°C were comparatively slight. The greatest change in days taken to reach firm soft was shown between fruit stored at 10 and 15°C.

Table 3. Days taken for small ‘Hass’ avocados to reach firm soft stage following various storage treatments

Trial	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Mid 1	3		4.7	4.7		3.5		3.3	4.7
	5		4.1	3.3	3.2	3.5	3.1	3.0	2.6
	7		5.1	3.9		3.4		3.1	
	10		4.5	3.1	3.7	2.3			
	15		2.5	-0.3	-2.4				
	20	6.0	2.1						
Mid 2	3		6.1	4.8		4.3		3.7	4.3
	5		6.5	5.1	4.1	4.0	3.9	2.9	3.1
	7		6.1	4.7		3.5		2.7	
	10		6.0	4.9	3.9	2.9			
	15		2.7	0.0	-2.4				
	20	7.1	1.9						
Late	3		6.2	5.3		4.3		4.0	4.9
	5		5.8	4.2	4.5	3.5	3.5	3.1	2.9
	7		6.0	4.9		3.6		2.7	
	10		5.9	4.2	3.6	2.3			
	15		4.6	0.7	-0.7				
	20	7.7	2.7						

The days taken to reach firm soft were very similar in corresponding treatments for large and small fruit (data not shown), with the exception of the Mid 1 trial. In this trial small fruit reached firm soft around 1-2 days earlier than corresponding large fruit. This was likely due to the delay prior to packing and associated break in the cold chain, with small fruit picked 3 days before large fruit.

Patterns observed in days to reach medium soft were very similar to those shown in reaching firm soft (Table 4). Fruit took an average of 3 days to ripen from firm soft to medium soft. No consistent differences

were observed between the 3 different trials in the days taken to ripen from firm soft to medium soft. The longer time taken to reach medium soft shown in some long treatments, such as 45 days at 3°C, may have resulted from mild chilling damage causing inhibition of ripening.

Table 4. Days taken for small ‘Hass’ avocados to reach medium soft stage following various storage treatments

Trial	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Mid 1	3		8.0	7.6		6.7		7.1	8.2
	5		8.0	6.8	5.9	5.8	7.3	5.5	7.0
	7		9.3	6.7		5.8		5.1	
	10		8.4	6.2	5.6	4.5			
	15		6.2	3.7	0.1				
	20	9.1	5.3						
Mid 2	3		7.8	7.3		7.2		8.4	9.5
	5		8.1	9.0	6.1	6.3	8.1	8.3	7.4
	7		7.7	7.9		6.3		7.7	
	10		7.7	7.7	5.7	5.6			
	15		5.5	2.9	1.7				
	20	9.5	4.5						
Late	3		8.9	7.5		7.6		6.4	8.0
	5		9.3	6.5	6.9	7.2	6.7	5.6	6.8
	7		9.6	7.2		6.7		4.9	
	10		9.3	6.6	6.6	6.1			
	15		8.8	4.1	2.3				
	20	10.1	6.3						

Figure 2 summarises the days taken to reach medium soft across all three trials, with internal chilling being observed in some of the longer treatments.

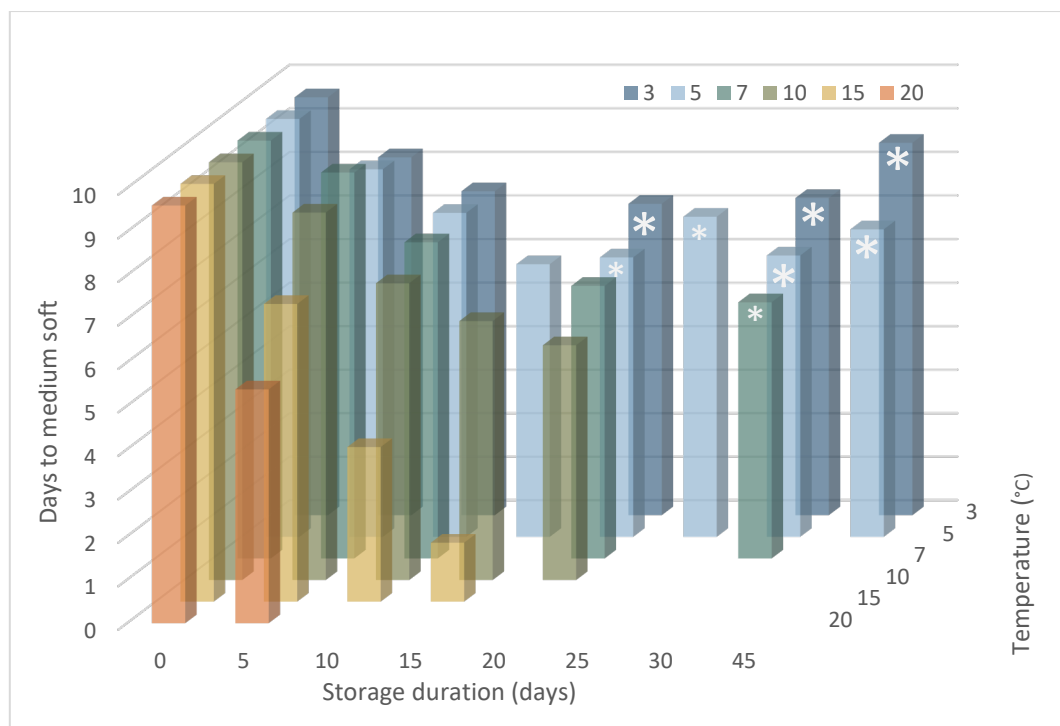


Figure 2. Days taken to reach medium soft at 20°C by small 'Hass' avocados after storage at various temperatures, with data pooled from 3 harvest timings.

(* Indicates treatments with internal chilling damage mean exceeding 1% volume, larger asterisks show chilling exceeding 5%)

Skin colour development

Colour development at medium soft generally averaged around score 5 (purple colour with less than 10% green). While some fruit retained more green skin colour at ripe, there were no obvious trends or patterns relating to storage treatments or NIR predicted DM values. In some fruit, skin colour seemed to develop from green to green-black, without any purple colour development. This type of colour development was generally observed to be more dull in sheen and less visually appealing. Green-black colour development was most common in long stored fruit (30 days or longer), but also occurred in fruit kept at 15 to 20°C (Table 5). It was less frequent in fruit stored at 10°C or less for up to 25 days.

Table 5. Index of green-black skin colour development in 'Hass' avocados after various storage conditions, with data pooled from 3 harvest timings (100 = green-black colour development occurring in all fruit).

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		0	12		13		26	56
	5		10	17	4	17	8	47	70
	7		4	8		14		30	
	10		11	17	14	8			
	15		20	30	33				
	20	29	36						
Large	5			7		2		32	90
	20	30	32						

Skin chilling injury

Chilling injury on the skin was characterised as discrete dark patches. Mild symptoms were observed in some fruit after 20 and 30 days of storage at 3 to 7°C (Table 6). Severe symptoms were recorded in all treatments after 45 days.

Table 6. Severity of discrete patches on 'Hass' avocados (average % surface area) at removal from various storage conditions, with data pooled from 3 harvest timings.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		0	0		1.7		1.5	15.4
	5		0	0	0	0.2	0.1	1.2	30.1
	7		0	0		0		2.0	
	10		0	0	0	0			
	15		0	0	0				
	20	0	0						
Large	5			0		0.3		0.7	43.4
	20	0	0						

Internal chilling injury

Symptoms of internal chilling damage appeared as diffuse discolouration of the flesh, as shown in Figure 3.



Figure 3. Internal diffuse discolouration symptoms in 'Hass' avocados associated with mild or severe chilling damage

Diffuse discolouration was observed predominantly in fruit stored for long periods at 3 or 5°C (Table 7). The chilling response was most severe in small fruit from the Mid 1 trial. In this trial substantial internal chilling damage emerged in small fruit following 20 days at 3 or 5°C. In the two later trials severe internal chilling tended to emerge only after 45 days. The small Mid 1 fruit were stored at 8°C for 3 days prior to the trial commencing. This effectively extended the duration of cool storage. The delay prior to packing also resulted in fruit starting to soften while in cold treatments. A strong chilling response was triggered by ripening of the fruit while in cold storage. Previous research has established that chilling damage is more likely when fruit start to ripen while in cold storage (Ekman 2017). A striking relationship was shown between the firmness of individual fruit at the end of storage and subsequent development of diffuse discolouration. In chill affected treatments (non-CA), small fruit that had softened below durometer firmness 65 during cold storage averaged 46% volume diffuse discolouration. In contrast, fruit that remained firmer than 65 averaged 3% (data combined across all trials). Similar trends were shown in large fruit.

Large fruit generally showed similar responses to small fruit, with minor chilling at 30 days, worsening after 45 days. Large fruit from the Mid 1 trial were less prone to chilling damage than small fruit. The large fruit in this trial were not exposed to cool storage prior to packing and did not soften during cold storage.

The large fruit in Mid 1 also showed lower levels of chilling compared with large fruit in the two later trials. Chilling sensitivity in fresh produce is complex and can be influenced by numerous variables, so it is difficult to establish a clear reason for this difference. Fruit maturity can influence chilling sensitivity in 'Hass', with previous research suggesting both immature and over-mature fruit can show higher sensitivity (Ekman 2017). This group of fruit had the lowest mean DM, averaging 23.7%. The large fruit in the Mid 2 trial had an average DM of 26.1%, and the late trial 31.7%, with similar levels of chilling injury. Weather conditions prior to harvest can also influence chilling sensitivity, but no substantial differences between batches were observed in temperatures leading up to harvest.

Table 7. Internal chilling injury severity (% diffuse discolouration of flesh) in 'Hass' avocados at medium soft stage following various storage treatments.

Trial	Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
			0	5	10	15	20	25	30	45
Mid 1	Small	3		0	0		18.3		16.8	23.5
		5		0.3	0.3	0	11.3	4.3	10.1	13.4
		7		0	0.3		0		4.0	
	Large	5			0		0		1.1	3.2
Mid 2	Small	3		0	0		0		0.3	11.6
		5		0	0	0	0	0	1.9	19.3
		7		0	0		1.3		1.7	
	Large	5			0		0		2.7	20.0
Late	Small	3		0	0		4.1		0	13.27
		5		0	0	0	0	1.0	4.4	17.67
		7		0	0		0		5.9	
	Large	5			0		0		6.4	21.1

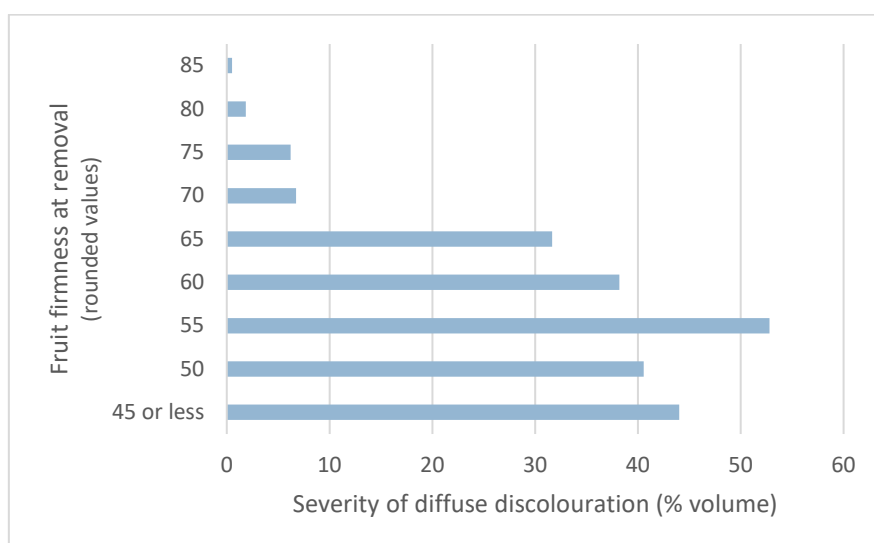


Figure 4. Relationship between fruit firmness at end of cold storage and development of diffuse discolouration in 'Hass' avocados.

(Using combined data from 3 trials of small fruit stored 20 days or longer at 5°C or less, without CA)

Rots

Body rots were an issue in all 3 trials, with around 24% of small fruit having rots recorded at medium soft. The rots worsened with long storage, with the majority of fruit showing rots after 45 days storage (Table 8). Large fruit showed slightly higher incidence and severity of body rots compared with small fruit, particularly when kept at constant 20°C (Table 9). The lowest overall incidence and severity of body rots tended to occur in fruit stored for 10 to 15 days at 7°C or lower. Results were similar across all 3 trials, with the exception of large fruit body rots tending to being slightly lower in the Mid 2 trial than the other 2 trials (data not shown).

Table 8. Incidence of body rots in medium soft 'Hass' avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		4	0		22		20	68
	5		13	11	2	20	20	36	71
	7		18	0		22		29	
	10		16	22	24	33			
	15		20	31	40				
	20	18	29						
Large	5			17		20		43	90
	20	50	63						

Table 9. Severity of body rots in medium soft 'Hass' avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		0.4	0.0		2.4		4.0	13.7
	5		1.5	0.7	0.0	1.0	3.6	2.5	12.0
	7		2.5	0.0		0.5		4.9	
	10		1.6	0.7	0.6	2.6			
	15		1.4	2.4	5.0				
	20	0.6	1.1						
Large	5			0.4		0.9		6.6	15.2
	20	2.7	4.3						

Stem end rots were less of an issue than body rots, with an average incidence of 7% and severity of less than 1% volume in small fruit across all trials (data not shown). Treatments extending to 45 days showed the worst levels of stem end rot, with around 18% of fruit affected, averaging 2-3% volume.

Consumer tolerance

The standard of internal quality when fruit reached medium soft was generally good (Table 10). Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, Harker et al. 2010). The percentage of acceptable small fruit generally remained at 80% or higher following storage periods of up to 25 days. Quality declined slightly at 30 days and was very poor after 45 days. Similarly, large fruit quality was good after storage at 5°C for 10 or 20 days, with a decline at 30 days,

and poor quality at 45 days. Large fruit also showed some internal quality issues when kept at constant 20°C.

Table 10. Percentage of 'Hass' avocados maintaining acceptable consumer tolerance for internal defect volume at medium soft stage after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		96	100		80		76	40
	5		93	93	96	87	84	73	29
	7		82	98		91		71	
	10		93	96	98	82			
	15		87	82	78				
	20	91	96						
Large	5			97		90		60	30
	20	77	77						

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage over durations of 20 to 45 days at 5°C. CA slightly reduced weight loss compared with air (Table 11), with this effect occurring consistently across all trials.

Table 11. Weight loss in 'Hass' avocados stored under air or CA at 5°C for various durations, with data pooled from 3 trials

Fruit size	Storage duration (days)	Weight loss after storage (%)	
		Air	CA
Small	20	2.5	1.7
	25	2.8	2.2
	30	4.3	2.8
	45	6.0	3.3
Large	20	2.2	1.7
	30	3.9	2.3
	45	5.2	2.9

CA maintained fruit firmness, with fruit remaining hard when stored under CA for up to 45 days (Table 12). In contrast, fruit firmness gradually declined in fruit held at 5°C in air. The Mid 1 trial small fruit showed a stronger softening response across all treatments, due to the delay between picking and packing.

Table 12. Firmness of 'Hass' avocados at removal from various storage treatments, with and without CA

Fruit Size	Storage duration (days)	Mid 1			Mid 2			Late	
		Air	CA		Air	CA		Air	CA
Small	20	67.0	78.0		83.0	82.1		79.1	79.2
	25	73.0	78.7		81.9	80.2		81.5	83.8
	30	70.7	77.4		79.6	83.5		72.8	79.0
	45	66.7	76.5		69.4	81.9		67.6	81.1
Large	20	79.4	80.7		84.6	82.9		80.5	80.1
	30	82.5	84.2		81.8	83.8		74.9	82.5
	45	75.4	84.7		70.1	82.8		71.8	84.6

Changes in skin colour showed a very similar pattern, with green skin colour being retained under CA (Table 13, Figure 5). In the Mid 1 trial, small fruit stored in air showed noticeable colour change even after 20 days. In the 2 later trials, differences in skin colour change between air and CA did not become apparent until 45 days.

Table 13. Skin colour score of 'Hass' avocados at removal from various storage treatments, with and without CA

Fruit Size	Storage duration (days)	Mid 1			Mid 2			Late	
		Air	CA		Air	CA		Air	CA
Small	20	2.9	2.0		2.0	2.0		1.9	1.8
	25	2.4	2.0		2.0	2.0		2.1	2.0
	30	2.6	2.1		2.2	2.0		2.0	1.9
	45	3.9	2.2		3.4	2.0		3.6	2.0
Large	20	2.0	2.0		2.0	2.0		2.0	1.8
	30	2.0	2.0		2.0	2.0		1.9	1.9
	45	3.3	2.0		3.6	2.0		3.6	2.0

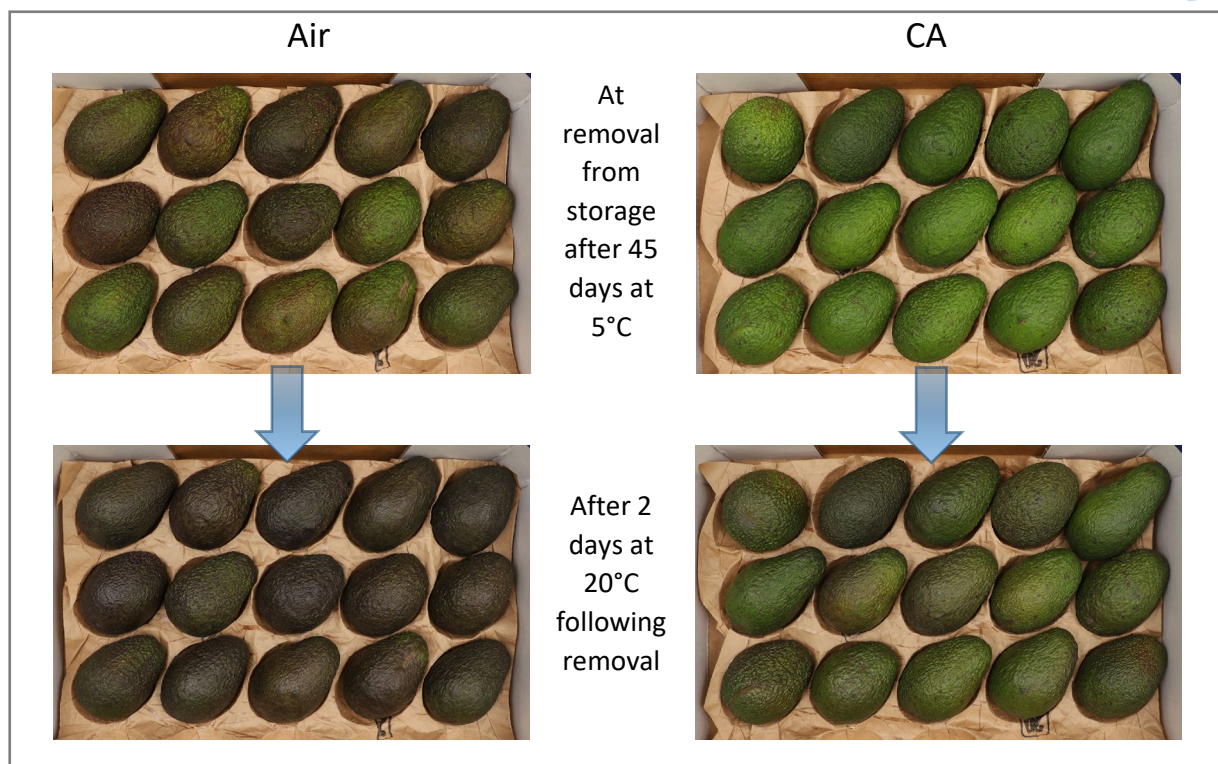


Figure 5. Differences in 'Hass' avocado colour under CA compared to air.
(in small fruit from the Late trial)

Discrete patches and green-black colour development were both substantially reduced by CA (Table 14).

Table 14. Severity of discrete patches (average % surface area) and index of black colour development in 'Hass' avocados following various storage treatments with or without CA (pooled from 3 trials)

Fruit size	Storage duration (days)	Discrete patches (%SA)		Index of black colour development	
		Air	CA	Air	CA
Small	20	0.2	0.1	17	9
	25	0.1	0.0	8	2
	30	1.2	0.0	47	2
	45	30.1	0.0	70	26
Large	20	0.3	0.1	2	7
	30	0.7	0.0	41	1
	45	43.4	0.0	92	4

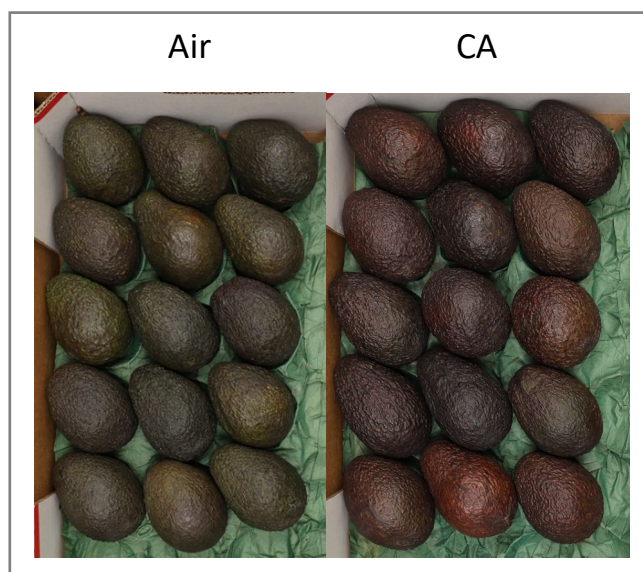


Figure 6. Differences in colour development in long stored 'Hass' avocados under air and CA:

Air stored fruit show green-black colour development, while CA stored fruit show more purple colour.

Photos are of small fruit from the Mid 2 trial after ripening to medium soft at 20°C following 45 days at 5°C

Storage under CA reduced body rot incidence and severity compared to air (Table 15). These benefits were strongest in the 2 later trials, where minimal body rots occurred under CA (data not shown). In the Mid 1 trial body rots were reduced by CA in both small and large fruit, but to a lesser extent than in the 2 later trials (data not shown).

Overall, CA was also generally beneficial in reducing stem end rot. Stem end rots were eliminated by CA in the 2 later trials (data not shown). Low levels of stem end rot occurred in these trials under air, and none were recorded under CA. In contrast, CA had inconsistent effects on stem end rot in the Mid 1 trial, in both large and small fruit (data not shown).

Table 15. Severity and incidence of rots in 'Hass' avocados at medium soft following storage at 5°C for various periods with or without CA.

Fruit size	Storage duration (days)	Body rot severity (% SA)		Body rot incidence (% fruit)		Stem end rot severity (% SA)		Stem end rot incidence (% fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	1.0	0.0	20.0	2.2	0.0	0.0	0.0	0.0
	25	3.6	1.1	20.0	13.3	0.2	0.0	9.0	0.0
	30	2.5	1.3	35.6	8.9	0.2	0.3	6.7	4.4
	45	12.0	1.6	71.1	15.6	1.6	0.5	17.7	6.7
Large	20	0.7	1.5	17.8	11.1	0.0	0.5	2.2	6.7
	30	5.5	1.4	37.8	24.4	0.1	0.2	2.2	6.7
	45	14.1	2.3	82.2	24.4	2.2	0.1	8.9	4.4

Storage under CA strongly reduced diffuse discolouration of the flesh in all batches except the Mid 1 small fruit (Table 16). This suggests that CA is not able to counter the chilling damage incurred when fruit start to ripen in cold storage.

Table 16. Diffuse discolouration (% volume) in 'Hass' avocados stored at 5°C with and without CA

Fruit Size	Storage duration (days)	Mid 1		Mid 2		Late	
		Air	CA	Air	CA	Air	CA
Small	20	11.3	0.3	0	0	0	0
	25	4.3	3.5	0	0	1.0	0.1
	30	10.1	11.0	1.9	0	4.4	0
	45	13.4	22.1	19.3	0.03	17.7	0
Large	20	0.0	0.0	0	0	0	0
	30	1.1	0.0	2.7	0	6.4	0
	45	3.2	0.0	20.0	0	21.1	1.3

Fruit stored under CA tended to take around 1 day longer than air-stored fruit to reach firm soft and medium soft stages after being transferred to 20°C (Table 17). Flesh quality declined with prolonged cool storage in air. Around 30% of fruit had unacceptable internal defects at 30 days, and the majority of fruit were unacceptable at 45 days. In contrast, CA maintained at least 90% acceptable internal quality even after 45 days.

Table 17. Days taken for 'Hass' avocados to reach firm soft and medium soft at 20°C following storage, and percentage of acceptable fruit at medium soft.

Fruit size	Storage duration (days)	Days to firm soft		Days to medium soft		Fruit with acceptable flesh quality (%)	
		Air	CA	Air	CA	Air	CA
Small	20	3.7	4.8	6.4	7.1	87	100
	25	3.5	4.2	7.4	7.3	84	91
	30	3.0	4.4	6.5	7.3	73	93
	45	2.8	4.4	7.1	7.3	29	91
Large	20	4.0	4.8	7.2	8.0	93	91
	30	3.4	5.4	7.1	7.9	67	87
	45	3.4	5.0	6.8	8.4	22	93

Pre-conditioning

Pre-conditioning was applied to a sub-set of treatments in the first 2 trials. Fruit were kept at 5°C for 5 days before being shifted to 3°C for the remainder of the storage period. No clear effects or trends were observed in these treatments (data not shown). Overall, measured quality traits in pre-conditioned fruit tended to be close to those shown in 3 and 5°C treatments.



Post-storage exposure to 3°C

In the late harvest trial, a sub-set of fruit were exposed to various durations of 3°C storage immediately after 20 days at 5°C. No obvious issues were detected in fruit stored for up to 8 days at 3°C following 20 days at 5°C (Table 18).

Table 18. Quality indices in 'Hass' avocados transferred to 3°C following 20 days at 5°C

Fruit size	Initial storage	Subsequent storage duration at 3°C (days)	Total storage (days)	Firmness at treatment end	Discrete patches (%SA)	Diffuse discolouration (% vol)	Days to firm soft	Days to med soft	Acceptable internal quality (% of fruit)
Small	20d at 5°C	0	20	79.1	0.7	0	3.5	7.2	93
		1	21	-	0	0	3.3	6.1	100
		2	22	82.4	0	0	3.5	6.5	100
		4	24	79.9	0	0	4.9	7.9	93
		5	25	82.9	0	0	3.7	6.7	100
		6	26	82.4	0	0	4.3	6.9	93
		7	27	80.6	0	0	4.5	7.3	100
		8	28	77.9	1.7	0	4.4	6.8	100
Large	20d at 5°C	0	20	80.5	1.0	0	4.1	8.5	87
		2	22	83.2	0	0	3.5	6.9	93
		5	25	83.3	0.1	0.7	3.3	7.3	87



4. Summaries and recommendations

- Storage at 5°C would typically be recommended for the best overall quality and shelf life in 'Hass' avocados, with rates of softening increasing substantially at temperatures over 10°C.
- CA storage provided clear benefits in long duration storage, maintaining fruit firmness and reducing defects.
- Under CA at 5°C, acceptable internal quality was possible following storage of 45 days.
- Strong impacts on fruit quality were shown when fruit were held for 3 days prior to packing, with a break in the cold chain. Further research on temperature fluctuation and delays prior to CA would be suggested to build these factors into the modelling.
- Ripening during cool storage was associated with higher severity of internal chilling damage, particularly when fruit softened to durometer firmness of lower than 70 at removal. This value could be useful as an indicator of potential chill damage.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

6. References

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Appendix 19

CQ 'Hass' avocado simulation trials report 2023b

Predicting fruit quality and shelf life for 'Hass' avocado

A 2023 season Central Queensland grower report

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Summary

A series of export simulation trials were completed with 'Hass' avocados to quantify fruit quality and shelf life response to a range of supply chain handling scenarios. Commercially mature fruit of 2 different sizes were harvested from a farm near Childers, Queensland in May, June and July 2023. The fruit were stored at 3, 5, 7, 10 and 15°C and 90% relative humidity (RH) for up to 45 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. The influence of controlled atmosphere (CA) storage and pre-conditioning treatments on fruit quality were also evaluated. Key observations included:

- Firmness changes in 'Hass' avocados were strongly affected by storage temperature, with cooler storage temperatures delaying fruit softening.
- A substantial increase in rate of softening occurred between 10 and 15°C.
- While early season fruit took longer to ripen and late season fruit ripened most rapidly, these differences narrowed following storage.
- Green-black skin colour development, which was less visually appealing than glossy purple skin colour, occurred more commonly after 30 days or longer in cool storage, and at warm storage temperatures (15-20°C).
- Skin chilling (discrete patches) started to appear after 20 days at 3-5°C, becoming more severe with longer storage duration.
- Internal chilling damage (diffuse discolouration) was affected by duration more than temperature, with similar levels shown at 3 and 5°C. Damage emerged after 20 days and progressively worsened with longer storage. While early season fruit appeared to be most susceptible to this type of damage, symptoms were also observed following 7°C storage in mid to late season fruit.
- Ripening during cool storage was associated with higher severity of internal chilling damage, particularly in fruit with durometer firmness 65 or softer at removal.
- Body and stem end rots were a key issue when fruit ripened to medium soft. Rots increased with long storage duration (20 days or longer) and warm storage temperatures (15 and 20°C).
- CA storage showed strong benefits in:
 - retaining fruit firmness
 - reducing moisture loss
 - reducing green-black colour development, rots and chilling damage
 - improving internal quality

Data from these trials will be used to generate shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, and exploring the impact of delays prior to CA storage on fruit quality.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2023 'Hass' avocado season. The main objective of the trial was to quantify the fruit quality and shelf life response of 'Hass' avocados to various supply chain conditions. The trial also investigated a wide range of factors affecting fruit quality and shelf life, including controlled atmosphere storage, fruit maturity (dry matter) and fruit size. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Hass' avocado fruit (targeting dry matter >23%) were sourced for trials during the 2023 season from a farm located near Childers, Queensland. Fruit were harvested at 3 different stages within the harvest period; 3 May (early), 13 June (mid) and 10 July (late). The fruit were placed into field bins and transferred to the nearby packing shed on the same day. On the following day, they were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Large (count 20) and small (count 28) fruit were used in the trials. Packed fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car for 3 hours at approx. 22-25°C and then kept overnight at approx. 20-24°C. Early and mid-season trials commenced on the day following packing. The late trial fruit were collected the day after packing, with the trial commencing 2 days after packing.

At the laboratory, the dry matter (DM) content was estimated for each individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of approximately 15 large and 15 small fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. All treatments were applied to a single tray of 15 small (count 28) fruit. Selected treatments were also applied to a tray of 15 large (count 20) fruit. A subset group at 5°C was stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Additional treatments tested the effect of preconditioning at 5°C for 5 days prior to 3°C storage. Fruit within the trials were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored during storage to calculate time x temperature units (TTU). Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of 'Hass' avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
3	5	10		20	30	45
5+3		10		20	30	45
5	5	10 ^L	15	20 ^L	25	30 ^L 45 ^L
5+CA				20 ^L	25	30 ^L 45 ^L
7	5	10		20	30	
10	5	10	15	20		
15	5	10	15			
20	0 ^L	5 ^L				

^L Indicates treatments were applied to trays of small and large fruit, while other treatment were applied only to small fruit
 5+3 treatments were pre-conditioned at 5°C for 5 days before being shifted to 3°C for the remainder of the storage period
 The durations of 5+3 treatments varied in the early trial, with total durations of 14, 25, 35 and 49 days.

5+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

Planned treatment durations were followed where possible, but in some cases durations were adjusted by up to +/- 2 days

At trial commencement all fruit were weighed. In addition, skin colour score and firmness were recorded for 15 large and 15 small fruit. Skin colour score was recorded according to the scale below:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx 25% colour development
- 4 = Approx 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, skin colour score, weight and firmness were recorded for all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

- 0 = None
- 1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.
- 2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.
- 3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.
- 4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.
- 5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After each storage treatment, fruit were shifted to 20°C for ongoing shelf life assessment, with fruit quality monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium soft (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury, the incidence of severe shrivel, and %SA of skin darkening. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Trial fruit had an average oven DM of 29%, with DM increasing as the season progressed (Table 2). Large fruit DM was significantly lower than small fruit in the Early trial (t-test, $p=0.03$). In the Mid and Late trials small and large fruit did not significantly differ in DM. The relationships between NIR predicted DM and oven DM were generally strong, but in the early data set these relationships were weak.

Table 2. Dry matter content in 2023 'Hass' trials

Trial	Harvest date	Small fruit DM	Large fruit DM
Early	3 May	26.9	24.8
Mid	13 June	29.3	29.9
Late	10 July	33.0	31.1

Weight loss

Fruit weight loss at cold removal tended to increase with storage time and temperature. For all treatments weight loss remained less than 6% (data not shown). Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Small fruit lost an average 5% of their weight after 5 days at 20°C and 65% RH. At 5°C and 90% RH, it took around 45 days for fruit to lose this amount of weight.

Firmness changes in storage treatments

Changes in small fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 15 and 20°C fruit ripened rapidly. Storage at cooler temperatures delayed the commencement of softening and slowed the rate of firmness change. The strongest temperature effect was shown in the difference between 10 and 15°C. Fruit stored at 15°C softened much more rapidly than those kept at 10°C.

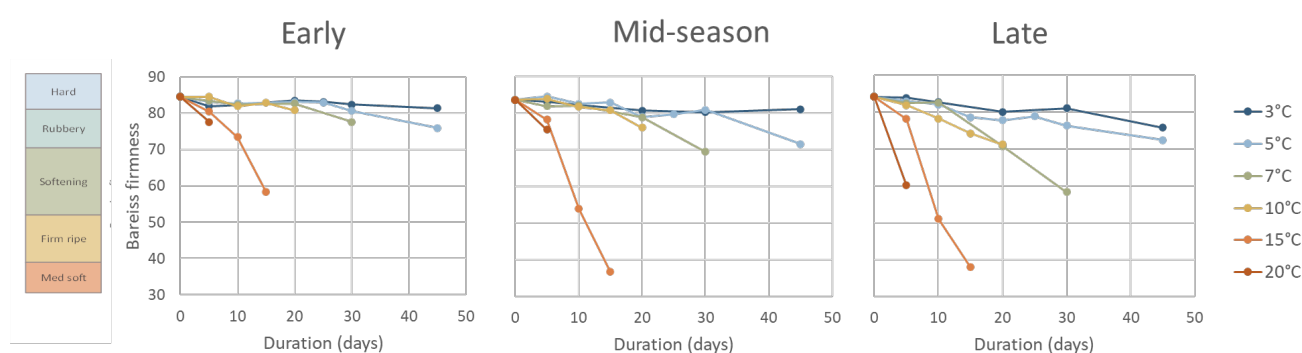


Figure 1. Changes in mean fruit firmness of small (count 28) 'Hass' avocados during storage at various temperatures

A clear trend was shown across the 3 harvest timings, with the rate of firmness change increasing through the season. Early season fruit kept at 20°C took an average of 11 days to reach firm ripe, compared with 8 days in mid-season, and 6 days in late season.

In large fruit, firmness changes recorded at 5 and 20°C generally followed similar trends to those shown in small fruit (data not shown). In the early trial, large fruit showed more softening than small fruit after 45 days at 5°C. In the mid and late trials large fruit softened more rapidly than small fruit at 20°C, but showed similar softening at 5°C.

Firmness changes during shelf life assessment

Harvest timing had a strong impact on the time taken for small fruit to reach firm ripe, particularly when kept constantly at 20°C (Table 3). Early season fruit took much longer to ripen to firm ripe, while late season fruit ripened most rapidly. These differences narrowed following storage.

The days taken to reach firm ripe reflected similar patterns to those seen in firmness values. Longer durations of storage and warmer storage temperatures tended to hasten subsequent softening to firm ripe after fruit were transferred to 20°C. However, differences between the range of 3 to 10°C were comparatively slight. The greatest change in days taken to reach firm ripe was shown between fruit stored at 10 and 15°C.

Cold storage for 25 days or longer at 3-5°C showed some signs of slowing subsequent ripening in early season fruit. This may have resulted from chilling damage inhibiting ripening. This response was not observed in mid and late season fruit.

Table 3. Days taken for small 'Hass' avocados to reach firm ripe stage following various storage treatments

Trial	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Early	3		7.9	5.9		5.1	6.1	7.0	8.6
	5		7.5	5.1		4.8	6.4	4.6	6.7
	7		9.6	6.9		4.9		4.1	
	10		8.6	7.7	5.3	4.8			
	15		6.9	3.0	0.7				
	20	11.3	5.3						
Mid	3		6.6	4.5		5.0		3.4	4.2
	5		5.8	5.0	4.7	4.0	3.8	4.3	3.5
	7		5.7	5.2		4.3		3.5	
	10		6.4	4.9	3.7	3.3			
	15		3.3	0.6	0.0				
	20	7.9	3.1						
Late	3		5.1	4.5		3.7		3.5	3.7
	5		5.1	5.4	5.1	3.6	4.0	2.9	3.5
	7		4.1	3.4		2.0		1.8	
	10		4.7	4.8	4.2	3.7			
	15		3.3	-0.3	-2.7				
	20	6.4	0.6						

Fruit took around 3-4 days to soften from firm ripe to medium soft. Early season fruit averaged 4 days, while mid and late season fruit averaged 3 days. The general trends observed in days taken for fruit to reach medium soft were very similar to those shown in reaching firm ripe (data not shown).

Large fruit showed similar responses in days taken to reach firm ripe to those shown in corresponding treatments for small fruit (data not shown).

Skin colour development

Colour development at medium soft generally averaged around score 5 (purple colour with less than 10% green). There was a tendency for fruit to show more colour development towards black as the season progressed, with medium soft colour score averaging 5.0 in early season, 5.2 in mid-season and 5.5 in late season. While some fruit retained more green skin colour at ripe, there were no obvious trends or patterns relating to storage treatments (data not shown). A very weak positive correlation was shown between NIR predicted DM and skin colour at medium soft (correlation co-efficient 0.23). Higher DM fruit showed a slight tendency to develop skin colour scores further towards black at medium soft.

In some fruit, skin colour seemed to develop from green to green-black, without any purple colour development. This type of colour development was generally observed to be more dull in sheen and less visually appealing. Green-black colour development was most common in long stored fruit (30 days or longer) and in fruit kept at 15 to 20°C (Table 4). It was less frequent in fruit stored at 10°C or less for 10-20 days. This type of colour change was more common in large fruit than in small fruit.

Table 4. Index of green-black skin colour development in 'Hass' avocados after various storage conditions, with data pooled from 3 harvest timings (100 = green-black colour development occurring in all fruit).

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		14	9		11		18	36
	5		23	6	5	8	24	33	27
	7		20	12		18		39	
	10		26	11	21	16			
	15		32	38	33				
	20	24	23						
Large	5			17		21		66	58
	20	42	58						

Skin chilling injury

Chilling injury on the skin was characterised as discrete dark patches, generally observed at removal from cold storage. Mild symptoms were first observed in some fruit after 20 days of storage at 3 to 5°C, becoming more severe with longer duration (Table 5). Discrete patches did not differ substantially between 3 and 5°C. The disorder was rarely observed following storage at 7°C. Early harvest fruit seemed to be more susceptible to skin chilling damage than later picks, but no consistent differences were seen due to fruit size.

Table 5. Severity of discrete patches on 'Hass' avocados (average % surface area) at removal from various storage conditions.

Trial	Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage					
			10	15	20	25	30	45
Early	Small	3	0		0.3	1.2	0.9	65.9
		5	0		0	1.1	7.5	62.0
		7	0		0		0.3	
	Large	5	0		0		7.0	93.7
Mid	Small	3	0		0		0	2.6
		5	0	0	0	0.4	0.1	9.3
		7	0		0		0	
	Large	5			0		0	17.0
Late	Small	3	0		3.3		9.0	14.4
		5	0	0	0.7	0.7	11.7	15.8
		7	0		0		0	
	Large	5	0		0		8.7	16.7

Internal chilling injury

Symptoms of internal chilling damage appeared as diffuse discolouration of the flesh, as shown in Figure 2.



Figure 2. Internal diffuse discolouration symptoms in 'Hass' avocados associated with mild or severe chilling damage

Diffuse discolouration was observed predominantly in fruit stored for long periods at 7°C or lower (Table 6). No consistent differences in diffuse discolouration were shown between 3 and 5°C. Early harvest fruit stored at 7°C tended to show less damage than those stored at cooler temperatures. However, in the 2 later trials, 7°C resulted in similar levels of damage to 3 and 5°C. The development of diffuse discolouration seemed to be more influenced by the storage duration than the temperature. Minor damage occurred following storage for 20 days, and symptoms generally became more severe with longer storage periods. Large fruit generally showed fairly similar responses to small fruit, with mild chilling observed after 20 days at 5°C, worsening as storage duration increased.

Flesh chilling damage appeared to be worsened by ripening of the fruit while in cold storage. Previous research has established that chilling damage is more likely when fruit start to ripen while in cold storage (Ekman 2017). A strong relationship was shown between the firmness of individual fruit at the end of storage and the development of diffuse discolouration (Figure 3). Under chilling conditions, small fruit that had softened below durometer firmness 65 during cold storage showed 61% incidence of diffuse

discolouration, averaging 18% flesh volume. In contrast, fruit that remained firmer than 65 averaged 31% incidence and 5% volume (data combined across all trials). Similar trends were shown in large fruit (data not shown). Fruit firmness of 65 corresponded to fruit moving from the 'softening' stage towards firm ripe, with firm ripe stage commencing at durometer firmness 54.

Table 6. Internal chilling injury incidence (% of fruit with any diffuse discolouration of flesh) in 'Hass' avocados at medium soft stage following various storage treatments.

Trial	Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage					
			10	15	20	25	30	45
Early	Small	3	0		40	60	73	60
		5	0		40	67	73	53
		7	0		7		13	
	Large	5	0		13		67	47
Mid	Small	3	0		7		13	20
		5	0	0	7	0	7	40
		7	0		0		40	
	Large	5			0		13	80
Late	Small	3	0		7		27	73
		5	0	0	7	7	33	80
		7	0		13		40	
	Large	5	0		20		67	100

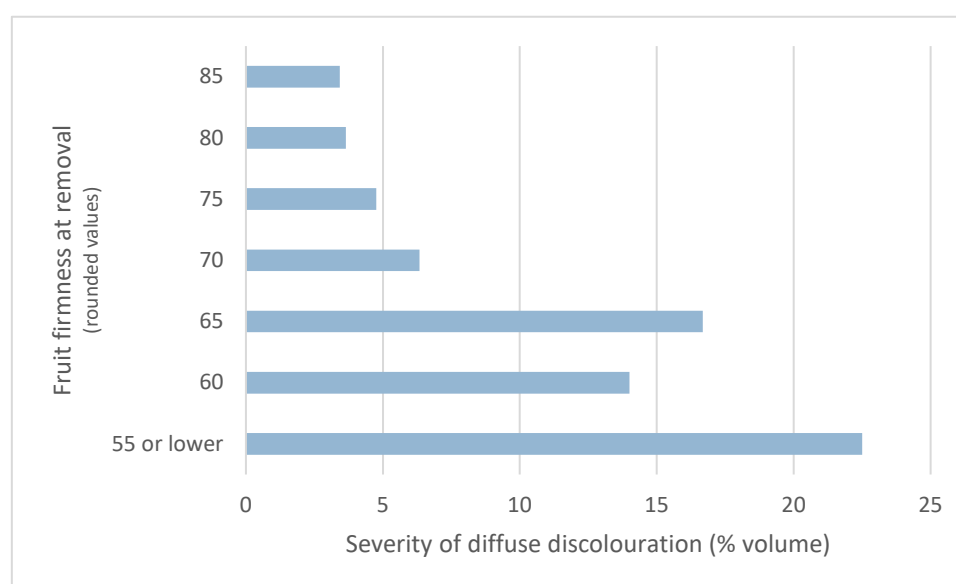


Figure 3. Relationship between fruit firmness at end of cold storage and severity of diffuse discolouration in 'Hass' avocados.

(Using combined data from 3 trials of small fruit stored 20 days or longer at 5°C or less, without CA)

While there was variation in chilling susceptibility across the 3 different harvest timings, no clear overarching trends were shown. Small early harvest fruit showed a tendency to develop diffuse discolouration earlier in storage. Fruit maturity can influence chilling sensitivity in 'Hass', with previous

research suggesting both immature and over-mature fruit can show higher sensitivity (Ekman 2017). However, in this trial no obvious patterns were observed between DM content of the different batches and chilling sensitivity. Similarly, no correlations were shown between individual fruit NIR estimated DM and internal chilling. Weather conditions prior to harvest can influence chilling sensitivity. The later 2 harvests were exposed to lower overnight minimum temperatures through May, with a few cold snaps occurring in this period. Chilling sensitivity in fresh produce is complex and can be influenced by numerous pre-harvest variables, so identifying reasons for variation is difficult.

Rots

Body rots were an issue in all 3 trials, with an average of 40% of small fruit having rots recorded at medium soft. The late season trial showed the highest overall levels of body rots (55% incidence) and mid season the least (26% incidence). Body rot issues worsened with long storage, with the majority of fruit showing rots at medium soft following storage of 30 days or longer (Table 7). Large fruit showed slightly higher incidence and severity of body rots compared with small fruit (Table 8). The lowest overall incidence and severity of body rots tended to occur in fruit stored for 5 to 15 days at 10°C or lower.

Table 7. Incidence of body rots in medium soft 'Hass' avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		27	27		42	47	47	80
	5		18	31	13	36	42	76	87
	7		29	20		40		62	
	10		27	20	22	53			
	15		36	42	47				
	20	47	31						
Large	5			57		40		76	98
	20	71	67						

Table 8. Severity of body rots in medium soft 'Hass' avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		1.3	1.6		3.7	3.7	5.3	17.0
	5		1.0	1.9	0.9	2.4	7.0	10.4	16.9
	7		1.0	0.7		1.6		10.9	
	10		0.9	1.6	0.6	3.9			
	15		1.3	2.3	5.7				
	20	0.8	1.7						
Large	5			5.5		2.3		12.3	21.3
	20	5.1	3.7						

Stem end rots were also an issue at medium soft stage, with an average incidence of 28% and severity of 2% volume in small fruit across all trials. This issue was most prevalent in the early harvest trial, where stem end incidence averaged 43% in medium soft small fruit and severity averaged 3.9% volume.

Stem end rots in small fruit seemed to increase both with storage temperature and duration of storage (Table 9). The severity of rots was lowest in fruit stored at 10°C or lower for up to 15 days (Table 10). In contrast, storage treatments seemed to have little impact on stem end rot development in large fruit.

Table 9. Incidence of stem end rots in medium soft ‘Hass’ avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		7	18		29		27	56
	5		11	20	20	31	33	42	53
	7		16	27		20		27	
	10		18	33	33	24			
	15		22	29	51				
	20	44	27						
Large	5			40		29		22	38
	20	42	44						

Table 10. Severity of stem end rots in medium soft ‘Hass’ avocados after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		0.9	1.0		2.9		1.9	8.9
	5		0.5	0.9	0.7	2.7	3.5	5.3	7.8
	7		0.5	1.0		2.4		1.7	
	10		0.4	1.2	1.2	1.1			
	15		1.6	2.6	2.5				
	20	0.8	1.9						
Large	5			2.6		2.4		2.5	1.7
	20	3.3	2.7						

Consumer tolerance

The internal quality of small fruit at medium soft was generally good after 5 days storage at 10°C or lower (Table 11). However, internal quality issues began to emerge following storage for 10 days, and increasingly worsened with prolonged storage. Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, Harker et al. 2010). Large fruit tended to show slightly more internal quality issues than small fruit.

Table 11. Percentage of 'Hass' avocados with unacceptable consumer tolerance for internal defect volume at medium soft stage after various storage conditions, with values pooled across 3 trials.

Fruit size	Storage temp (°C)	Storage duration (days) prior to ongoing 20°C storage							
		0	5	10	15	20	25	30	45
Small	3		4	16		29		36	80
	5		4	16	7	24	33	58	84
	7		4	13		13		53	
	10		4	13	11	18			
	15		13	22	29				
	20	20	18						
Large	5			30		20		73	98
	20	40	31						

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage for 20 to 45 days at 5°C. CA reduced weight loss compared with air (Table 12), with this effect occurring consistently across all trials.

Table 12. Weight loss in 'Hass' avocados stored under air or CA at 5°C for various durations, with data pooled from 3 trials

Fruit size	Storage duration (days)	Weight loss after storage (%)	
		Air	CA
Small	20	2.2	1.8
	25	2.6	2.3
	30	3.4	2.5
	45	5.2	3.4
Large	20	2.0	1.6
	30	3.1	2.1
	45	4.8	2.6

CA maintained fruit firmness, with fruit remaining hard when stored under CA for up to 45 days (Table 13). In contrast, fruit firmness gradually declined in fruit held at 5°C in air.

Table 13. Firmness of 'Hass' avocados at removal from storage treatments, with and without CA, with data pooled from 3 trials

Fruit size	Storage duration (days)	Durometer firmness after storage	
		Air	CA
Small	20	80.0	80.8
	25	80.5	81.3
	30	79.3	82.5
	45	71.7	80.4
Large	20	80.3	81.6
	30	78.1	83.0
	45	68.5	81.8

Skin colour development was minimised by CA storage (Table 14). In early season fruit, skin colour remained green during storage. The development of skin colour during 5°C storage increased as the season progressed and was most noticeable in late season fruit.

Table 14. Skin colour score of 'Hass' avocados at removal from various storage treatments, with and without CA

Fruit Size	Storage duration (days)	Early		Mid		Late	
		Air	CA	Air	CA	Air	CA
Small	20	2.0	2.0	2.0	1.9	2.5	2.3
	25	2.0	2.0	2.0	1.9	2.4	2.2
	30	2.0	2.0	2.1	2.0	3.1	2.2
	45	2.0	2.0	2.9	2.0	3.5	2.4
Large	20	2.0	2.0	2.0	2.0	2.3	2.2
	30	2.0	2.0	2.1	2.0	2.7	2.0
	45	2.0	2.0	3.0	2.0	3.6	2.1

CA strongly reduced the development of green-black skin colour (Table 15). This type of skin colour development was less visually appealing than glossy purple skin colour (Figure 4). Green-black colour occurred more commonly in large fruit and was more of an issue late in the season. In the late season trial, green-black colour development was prevalent even in small fruit stored for 25 days.

Table 15. Index of black colour development in 'Hass' avocados following various storage treatments with or without CA (where 100 indicates all fruit developed green-black colour)

Fruit Size	Storage duration (days)	Early		Mid		Late	
		Air	CA	Air	CA	Air	CA
Small	20	3	0	13	0	7	0
	25	0	10	10	10	63	20
	30	20	0	17	0	63	10
	45	10	0	17	13	53	47
Large	20	30	7	17	0	17	3
	30	50	0	67	3	80	7
	45	57	0	53	3	63	37



Figure 4. Differences in colour development in long stored ‘Hass’ avocados under air and CA:

Air stored fruit showed green-black colour development, while CA stored fruit showed more purple colour.

Photos are of large fruit from the early harvest trial after 8 days of ripening at 20°C following 31 days at 5°C

Discrete dark patches on the skin symptomatic of chilling injury were strongly reduced by CA compared with air (Table 16). These symptoms were most severe in early season fruit stored for 45 days.

Table 16. Severity of discrete patches (average % surface area) in ‘Hass’ avocados following various storage treatments with or without CA

Fruit Size	Storage duration (days)	Early		Mid		Late	
		Air	CA	Air	CA	Air	CA
Small	20	0	0	0	0	1	0
	25	1	0	0	0	1	0
	30	8	0	0	0	12	0
	45	62	3	9	0	16	4
Large	20	0	0	0	0	0	0
	30	7	1	0	0	9	0
	45	94	1	17	0	17	1

Storage under CA strongly reduced body rot incidence and severity compared to air (Table 17). CA also reduced stem end rot in small fruit, but had minimal impact in large fruit.

Table 17. Severity and incidence of rots in 'Hass' avocados at medium soft following storage at 5°C for various periods with or without CA (pooled data from 3 trials)

Fruit size	Storage duration (days)	Body rot severity (% SA)		Body rot incidence (% fruit)		Stem end rot severity (% SA)		Stem end rot incidence (% fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	2.4	1.4	36	18	2.7	1.4	31	29
	25	7.0	2.2	42	22	3.5	0.4	33	18
	30	10.4	2.4	76	27	5.3	0.9	42	20
	45	16.9	1.2	87	20	7.8	1.3	53	24
Large	20	2.3	1.6	40	33	2.4	1.1	29	29
	30	12.3	3.1	76	36	2.5	1.0	22	22
	45	21.3	5.3	98	56	1.7	2.5	38	49

Storage under CA strongly reduced the incidence and severity of diffuse flesh discolouration symptomatic of chilling injury (Table 18).

Table 18. Diffuse discolouration severity and incidence in 'Hass' avocados stored at 5°C with and without CA (pooled data from 3 trials)

Fruit Size	Storage duration (days)	Diffuse discolouration severity (% flesh volume)		Diffuse discolouration incidence (% of fruit)	
		Air	CA	Air	CA
Small	20	3.6	0.9	18	4
	25	2.0	1.7	24	7
	30	5.2	1.3	38	4
	45	12.2	0.7	58	4
Large	20	1.7	0.9	11	2
	30	13.2	1.2	49	7
	45	21.0	3.3	76	18

Fruit stored under CA tended to take slightly longer than air-stored fruit to reach firm ripe after being transferred to 20°C (Table 19). However, this effect was very small, averaging 0.8 days. The days taken to reach medium soft did not differ between CA and air.

Flesh quality declined with prolonged cool storage in air. Following 30 days of air storage, most fruit developed unacceptable internal defects when ripened to medium soft. For small fruit, the use of CA prevented loss of internal quality for storage treatments of up to 45 days. For large fruit, CA maintained internal fruit quality for at least 30 days, but a decline in quality occurred after 45 days.

Table 19. Days taken for 'Hass' avocados to reach firm ripe and medium soft at 20°C following storage, and percentage of unacceptable fruit at medium soft (data pooled from 3 trials)

Fruit size	Storage duration (days)	Days to firm ripe		Days to medium soft		Fruit with unacceptable flesh quality (%)	
		Air	CA	Air	CA	Air	CA
Small	20	4.1	5.2	7.8	8.5	24	22
	25	4.7	5.2	8.9	8.6	33	16
	30	3.9	4.8	8.6	8.0	58	18
	45	4.6	4.5	8.5	7.8	84	22
Large	20	3.6	4.7	7.0	7.4	20	18
	30	3.2	4.4	6.7	7.4	73	18
	45	2.9	3.9	6.0	7.3	98	40

Pre-conditioning

Pre-conditioning was applied to a sub-set of treatments, with fruit kept at 5°C for 5 days before being shifted to 3°C for the remainder of the storage period. No clear effects or trends were observed in these treatments (data not shown). Overall, measured quality traits in pre-conditioned fruit tended to be close to those shown in 3 and 5°C treatments.

4. Summaries and recommendations

- Storage at 5°C would typically be recommended for the best overall quality and shelf life in 'Hass' avocados, with rates of softening increasing substantially at temperatures over 10°C.
- Symptoms of chilling occurred at 3, 5 and 7°C and were more strongly linked with the duration of storage than temperature.
- Ripening during cool storage was associated with higher severity of internal chilling damage, particularly when fruit softened to durometer firmness of lower than 70 at removal. This value could be useful as an indicator of chill damage risk.
- Many defects observed in medium soft fruit were worsened by long storage duration (20 days or longer) or warm storage temperatures (15 and 20°C).
- CA storage provided very strong benefits in long duration storage, maintaining fruit firmness, reducing defects and improving internal quality.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

6. References

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Gamble, J., F. R. Harker, S. R. Jaeger, A. White, C. Bava, M. Beresford, B. Stubbings, M. Wohlers, P. J. Hofman and A. Woolf (2010). "The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase." *Postharvest Biology and Technology* **57**: 35-43.

Appendix 20

NQ 'Hass' avocado simulation trials report 2024a



Predicting fruit quality and shelf life for ‘Hass’ avocado

John Archer and Minh Nguyen, Department of Agriculture and Fisheries

Summary

An export simulation trial was conducted with ‘Hass’ avocados to assess the impact of different supply chain handling and storage conditions on fruit quality and shelf life. The trial involved commercially mature fruit of size 30 harvested from a farm in North Queensland (NQ) in 2024.

The avocados were stored at 3, 5, 7, 10 and 15°C, with 90% relative humidity (RH) for 5 to 40 days to replicate conditions observed in monitored air and seafreight supply chains. Sub-samples of fruit were periodically removed from storage and held at 20°C and 65% RH to assess their remaining shelf life. Additionally, the influence of controlled atmosphere (CA) storage at 3°C on fruit quality was evaluated.

Key observations from the trials included:

- Firmness Change: At lower temperatures (e.g., 3°C and 5°C), avocados maintain their firmness for longer periods.
- Chilling Injury: Chilling injury became noticeable after 17 days of storage at 3°C and 20 days at 5°C.

The data gathered from these trials will be used to develop and update best practice handling guidelines and decision aid tools based on predictive models for avocado shelf life and fruit quality. Future work will focus on exploring the relationship between fruit dry matter content and shelf life, extending the potential for low-temperature shipping durations, and examining the variation in fruit quality across different batches and blocks.

Introduction

The Serviced Supply Chains II project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters—whether aspiring, emerging, or established, helping them maximize product value, reduce claims, and expand trade volume. The primary objectives of the project are:

- Develop predictive shelf-life models for a wide range of fresh horticultural produce.
- Apply these models to create decision aid tools and update handling guidelines for improved quality and consistency.

This report focuses on the export simulation trial work conducted during the 2024 ‘Hass’ avocado season on fruit grown in North Queensland. The central objective of these trials was to assess the fruit quality and shelf-life response of ‘Hass’ avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, such as CA storage and fruit maturity (dry matter content). The data generated from these trials will contribute to the development of accurate predictive models for avocado quality and shelf life, enhancing decision-making for exporters and stakeholders



Materials and Methods

Fruit Selection and Harvesting

Commercially mature ‘Hass’ avocado fruit, with a target dry matter (DM) content of >23%, were selected for the trials during the 2024 season. The fruit were harvested by a commercial picking crew on 4/06/2024 from a farm located in North Queensland, and transported to a nearby packing house. The harvested fruit were transferred to the packing facility within 24 hours of harvest.

Post-Harvest Treatment and Packing

Upon arrival at the packing house, the avocados were treated with a fungicide, sorted by size and quality, and then packed into cardboard trays. The packed fruit of count 30 were transported in an air-conditioned vehicle to the Cairns Research Facility within 3 hours, maintaining a temperature of 22-25°C. The fruit was kept overnight at 20°C to stabilize before further processing.

Dry Matter Content Measurement

At the laboratory, the dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values, and then sorted by DM content. Fruit was assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of 20 fruits per size category were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

The fruit were assigned to different storage temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. Each treatment was applied to a single tray of 20 fruit. A subset of fruit stored at 5°C was held under CA conditions at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

At the conclusion of each treatment storage period, the fruit were moved to 20°C for further assessment of their remaining shelf life. The air temperature adjacent to the fruit was monitored from the time of collection at the packing shed through to removal from the cold storage treatments. This allowed for the calculation of time × temperature units (TTU), which helped quantify the effects of storage duration and temperature.

Table 1 Number of treated fruit at each treatment temperature.

Treatment Temperature (°C)	Controlled Atmosphere	Treatment Duration (Days)							
		0	5	10	17	20	25	31	40
3	FALSE	24		24	24	24	24	24	
3	TRUE				24	24	24	24	
5	FALSE	24		24		24	24	24	24
7	FALSE	24		24		24		24	
10	FALSE	24		24		24		24	
15	FALSE	24	24	24					
20	FALSE	24	24	24					

Humidity Control

Relative humidity (RH) inside the cold storage rooms was maintained at approximately 90% to simulate typical cold storage conditions. Once removed from storage, the fruit were placed in a controlled environment at 20°C, with the RH held at 65% to replicate retail conditions.

Bareiss Firmness Measurement

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit. A firmness value of 54 was defined as the threshold for firm soft (FS), while the end of shelf life (ESL) was determined when firmness reached 39. These benchmarks provided consistent criteria for assessing ripeness and the remaining usability of the fruit during the trials.

Results

Dry matter

Table 2 Dry Matter Content Analysis

Fruit Size	Average DM (%)	Maximum DM (%)	Minimum DM (%)	Standard Error (%)
30	28	35.6	24.6	1.37

Changes in Fruit Firmness During Storage

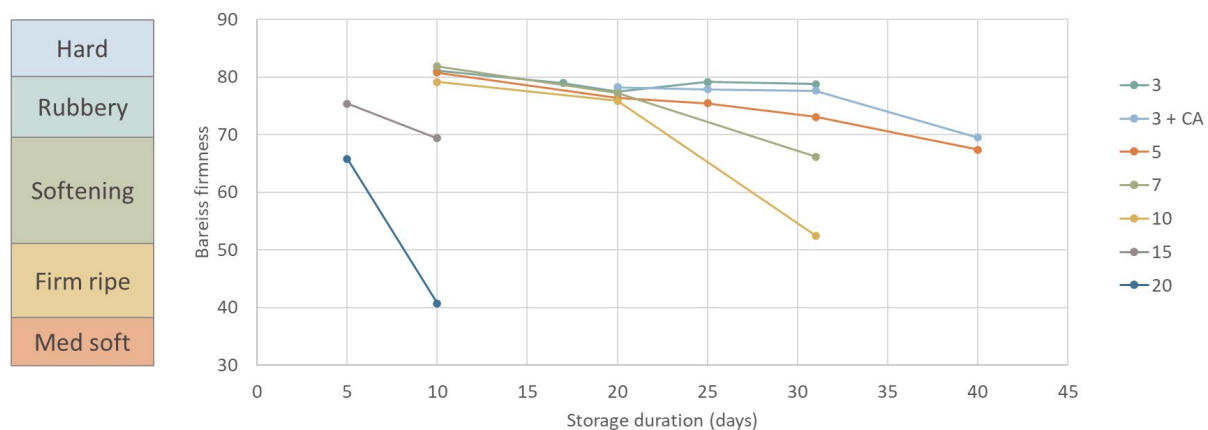


Figure 1. Effect of storage duration and temperature on avocado firmness

Figure 1 shows how avocado firmness changes over storage duration at different temperatures. The y-axis represents the firmness (measured in Bareiss units), and the x-axis represents the storage duration in days. Each line corresponds to a specific storage temperature (e.g., 3°C, 5°C, etc.), with "3 + CA" indicating storage at 3°C under controlled atmosphere conditions.

Key observations:

At higher temperatures (e.g., 10°C, 15°C, and 20°C), avocados soften more rapidly, as indicated by the sharper decline in firmness.

At lower temperatures (e.g., 3°C and 5°C), avocados maintain their firmness for longer periods.

The color-coded bands on the left categorize firmness levels, with the shift in firmness over time moving from "Hard" to "Med Soft." This illustrates how temperature and storage duration significantly impact avocado firmness upon removal from storage.

Impact of Storage Duration on Fruit Defects

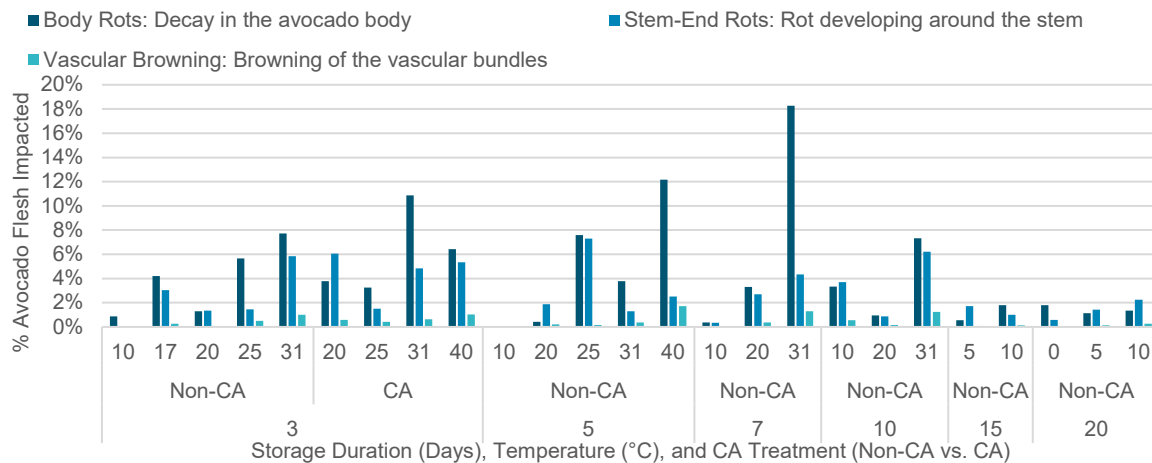


Figure 2 Impact of storage duration, temperature, and controlled atmosphere (CA) on avocado quality defects.

Figure 2 shows the percentage of avocado flesh affected by various types of quality defects, including Body Rots (decay in the body), Stem-End Rots (rot near the stem) and Vascular Browning (browning of vascular bundles).

Internal chilling injury

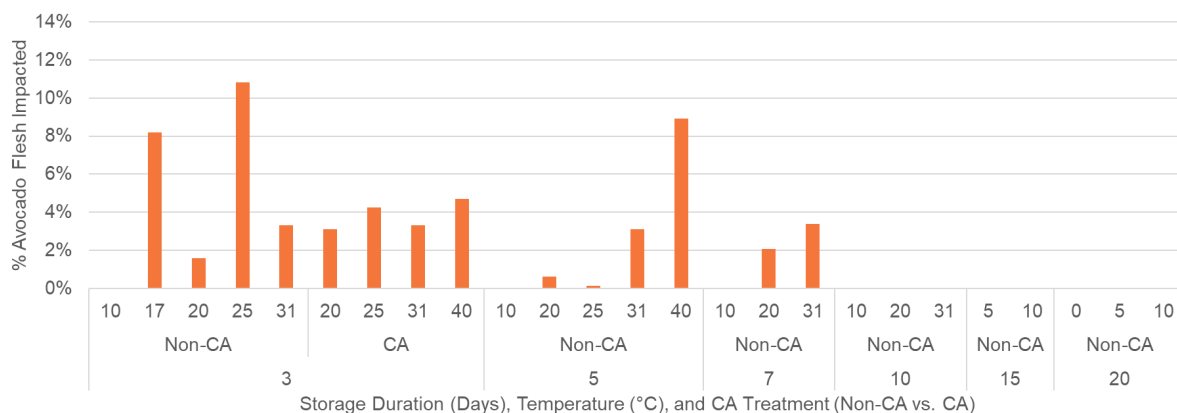


Figure 3. Incidence of diffuse discoloration (chilling injury) in avocados under different storage conditions.

The percentage of avocado flesh impacted by diffuse discoloration varies with storage duration, temperature, and whether stored under controlled atmosphere (CA) or non-controlled atmosphere (Non-CA) conditions. Non-CA storage, particularly at lower temperatures and longer durations, shows higher rates of discoloration.

Table 3 Shelf Life (SL Days) of Avocados Under Different Storage Temperatures and Controlled Atmosphere (CA)

Storage Temperature (°C)	Controlled Atmosphere (CA)	Treatment Duration (Days)							
		0 Days	5 Days	10 Days	17 Days	20 Days	25 Days	31 Days	40 Days
3	Non-CA			7.08	7.79	7.33	7.75	7.88	
3	CA					9.08	7.92	9.46	8.83
5	Non-CA			7.00		5.96	7.75	6.79	7.21
7	Non-CA			6.96		6.33		7.35	
10	Non-CA			7.63		5.17		4.58	
15	Non-CA		7.88	4.17					
20	Non-CA	13.00	4.96	1.25					

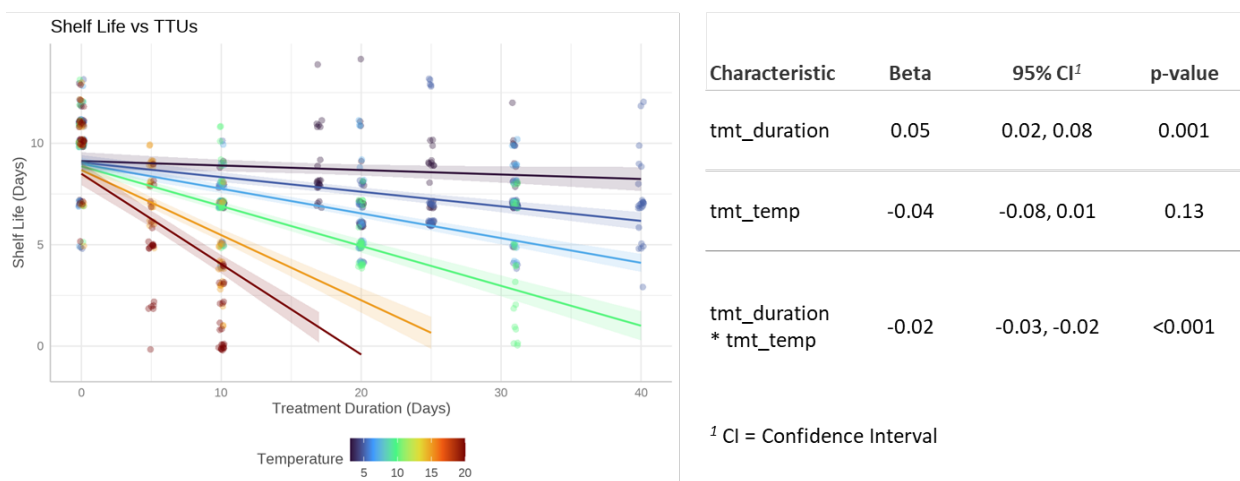


Figure 4. Relationship between shelf life, treatment duration, and temperature.

Table 3 and Figure 4 show how shelf life declined more rapidly as treatment duration increased, particularly at higher storage temperatures. The lines represent different temperatures, with cooler colours (blue) for lower temperatures and warmer colours (red) for higher ones. The dots represent measured values, while the shaded areas indicate the confidence interval for predictions. The table summarizes the impact of treatment duration and temperature, showing that both have an impact on shelf life. Longer treatments and higher temperatures reduce the shelf life of fruit more quickly.

Summary

Lower temperatures (3°C to 7°C): generally retained higher shelf life values, especially under Controlled Atmosphere (CA). For example:

At 3°C Non-CA, shelf life remained above 7 days even at 25 days of storage.

At 3°C CA, shelf life was 9.46 days at 25 days of storage.

Higher temperatures (10°C to 20°C): Shelf life decreased significantly at higher temperatures, with avocados showing rapid deterioration:

At 20°C Non-CA, shelf life dropped from 13 days at 0 days to only 1.25 days by 10 days of storage.

Appendix 21

NQ 'Hass' avocado simulation trials report 2024b

Predicting fruit quality and shelf life for ‘Hass’ avocado

John Archer and Minh Nguyen, Department of Agriculture and Fisheries

Summary

An export simulation trial was conducted with ‘Hass’ avocados to assess the impact of different supply chain handling and storage conditions on fruit quality and shelf life. The trial involved commercially mature fruit of size 20 and 28 harvested from a farm located in North Queensland in 2024.

The avocados were stored at 3, 5, 7, 10 and 15°C, with 90% relative humidity (RH) for 5 to 40 days to replicate conditions observed in monitored air and seafreight supply chains. Sub-samples of fruit were periodically removed from storage and held at 20°C and 65% RH to assess their remaining shelf life. Additionally, the influence of controlled atmosphere (CA) storage at 3°C on fruit quality was evaluated.

Key observations from the trials included:

- Low Temperatures (3°C–7°C): Fruit remained firmer for longer, translating to a shelf life of 7–9 days once moved to 20°C. However, chilling injury (diffuse discoloration) was more pronounced after about 17–20 days of storage at 3°C or 5°C.
- High Temperatures (10°C–20°C): Avocados softened much faster, with shelf life dropping to under three days if stored for 6–10 days at these higher temperatures.

The data gathered from these trials will be used to develop and update best practice handling guidelines and decision aid tools based on predictive models for avocado shelf life and fruit quality. Future work will focus on exploring the relationship between fruit dry matter content and shelf life, extending the potential for low-temperature shipping durations, and examining the variation in fruit quality across different batches and blocks.

Introduction

The Serviced Supply Chains II project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters—whether aspiring, emerging, or established, helping them maximize product value, reduce claims, and expand trade volume. The primary objectives of the project are:

- Develop predictive shelf-life models for a wide range of fresh horticultural produce.
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This report focuses on the export simulation trial work conducted during the 2024 ‘Hass’ avocado season on fruit grown in North Queensland. The central objective of these trials was to assess the fruit quality and shelf-life response of ‘Hass’ avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, such as CA storage and fruit maturity (dry matter content). The data generated from these trials will contribute to the development of accurate predictive models for avocado quality and shelf life, enhancing decision-making for exporters and stakeholders

Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Hass' avocado fruit, with a target dry matter (DM) content of >23%, were selected for the trials during the 2024 season. The fruit were harvested by a commercial picking crew on 9/06/2024 from a farm in North Queensland, and transferred to a nearby packing house. The harvested fruit were transferred within 24 hours.

Post-Harvest Treatment and Packing

Upon arrival at the packing house, the avocados were treated with a fungicide, sorted by size and quality, and then packed into cardboard trays. The packed fruit of count 30 were transported in an air-conditioned vehicle to the Cairns Research Facility within 3 hours, maintaining a temperature of 22-25°C. The fruit was kept overnight at 20°C to stabilize before further processing.

Dry Matter Content Measurement

At the laboratory, the dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values, and then sorted by DM content. Fruit was assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of 20 fruits per size category were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

The fruit were assigned to different storage temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. Each treatment was applied to a single tray of 20 fruit. A subset of fruit stored at 5°C was held under CA conditions at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

At the conclusion of each treatment storage period, the fruit were moved to 20°C for further assessment of their remaining shelf life. The air temperature adjacent to the fruit was monitored from the time of collection at the packing shed through to removal from the cold storage treatments. This allowed for the calculation of time × temperature units (TTU), which helped quantify the effects of storage duration and temperature.

Table 1 Number of treated fruit at each treatment temperature.

Trial 2			
Fruit Size	CA	Treatment Temperature (°C)	Treatment Duration (hours)
Large	Non CA	3	10, 17, 20, 24, 31, 41
	CA	3	20, 26, 31, 41
	Non CA	20	0
Small	Non CA	3	10, 17, 20, 24, 30
	CA	3	20, 24, 30, 41
	Non CA	5	10, 20, 24, 30, 40
		7	10, 20, 30
		10	10, 20, 30
		15	6, 10
		20	0, 6, 10

Humidity Control

Relative humidity (RH) inside the cold storage rooms was maintained at approximately 90% to simulate typical cold storage conditions. Once removed from storage, the fruit were placed in a controlled environment at 20°C, with the RH held at 65% to replicate retail conditions.

Bareiss Firmness Measurement

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit. A firmness value of 54 was defined as the threshold for firm soft (FS), while the end of shelf life (ESL) was determined when firmness reached 39. These benchmarks provided consistent criteria for assessing ripeness and the remaining usability of the fruit during the trials.

Results

Dry matter

Table 2 Dry Matter Content Analysis

Fruit Size	Average DM (%)	Maximum DM (%)	Minimum DM (%)	Standard dev (%)
Small	28.6	32.8	24.8	1.47
Large	28.6	35.6	23.2	1.65

Changes in Fruit Firmness During Storage

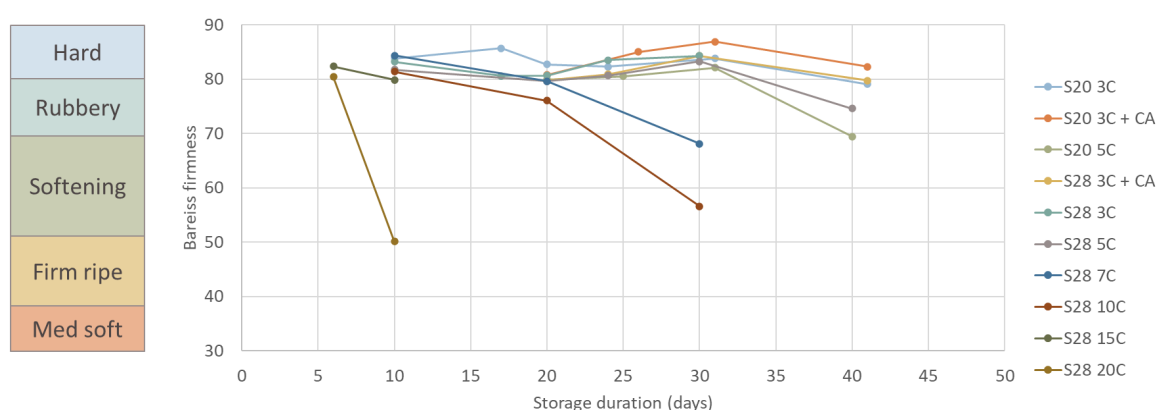


Figure 1. Effect of storage duration and temperature on avocado firmness

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Key observations:

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Impact of Storage Duration on Fruit Defects

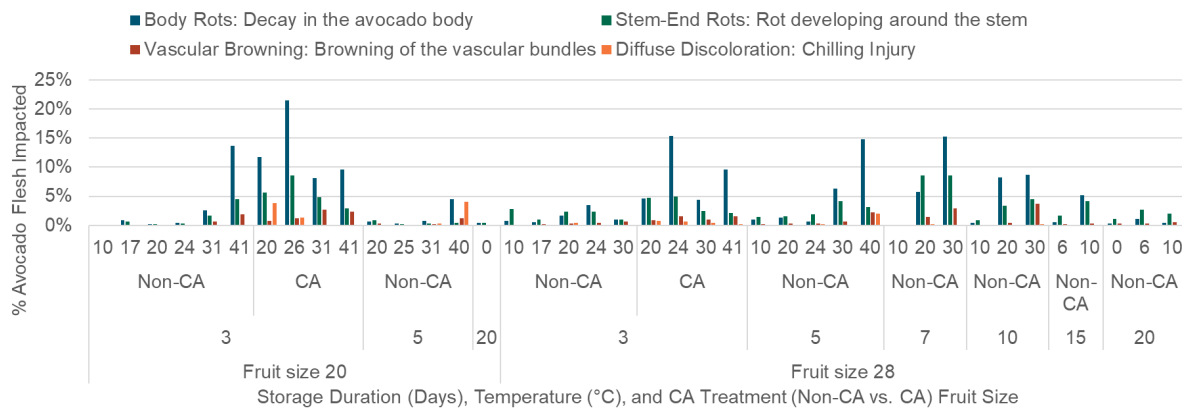


Figure 2 Impact of storage duration, temperature, and controlled atmosphere (CA) on avocado quality defects.

Figure 2 shows the percentage of avocado flesh affected by various types of quality defects, including Body Rots (decay in the body), Stem-End Rots (rot near the stem) and Vascular Browning (browning of vascular bundles).

Internal chilling injury

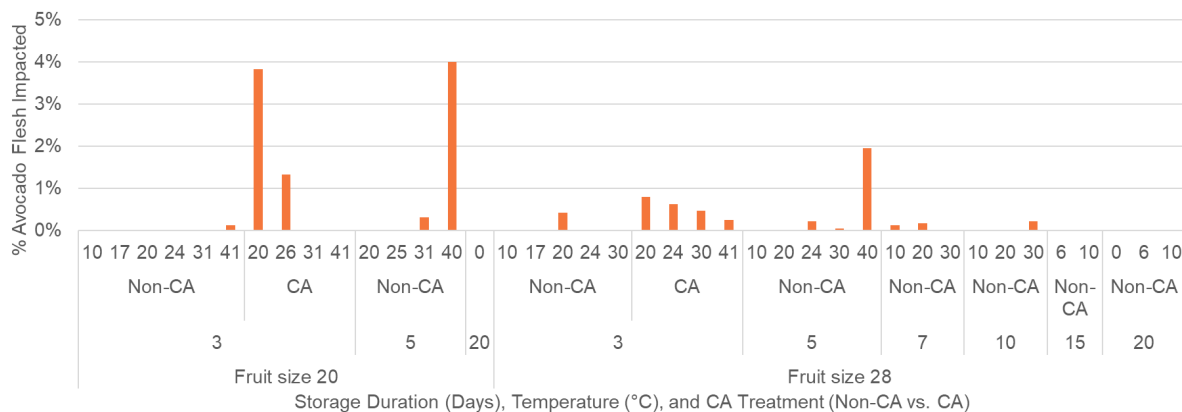


Figure 3. Incidence of diffuse discoloration (chilling injury) in avocados under different storage conditions.

Figure 3 shows a focus on avocado flesh impacted by diffuse discoloration (Internal chilling injury) varies with storage duration, temperature, and whether stored under controlled atmosphere (CA) or non-controlled atmosphere (Non-CA) conditions. Non-CA storage, particularly at lower temperatures and longer durations, shows higher rates of discoloration.

Table 3 Shelf Life (SL Days) of Avocados Under Different Storage Temperatures and Controlled Atmosphere (CA)

Fruit Size	Storage Temperature (°C)	Controlled Atmosphere (CA)	Treatment Duration (Days)								
			0	6	10	17	20	24	26	30	40/41
Large	3	Non-CA			6.96	7.67	7.29	7.67			8.33
Large	3	CA					9.75		10.63		9.88
Large	5	Non-CA					7.40	5.93			5.22
Large	20	Non-CA	10.17								
Small	3	Non-CA			8.08	8.21	8.50	8.88		8.42	
Small	3	CA					9.38	9.29		9.08	9.63
Small	5	Non-CA			8.58		8.04	7.58		7.96	8.04
Small	7	Non-CA			6.50		8.38			7.33	
Small	10	Non-CA			7.29		6.79			4.04	
Small	15	Non-CA		7.13	6.00						
Small	20	Non-CA	11.25	6.13	2.46						

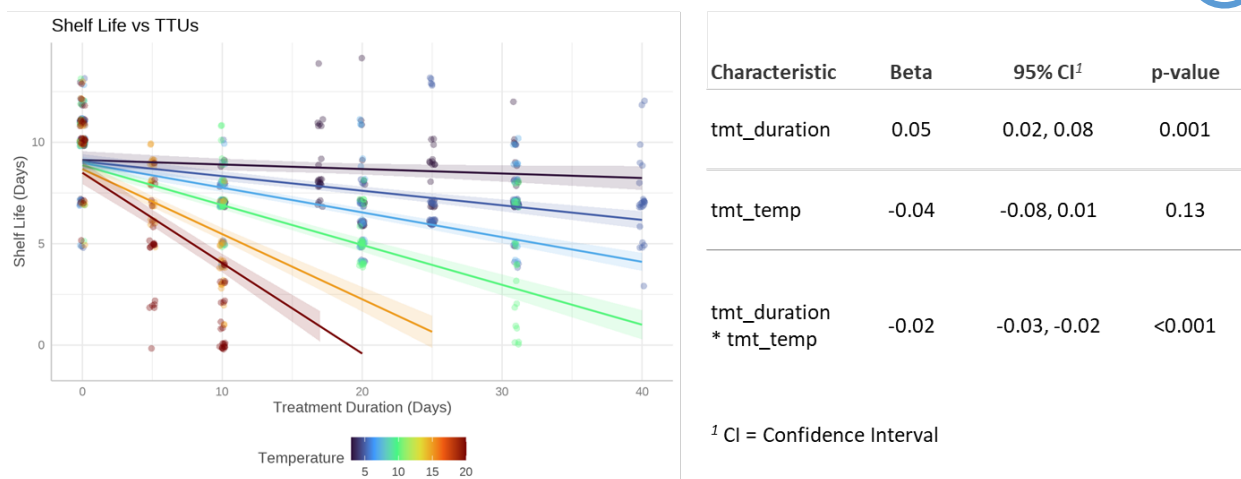


Figure 4. Relationship between shelf life, treatment duration, and temperature.

Table 3 and Figure 4 show how the shelf life of fruit decreases as the treatment duration increases, with higher temperatures causing a faster decline. The lines represent different temperatures, with cooler colours (blue) for lower temperatures and warmer colours (red) for higher ones. The dots represent measured values, while the shaded areas indicate the confidence interval for predictions. The table summarizes the impact of treatment duration and temperature, showing that both have a significant effect on shelf life. Longer treatments and higher temperatures reduce the shelf life of fruit more quickly.

Summary

These trials demonstrate that both temperature and storage duration have a substantial impact on 'Hass' avocado quality and shelf life:

Temperature Effects:

- **Low Temperatures (3°C–7°C):** Prolonged storage under refrigerated conditions can preserve firmness and extend shelf life beyond 7–9 days once transferred to ripening conditions at 20°C. However, chilling injury (diffuse discoloration) becomes more likely after about 17–20 days at 3°C or 5°C.
- **High Temperatures (10°C–20°C):** Fruit soften more rapidly, shortening shelf life significantly. For example, at 20°C, the remaining shelf life can drop from over 10 days to under 3 days in as little as 6–10 days of storage

Practical Implications:

- **Export Strategies:** Optimizing temperature and atmosphere conditions allows for longer shipping times without compromising fruit quality.
- **Risk Management:** Monitoring time–temperature units (TTU) throughout the supply chain to predict and prevent quality losses.

Appendix 22

CQ 'Hass' avocado maturity trials report 2024a



Impact of maturity on 'Hass' avocado fruit quality and shelf life

2024 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish

Department of Primary Industries

Summary

The trial aimed to explore the effects of fruit maturity on the shelf life and quality of 'Hass' avocados. Fruit were segregated into three maturity grades based on NIR (near-infrared spectroscopy) estimated dry matter (DM) and then stored under a variety of supply chain conditions. The fruit were then shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from these trials included:

- Within a single harvest, maturity levels did not have strong effects on shelf life and quality.
- In fruit kept constantly at 20°C, lower DM was associated with greater green skin colour retention at medium ripe.
- High DM fruit showed slightly greater incidence of diffuse discolouration after 21 days at 5°C in air, compared with low maturity fruit.
- Following storage for 21 days at 5°C in air, high DM fruit took slightly longer to ripen and had slightly longer shelf life than fruit with low and mid-level DM.
- Under CA storage, no significant differences were shown between the 3 maturity groups.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

Previous research has shown that fruit maturity can have significant impacts on the shelf life and quality of avocados¹. Immaturity can result in issues with ripening, poor eating quality and increased development of rots². Increasing maturity has been shown to result in more rapid and even ripening and reduced susceptibility to chilling injury³. However, rots and internal disorders can increase in late season harvests. The current trial was completed during the 2024 'Hass' avocado season using fruit from a Central Queensland (CQ) farm. The main focus was the impact of fruit DM variation within a single harvest on shelf life and quality. Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

Fruit were segregated at the packing shed into three maturity grades based on NIR estimated DM, and then transferred into 3 different storage regimes, as shown in Table 1. Following storage, the fruit were shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality.

A total of 9 treatment groups (maturity x storage regime) were included in the design, with 60 Hass avocado fruit within each treatment.

Table 1. Storage conditions applied to Hass avocados of 3 maturity grades.

Temperature	Duration (days)	Controlled atmosphere	Approx RH (%)
20°C	-	-	65
5°C	21	-	85
5°C	21	2% O ₂ and 5% CO ₂	85

Commercially harvested 'Hass' avocado fruit were sourced from a farm located near Childers, Queensland. Fruit were harvested on 14th June 2024, placed into field bins and transferred to the nearby packing shed on the same day. They were kept at 7°C over the weekend and were processed through the commercial pack line on 18th June. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of approx. count 24 size fruit were used in the trial.

In the packing shed, the DM content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. Trial fruit were grouped by NIR predicted DM

¹ Ekman, JH. 2017. Pre- and postharvest management of avocados: A review of best practice, Hort Innovation: 67.

² Pak HA, Dixon J, Cutting JGM. 2003. Influence of early season maturity on fruit quality in New Zealand Hass avocados. NZ AGA Ann. Res. Rep. 3:54-59.

³ Dixon J, Smith DB, Elmsly TA. 2004. Fruit age, storage temperature and maturity effects on Hass avocado fruit quality and ripening. NZ AGA Ann. Res. Rep. 4:47-53

values into low, medium and high DM groups, as shown in Table 2. Figure 1 shows a graphical representation of the maturity groups across an idealised normal distribution.

Table 2. Maturity brackets of 'Hass' avocado fruit grouped by NIR predicted DM ranges

Maturity group	Range of NIR predicted DM	Mean oven dried DM (%)
Low	24 - 26.8	24.8
Mid	27.4 - 28.5	26.7
High	29.1 - 33	29.8

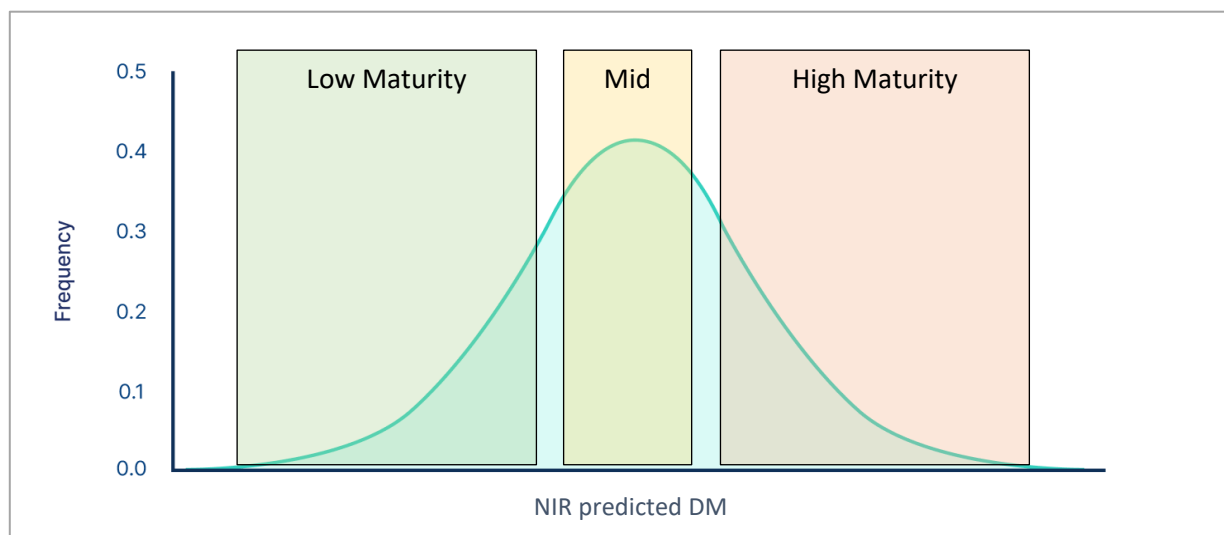


Figure 1. A graphical representation of the maturity groups within an idealised normal distribution

Trial fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 23°C) for 3 hours and were then kept overnight at 20°C.

A sub-set of 36 fruit were assessed for DM using the traditional oven drying method. NIR estimated DM was recorded at dorsal and ventral regions and the same area was sampled for assessment of DM content. A small area of skin was removed, and a sample of avocado flesh excised from each side using a cork borer. The flesh was finely diced and placed into a pre-weighed plastic container. After measurement of fresh weight, the samples were dried at 65°C in a drying oven until at a constant weight (approximately 48 h). The DM content was expressed as the proportion (%) of dry tissue weight relative to the initial fresh weight. Corresponding NIR and DM measurements were collected for each fruit side. The relationship between NIR predicted DM and measured oven DM was used to correct NIR values for trial fruit.

The air temperature adjacent to fruit was monitored throughout the trials, commencing at the pack shed. Logged temperatures and the nearest available weather station data were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 85%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed. Colour score and durometer firmness were recorded for 20 fruit from each maturity group. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading.



Skin colour was scored using the following scale:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx. 25% colour development
- 4 = Approx. 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

When fruit were removed from storage treatments, weight and firmness were measured in all fruit. The surface area (%SA) of discrete patches on the skin (chilling injury) was also recorded.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 39 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven DM ranged from 22.5 to 32.7, averaging 27.1%. The relationships between NIR predicted DM and oven DM were strong in this trial, averaging $R^2=0.81$ (data not shown). The maturity groups showed reasonable segregation into brackets of oven-dried DM, although there was some overlap of values between the groups (Figure 2). The middle group (Mid) showed much less variability in DM due to being in the middle of the normal distribution of DM values (as shown in Figure 1).

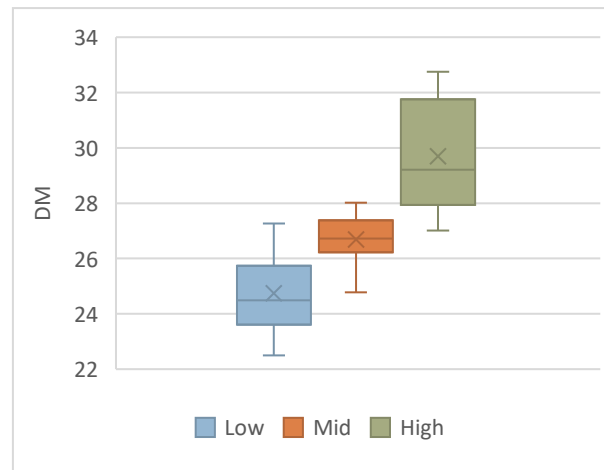


Figure 2. Summary of DM values within each maturity group

The box and whisker plot summarises the data within each group, showing the mean (x), median (horizontal line), range (capped vertical lines) and quartiles (boxes).

Fruit quality and shelf life

No differences in firmness or skin colour were shown between the maturity groups at trial commencement. Skin colour at removal was very similar across all treatments, and did not differ due to maturity (data not shown). Fruit stored for 21 days under air or CA showed similar firmness at removal, with no differences shown due to maturity (data not shown).

High maturity fruit lost slightly less weight following 21 days at 5°C in air than the other groups (Table 3). CA storage reduced weight loss, and no maturity effects were observed under CA.

High maturity fruit took slightly longer to reach firm ripe and had slightly longer shelf life than low and mid groups, in contrast to previously reported trends. Under CA and at 20°C there were no significant differences in ripening or shelf life due to maturity.

Maturity affected the retention of green skin colour at medium ripe in fruit stored at 20°C. Low maturity fruit retained the most green skin colour, and high maturity fruit the least. Fruit stored for 21 days showed less retention of green skin colour, particularly under CA, and maturity effects were not significant.

Table 3. Weight loss, ripening, shelf life and green skin colour retention in 'Hass' avocado fruit at 3 maturity levels following various storage treatments

Maturity group	Weight loss at removal (%)	Days to firm ripe	Shelf life at removal	Green skin %SA at medium ripe
Constant 20°C				
Low	-	6.9	10.5	11.3 c
Mid	-	6.8	10.4	6.4 b
High	-	6.9	10.4	2.6 a
Air - 21d at 5°C				
Low	2.7 b	3.7 a	8.2 a	5.7
Mid	2.7 b	3.7 a	8.7 a	5.5
High	2.5 a	4.1 b	9.3 b	4.0
CA - 21d at 5°C				
Low	2.2	4.9	8.8	0.6
Mid	2.2	4.8	9.0	0.6
High	2.1	5.0	9.2	0.2

Different letters show a significant difference at $p < 0.05$ between maturity groups within each treatment

Internal quality at medium ripe varied between storage treatments but was not strongly affected by maturity (Table 4). High maturity fruit showed greater incidence of diffuse discolouration than low maturity fruit after 21 days in air. But otherwise no significant differences were shown between the 3 maturity groups.

Table 4. Internal quality at medium ripe of 'Hass' avocados at 3 maturity levels following various storage treatments

Maturity group	Body rot severity (% vol)	Body rot incidence (% fruit)	Stem end rot severity (% vol)	Stem end rot incidence (% fruit)	Diffuse discolour. severity (% vol)	Diffuse discolour. any incidence (% fruit)	Diffuse discolour. >5% vol incidence (% fruit)	Unacceptable fruit (%)
Constant 20°C								
Low	1.8	33	0.08	3	0.0	2	0	8
Mid	0.7	23	0.08	2	0.1	7	0	2
High	1.7	33	0.17	8	0.1	3	0	5
Air - 21d at 5°C								
Low	2.2	42	0.22	5	1.2	10 a	7	12
Mid	5.9	40	0.72	13	1.4	22 ab	10	25
High	4.9	38	0.60	17	2.5	33 b	17	27
CA - 21d at 5°C								
Low	1.2	25	0.07	2	0.1	3	0	3
Mid	0.9	23	0.10	5	0.0	2	0	3
High	0.7	15	0.03	2	0.1	3	0	3

Different letters show a significant difference at $p < 0.05$ between maturity groups within each treatment



4. Summaries and recommendations

- Fruit DM variation within a single harvest had relatively minor impacts on fruit shelf life and quality.
- Lower DM was associated with greater green skin colour retention at medium ripe in fruit kept constantly at 20°C.
- Diffuse discolouration was slightly more common in high DM fruit after 21 days at 5°C in air, compared with low maturity fruit.
- High DM fruit took slightly longer to ripen and had slightly longer shelf life than fruit with low and mid level DM following storage for 21 days at 5°C in air.
- No significant differences were shown between the 3 maturity groups when kept under CA storage.
- DM is a critical value in determining when fruit are ready to harvest, but once the threshold of 23% is reached, further increases in DM may not strongly impact fruit quality outcomes.
- Adding DM as a factor in predictive models could increase the precision of shelf life estimates, but DM does not appear to be a critical element.
- Previous research has shown that 'Hass' avocado DM did not change over a series of late harvest picks, but fruit quality declined later in the season (rots, vascular browning and flesh greying increased)⁴. These results suggest that harvest timing may provide greater predictive power to the models than fruit DM.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support. This work was part of the broader Serviced Supply Chains II project (AM21000) that was funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland, Department of Energy, Environment and Climate Action, Victoria, Department of Agriculture and Fisheries, Northern Territory, Department of Primary Industries and Regional Development, Western Australia, Pinata Farms Pty Ltd and Summerfruit Australia Ltd.



⁴ Hofman, PJ, Jobin-Décor, MP, & Giles, J. 2000. Percentage of dry matter and oil content are not reliable indicators of fruit maturity or quality in late-harvested 'Hass' avocado. *HortScience*, 35(4), 694-695.

Appendix 23

CQ 'Hass' avocado maturity trials report 2024b



Impact of maturity on 'Hass' avocado fruit quality and shelf life

2024 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish

Department of Primary Industries

Summary

The trial aimed to explore the effects of fruit maturity on the shelf life and quality of 'Hass' avocados. Fruit were segregated into three maturity grades based on NIR (near-infrared spectroscopy) estimated dry matter (DM) and then stored under a variety of supply chain conditions. The fruit were then shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from these trials included:

- Within a single harvest, DM levels had some significant effects on shelf life and quality.
- Higher DM fruit took slightly longer to ripen and had significantly longer shelf life.
- Higher DM fruit tended to lose slightly less weight during storage.
- Lower DM fruit were more likely to show black skin colour development, while higher DM fruit were more likely to develop purple skin colour.
- There was a very slight tendency for lower DM fruit to develop more body rots, but internal quality was not strongly affected by maturity within the range tested.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

Previous research has shown that fruit maturity can have significant impacts on the shelf life and quality of avocados¹. Immaturity can result in issues with ripening, poor eating quality and increased development of rots². Increasing maturity has been shown to result in more rapid and even ripening and reduced susceptibility to chilling injury³. However, rots and internal disorders can increase in late season harvests. The current trial was completed during the 2024 'Hass' avocado season with Central Queensland (CQ) grown fruit. The main focus was the impact of fruit DM variation within a single harvest on shelf life and quality. Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

Fruit were segregated at the packing shed into three maturity grades based on NIR estimated DM, and then transferred into 3 different storage regimes, as shown in Table 1. Following storage, the fruit were shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality.

A total of 9 treatment groups (maturity x storage regime) were included in the design, with 60 Hass avocado fruit within each treatment.

Table 1. Storage conditions applied to Hass avocados of 3 maturity grades.

Temperature	Duration (days)	Controlled atmosphere	Approx RH (%)
20°C	-	-	65
5°C	21	-	85
5°C	21	2% O ₂ and 5% CO ₂	85

Commercially harvested 'Hass' avocado fruit were sourced from a farm located near Childers, Queensland. Fruit were harvested on approx. 4th June 2024, placed into field bins and transferred to the nearby packing shed for processing through a commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 23 size fruit were used in the trial.

In the packing shed, the DM content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. Trial fruit were grouped by NIR predicted DM

¹ Ekman, JH. 2017. Pre- and postharvest management of avocados: A review of best practice, Hort Innovation: 67.

² Pak HA, Dixon J, Cutting JGM. 2003. Influence of early season maturity on fruit quality in New Zealand Hass avocados. NZ AGA Ann. Res. Rep. 3:54-59.

³ Dixon J, Smith DB, Elmsly TA. 2004. Fruit age, storage temperature and maturity effects on Hass avocado fruit quality and ripening. NZ AGA Ann. Res. Rep. 4:47-53

values into low, medium and high DM groups, as shown in Table 2. Figure 1 shows a graphical representation of the maturity groups across an idealised normal distribution.

Table 2. Maturity brackets of 'Hass' avocado fruit grouped by NIR predicted DM ranges

Maturity group	Range of NIR predicted DM	Mean oven dried DM (%)
Low	23 - 26.2	26.1
Mid	26.8 - 28.1	27.5
High	28.7 - 31.9	29.3

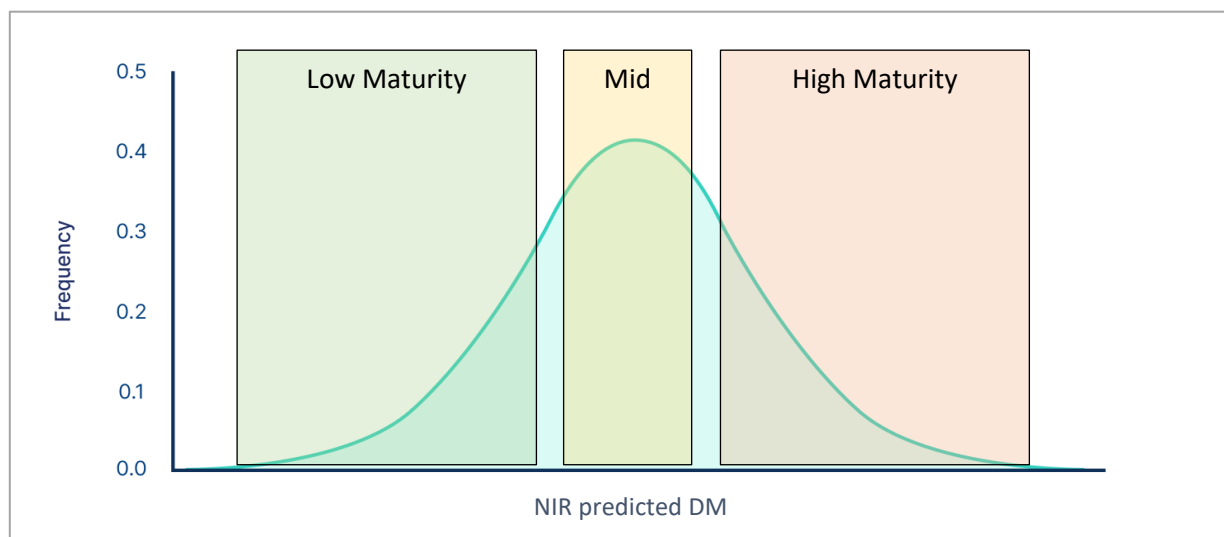


Figure 1. A graphical representation of the maturity groups within an idealised normal distribution

Trial fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 23°C) for 3 hours and were then kept overnight at 20°C.

A sub-set of 36 fruit were assessed for DM using the traditional oven drying method. NIR estimated DM was recorded at dorsal and ventral regions and the same area was sampled for assessment of DM content. A small area of skin was removed, and a sample of avocado flesh excised from each side using a cork borer. The flesh was finely diced and placed into a pre-weighed plastic container. After measurement of fresh weight, the samples were dried at 65°C in a drying oven until at a constant weight (approximately 48 h). The DM content was expressed as the proportion (%) of dry tissue weight relative to the initial fresh weight. Corresponding NIR and DM measurements were collected for each fruit side. The relationship between NIR predicted DM and measured oven DM was used to correct NIR values for trial fruit.

The air temperature adjacent to fruit was monitored throughout the trials. Logged temperatures and the nearest available weather station data were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 85%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed. Colour score and durometer firmness were recorded for 20 fruit from each maturity group. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading.

Skin colour was scored using the following scale:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx. 25% colour development
- 4 = Approx. 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

When fruit were removed from storage treatments, weight and firmness were measured in all fruit. The surface area (%SA) of discrete patches on the skin (chilling injury) was also recorded.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 39 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven DM ranged from 24.1 to 33.0, averaging 27.6%. The relationships between NIR predicted DM and oven DM were moderate in this trial, averaging $R^2=0.66$ (data not shown). The maturity groups showed general segregation into brackets of oven-dried DM, but there was substantial overlap of values between the groups (Figure 2). The middle group (Mid) showed much less variability in DM due to being in the middle of the normal distribution of DM values (as shown in Figure 1).

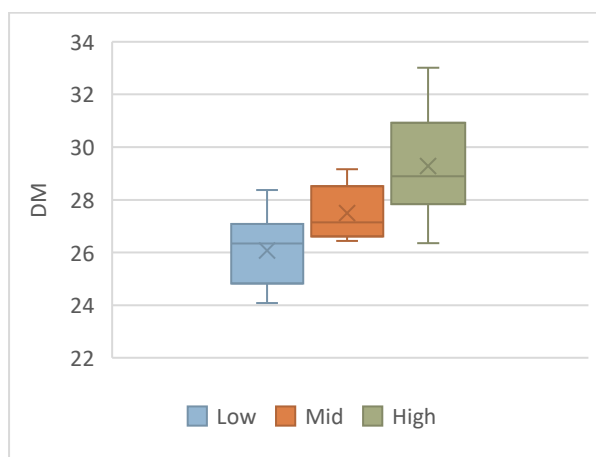


Figure 2. Summary of DM values within each maturity group

The box and whisker plot summarises the data within each group, showing the mean (x), median (horizontal line), range (capped vertical lines) and quartiles (boxes).

Fruit quality and shelf life

At the trial commencement the 3 maturity groups showed similar firmness and skin colour (data not shown). Skin colour at removal from storage was also very similar across all treatments, and did not differ

due to maturity (data not shown). Fruit stored for 21 days under air or CA showed similar firmness at removal, with no differences shown due to maturity (data not shown).

Maturity affected fruit weight loss, with higher DM fruit tending to lose less weight (Table 3). Higher maturity fruit took slightly longer to reach firm ripe and had slightly longer shelf life. Previous research has suggested the opposite trend. Maturity also affected the skin colour at medium ripe. Lower DM fruit were more likely to show black skin colour, while higher DM fruit were more likely to develop purple skin colour.

Table 3. Weight loss, ripening, shelf life and green skin colour retention in 'Hass' avocado fruit at 3 maturity levels following various storage treatments

Maturity group	Weight loss at removal (%)	Days to firm ripe	Shelf life at removal	Black skin colour score at medium ripe (0=purple, 1=black)
Constant 20°C				
Low	-	8.2 a	11.2 a	0.54 b
Mid	-	8.6 ab	12.5 b	0.49 b
High	-	9.1 b	13.1 b	0.25 a
Air - 21d at 5°C				
Low	2.9 c	3.4 a	7.7 a	0.62 b
Mid	2.7 b	3.7 b	8.4 b	0.40 a
High	2.5 a	4.0 c	8.6 b	0.32 a
CA - 21d at 5°C				
Low	2.4 b	5.1 a	9.3 a	0.54 b
Mid	2.4 b	4.8 a	9.0 a	0.49 ab
High	2.2 a	5.5 b	10.2 b	0.41 a

Different letters show a significant difference at $p < 0.05$ between maturity groups within each treatment

Maturity showed some effects on internal quality at medium ripe, but these were not strong or consistent (Table 4). Overall, low maturity fruit showed slightly more tendency towards body rots than higher maturity fruit. Maturity did not show any significant effects on stem end rots or diffuse discolouration. The overall level of unacceptable fruit did not vary substantially between the 3 maturity groups.

Table 4. Internal quality at medium ripe of 'Hass' avocados at 3 maturity levels following various storage treatments

Maturity group	Body rot severity (% vol)	Body rot incidence (% fruit)	Stem end rot severity (% vol)	Stem end rot incidence (% fruit)	Diffuse discolour. severity (% vol)	Diffuse discolour. any incidence (% fruit)	Diffuse discolour. >5% vol incidence (% fruit)	Unacceptable fruit (%)
Constant 20°C								
Low	6.2 b	78	6.3	68	0	0	0	48
Mid	3.0 a	70	3.7	50	0	0	0	23
High	3.6 a	68	4.2	50	0	0	0	37
Air - 21d at 5°C								
Low	6.2	75 b	2.2	39	2.1	6	4	39
Mid	3.7	61 ab	1.5	24	0.2	8	0	24
High	4.2	49 a	1.4	24	1.4	8	2	20
CA - 21d at 5°C								
Low	4.1	75 b	2.8	40	0	0	0	28
Mid	3.9	52 a	2.7	43	0	0	0	27
High	3.4	60 ab	2.2	33	0	0	0	18

Different letters show a significant difference at $p < 0.05$ between maturity groups within each treatment

4. Summaries and recommendations

- Fruit DM variation within a single harvest had some impacts on fruit shelf life and quality.
- Weight loss was higher in fruit with lower DM.
- Fruit with higher DM took slightly longer to ripen and had longer shelf life.
- Low DM fruit tended to develop blacker skin colour tone, compared with more purple skin colour in higher DM fruit.
- Internal quality was fairly similar across the different maturity levels, but there was a very slight tendency for lower DM fruit to develop more body rots.
- Incorporating DM as a factor in future models may add to the precision of shelf life predictions.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 24

**CQ 'Hass' avocado controlled atmosphere trials report
2024a**



Impact of delays prior to storage on 'Hass' avocado fruit quality and shelf life

2024 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish,

Department of Primary Industries

Summary

The trial aimed to explore the effects of delays prior to storage on the shelf life and quality of 'Hass' avocados. Fruit were stored for 3 different delay periods of 2, 4 or 7 days at 5°C, prior to air or controlled atmosphere (CA) storage at 3 or 5°C. At 3°C, storage durations of 16 or 21 days were tested, while 5°C treatments were for 21 days. Following treatment, fruit were held at 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from these trials included:

- Pre-storage delay durations ranging from 2 to 7 days at 5°C generally resulted in similar fruit ripening and quality.
- In air stored fruit kept at 5°C for 21 days, increasing the delay prior to storage from 2 to 7 days increased diffuse discolouration incidence and severity. This effect was mitigated by the use of CA.
- Increasing delays may have slightly increased body rots, but these results were not clear or consistent.
- Pre-conditioning for 5 additional days at 5°C prior to 3°C storage did not show any notable effects on fruit ripening or quality.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers CA delay trial work completed during the 2024 'Hass' avocado season. The main objective of the trial was to quantify the impact of delays prior to CA on fruit quality and shelf life responses of 'Hass' avocados. The trial also investigated the impact of preconditioning prior to 3°C storage and tested a potential market access treatment of 16 days at 3°C. Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

The trial design included 3 different delay periods of 2, 4 or 7 days at 5°C, prior to CA storage at 3 or 5°C (Table 1). Storage durations of 21 days were tested at 3°C and 5°C. Fruit responses to a potential market access cold treatment were also explored through treatment at 3°C for 16 days. All storage treatments were tested with and without CA. Relative humidity (RH) was maintained near 85% in all treatments. Following storage, fruit were shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. A total of 19 treatment groups (delay x temperature x duration x CA) were included in the design. Each treatment was applied to 3 replicate trays of 10 'Hass' avocado fruit.

Table 1. CA delay and preconditioning storage conditions applied to 'Hass' avocados.

Delay (days at 5°C)	Treatment temperature	CA	Duration (days)
0 days	20°C	-	-
2 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21
4 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21
7 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21

CA = controlled atmosphere of 2% O₂ and 5% CO₂



Commercially mature 'Hass' avocado fruit (targeting dry matter >23%) were sourced for the trial during the 2024 season. Fruit were harvested on 28th May 2024 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to the nearby packing shed on the same day. On the following day they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 28 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 23°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

The air temperature adjacent to fruit was monitored throughout the trials, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 85%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed. Colour score and durometer firmness were recorded for 20 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. Skin colour was scored using the following scale:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx. 25% colour development
- 4 = Approx. 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

When fruit were removed from storage treatments, weight and firmness were measured in all fruit. The surface area (%SA) of discrete patches on the skin (chilling injury) was also recorded.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 39 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven dry matter averaged 27.6%, with all fruit having DM of 23% or higher. The relationships between NIR predicted DM and oven DM were strong in this trial, averaging $R^2=0.78$ (data not shown).

Fruit quality and shelf life

Fruit weight loss varied under different treatments, but did not seem to be affected by the length of delay prior to storage (data not shown). Skin colour at removal was similar across all treatments, and did not differ due to delay (data not shown). Fruit firmness at removal from storage treatments was very firm across all treatments (Table 2). Fruit kept at 5°C in air seemed slightly softer than other treatments, but delay pre-treatments from 2 to 7 days did not appear to substantially change firmness.

Table 2. Durometer firmness of 'Hass' avocado fruit at removal from various storage treatments

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	85.7			
3°C	16	Air		84.9	84.8	84.4
	16	+CA		84.2	84.7	84.4
3°C	21	Air		84.8	84	85.2
	21	+CA		84.3	84.4	84.4
5°C	21	Air		82.4	81.8	83.2
	21	+CA		83.3	84.4	84.1

CA generally slowed ripening slightly compared with fruit stored in air, by an average of around 0.7 days (Table 3). Delays of 2 to 7 days prior to storage treatment did not have any consistent impacts on ripening.

Table 3. Days at 20°C taken for 'Hass' avocados to reach firm ripe after various storage treatments

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	6.7			
3°C	16	Air		3.5	4.5	4.0
	16	+CA		3.8	4.5	4.5
3°C	21	Air		4.0	4.0	4.5
	21	+CA		4.7	4.9	4.8
5°C	21	Air		3.3	3.0	3.5
	21	+CA		4.1	4.5	4.7

Quality traits measured at medium ripe stage were used to estimate when fruit would reach end of shelf life. Fruit were considered at end of shelf life when oversoft (Bareiss firmness of 30 or less) or if rots exceeded 10% flesh volume. Remaining shelf life averaged around 8 days after storage treatments (Table 4). While some variation was seen between treatments, 2 to 7 day pre-treatments at 5°C did not have any consistent impact on shelf life.

Table 4. Remaining shelf life (days at 20°C) of 'Hass' avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	10.4			
3°C	16	Air		7.5	7.9	7.3
	16	+CA		7.6	7.8	7.6
3°C	21	Air		7.6	7.8	8.8
	21	+CA		8.0	8.3	7.6
5°C	21	Air		6.8	6.9	7.5
	21	+CA		7.3	7.7	7.9

Green skin colour retention at medium ripe was highest in fruit kept constantly at 20°C (Table 5). Retention of green skin at ripe was also high in the 21 day 5°C air-stored treatments. No clear effects were shown by the delay pre-treatments at 5°C.

Table 5. Green skin retention (%SA) at medium ripe in 'Hass' avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	37.5			
3°C	16	Air		7.3	1.7	7.5
	16	+CA		4.5	3.0	8.2
3°C	21	Air		8.2	4.7	3.2
	21	+CA		4.7	2.6	6.7
5°C	21	Air		24.4	18.9	21.2
	21	+CA		5.2	4.7	8.3

Delays at 5°C did not have any clear or consistent impacts on the development of discrete patches, which occurred at very low levels in this trial (data not shown).

Diffuse discolouration following 5°C storage for 21 days was affected by delays (Table 6). An additional 5 days of delay significantly increased the incidence and volume of diffuse discolouration in fruit stored in air at 5°C for 21 days (Figure 1). Corresponding treatments stored in CA showed very low levels of diffuse discolouration that did not differ with delay. Levels of diffuse discolouration were also low in 3°C fruit, despite the cooler storage conditions, and did not show any delay effects. Treatments of 4+21 days and 7+21 days at 5°C in air caused a substantial amount of diffuse discolouration (>10% of fruit exceeding 5% volume), while overall levels were very low in all other treatments.

Table 6. Incidence of any diffuse discolouration of the flesh at medium ripe in 'Hass' avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	0			
3°C	16	Air		7	3	0
	16	+CA		3	0	0
3°C	21	Air		3	0	13
	21	+CA		0	10	7
5°C	21	Air		3	23	37
	21	+CA		0	0	10

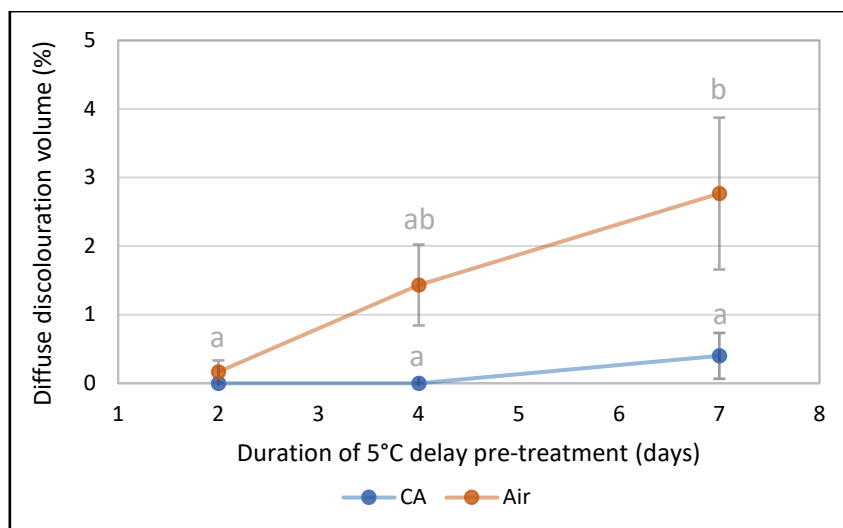


Figure 1. Diffuse discolouration volume (average % across all fruit) in ‘Hass’ avocados following delays prior to storage at 5°C for 21 days with and without CA

Different letters indicate a significant difference between treatments at $p < 0.05$

Error bars show standard error

While there was some appearance of delay treatment effects on body rots, these were not consistent between 3 and 5°C treatments (Table 7, Table 8). Body rots appeared to increase with longer pre-treatment delay, particularly in the 5°C treatments. The pre-treatment effects on body rots were not strong or consistent across treatments. There may be complex interacting effects of delays under different storage conditions. However, a large degree of inherent variation occurs in rot data, so effects can be difficult to accurately detect without very large sample sizes.

Table 7. Severity of body rots (average % volume across all fruit) at medium ripe in ‘Hass’ avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	0.8			
3°C	16	Air		1.8	1.4	4.2
	16	+CA		2.1	0.5	0.9
3°C	21	Air		3.3	1.7	7.4
	21	+CA		7.7	6.8	3.9
5°C	21	Air		1.6	7.5	9.5
	21	+CA		1.9	1.2	3.5

Table 8. Incidence of body rots (% of fruit) at medium ripe in ‘Hass’ avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	33			
3°C	16	Air		27	27	23
	16	+CA		43	20	7
3°C	21	Air		23	43	70
	21	+CA		50	60	40
5°C	21	Air		10	47	67
	21	+CA		10	13	37

Delays at 5°C did not have any clear or consistent impacts on the development of stem end rots, which occurred at relatively low levels in this trial (data not shown).

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Overall, the levels of unacceptable internal defects in medium ripe fruit tended to be higher following an extra 5 days of delay at 5°C prior to storage (Table 9). The effect appeared to be stronger in air stored treatments, and lessened by the use of CA. However, the inherent variability of this measure made it difficult to determine any clear effects.

Table 9. Percentage of ‘Hass’ avocados with unacceptable internal defects at medium ripe stage, after various storage conditions.

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	7			
3°C	16	Air		3	7	13
	16	+CA		7	0	7
3°C	21	Air		10	7	37
	21	+CA		27	27	27
5°C	21	Air		7	33	43
	21	+CA		7	3	13

Pre-conditioning effects

The effects of preconditioning could be tested by comparing 5°C storage for 23 days against 3°C storage with pre-conditioning at 5°C for 2 or 7 days. The total duration of these 3 treatments was 23 days.

Pre-conditioning treatments had minimal impact on fruit quality. Differences were seen between the 3 and 5°C treatments, but fruit pre-conditioned for 2 or 7 days prior to 3°C storage were generally very similar. Pre-conditioning seemed to reduce body rot in 3°C CA treated fruit, however, it seems likely this is due to inherent variation and not a genuine effect. The same effect was not observed in air stored fruit. The higher levels of unacceptable fruit shown following the 21d 3°C treatment in CA were due to higher body rot levels.

Table 10. Impact of pre-conditioning treatments on fruit ripening and quality traits in ‘Hass’ avocados

Treatment regime	Weight loss at removal (%)	Firmness at removal	Green skin %SA at medium ripe	Body rot severity (% vol)	Body rot incidence (% fruit)	Diffuse discol. severity (% vol)	Diffuse discol. incidence (% fruit)	Shelf life at removal	Unacceptable fruit (%)
Air stored treatments									
7d 5°C + 16d 3°C	1.8	84.4	7.5	4.2	23.3	0.0	0.0	7.3	13
2d 5°C + 21d 3°C	1.7	84.8	8.2	3.3	23.3	0.3	3.3	7.6	10
2d 5°C + 21d 5°C	3.4	82.4	24.4	1.6	10.0	0.2	3.3	6.8	7
CA stored treatments									
7d 5°C + 16d 3°C	1.6	84.4	8.2	0.9	6.7	0.0	0.0	7.6	7
2d 5°C + 21d 3°C	1.5	84.3	4.7	7.7	50.0	0.0	0.0	8.0	27
2d 5°C + 21d 5°C	3.0	83.3	5.2	1.9	10.0	0.0	0.0	7.3	7



Potential for 3°C market access treatment

A storage regime of 3°C for 16 days was included in the trial design to explore the impacts of a potential market access treatment on 'Hass' avocado fruit quality. In this trial, the treatment did not appear to cause any issues with fruit quality. The treatments incorporating 16 days at 3°C showed the most favourable overall outcomes for consumer tolerance thresholds. However, this test was very preliminary in nature. Chilling susceptibility can vary widely due to pre-harvest conditions, so further rigorous testing of this regime would be essential prior to adoption.

4. Summaries and recommendations

- Holding fruit for an additional 5 days at 5°C prior to storage generally did not cause substantial issues with quality.
- Prolonging cold storage at 5°C likely caused small and incremental loss of quality. These types of changes are difficult to detect in experimental trials given the inherent variability of fresh produce.
- For fruit stored for 21 days at 5°C in air, a 7-day delay prior to storage increased diffuse discolouration compared with a 2-day delay. However, this effect was mitigated by CA storage.
- Short delays to the commencement of CA did not result in any substantial differences in ripening or quality.
- Pre-conditioning for an extra 5 days at 5°C prior to 3°C storage did not affect fruit ripening and quality.
- Preliminary testing of a potential market access treatment (16 days at 3°C) did not cause any quality issues in 'Hass' avocados.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 25

**CQ 'Hass' avocado controlled atmosphere trials report
2024b**



Impact of delays prior to storage on 'Hass' avocado fruit quality and shelf life

2024 season Central Queensland grower report

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Department of Primary Industries

Summary

The trial aimed to explore the effects of delays prior to storage on the shelf life and quality of 'Hass' avocados. Fruit were stored for 3 different delay periods of 2, 4 or 7 days at 5°C, prior to air or controlled atmosphere (CA) storage at 3 or 5°C. At 3°C, storage durations of 16 or 21 days were tested, while 5°C treatments were for 21 days. Following treatment, fruit were held at 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from these trials included:

- Pre-storage delays of 2 to 7 days at 5°C had some impacts on fruit ripening and quality, but these were often mitigated by CA storage.
- Longer delays resulted in slightly more colour development at removal from storage. This effect was reduced or eliminated under CA storage.
- Increasing the pre-storage delay from 2 to 7 days caused an average loss of 0.5 days shelf life.
- Delays increased the severity and incidence of diffuse discolouration in the air stored treatments.
- CA stored treatments showed low levels of diffuse discolouration that did not increase with the addition of 2 to 7 day delays.
- Pre-conditioning treatments prior to 3°C storage did not show any beneficial effects in this trial.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers CA delay trial work completed during the 2024 'Hass' avocado season. The main objective of the trial was to quantify the impact of delays prior to CA on fruit quality and shelf life responses of 'Hass' avocados. The trial also investigated the impact of preconditioning prior to 3°C storage and tested a potential market access treatment of 16 days at 3°C. Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

The trial design included 3 different delay periods of 2, 4 or 7 days at 5°C, prior to CA storage at 3 or 5°C (Table 1). Storage durations of 21 days were tested at 3°C and 5°C. Fruit responses to a potential market access cold treatment were also explored through treatment at 3°C for 16 days. All storage treatments were tested with and without CA. Relative humidity (RH) was maintained near 85% in all treatments. Following storage, fruit were shifted to 20°C and 65% relative humidity (RH) for ongoing assessment of ripening and quality. A total of 19 treatment groups (delay x temperature x duration x CA) were included in the design. Each treatment was applied to 3 replicate trays of 10 'Hass' avocado fruit.

Table 1. CA delay and preconditioning storage conditions applied to 'Hass' avocados.

Delay (days at 5°C)	Treatment temperature	CA	Duration (days)
0 days	20°C	-	-
2 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21
4 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21
7 days	3°C	-	16
		CA	16
	3°C	-	21
		CA	21
	5°C	-	21
		CA	21

CA = controlled atmosphere of 2% O₂ and 5% CO₂



Commercially mature 'Hass' avocado fruit (targeting dry matter >23%) were sourced for the trial during the 2024 season. Fruit were harvested on 8-9th July 2024 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to the nearby packing shed. On 10th July they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 30 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 23°C) for 3 hours and were then kept overnight at approx. 21°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

The air temperature adjacent to fruit was monitored throughout the trials, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 85%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed. Colour score and durometer firmness were recorded for 20 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. Skin colour was scored using the following scale:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx. 25% colour development
- 4 = Approx. 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

When fruit were removed from storage treatments, weight and firmness were measured in all fruit. The surface area (%SA) of discrete patches on the skin (chilling injury) was also recorded.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 39 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven dry matter averaged 31.4%, with all fruit having DM of 23% or higher. The relationships between NIR predicted DM and oven DM were strong in this trial, averaging $R^2=0.80$ (data not shown).

Fruit quality and shelf life

Under some conditions, skin colour tended to be slightly more developed when fruit were delayed for longer (Table 2). The 7 day delay increased skin colour score for 3°C 16 day treatments compared with shorter delays. Skin colour was also more developed following delays prior to 21 days storage at 5°C. In the 5°C fruit, this effect was mitigated by CA storage.

Table 2. Skin colour score of 'Hass' avocado fruit at removal from various storage treatments

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	1.7			
3°C	16	Air		1.7	1.6	2.0
	16	+CA		1.7	1.7	1.9
3°C	21	Air		2.0	2.0	2.1
	21	+CA		1.9	1.9	2.0
5°C	21	Air		2.0	2.2	2.4
	21	+CA		1.9	2.0	2.0

Fruit weight loss varied under different treatments but was not strongly affected by the length of delay prior to storage (data not shown). Fruit firmness at removal from storage treatments was very firm, averaging 80 or higher across all treatments (data not shown). Delay pre-treatments from 2 to 7 days did not appear to substantially differ in firmness.

CA generally slowed ripening slightly compared with fruit stored in air, by an average of around 0.5 days (Table 3). Delays of 2 to 7 days prior to storage treatment did not have any consistent impacts on ripening. In fruit stored for 16 days at 3°C, the 7 day delay slightly reduced ripening time compared to shorter delays.

Table 3. Days at 20°C taken for 'Hass' avocados to reach firm ripe after various storage treatments

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	8.7			
3°C	16	Air		5.1	5.1	4.3
	16	+CA		5.5	5.3	4.6
3°C	21	Air		4.7	4.7	5
	21	+CA		4.8	5.7	4.8
5°C	21	Air		3.6	3.9	4.1
	21	+CA		4.5	4.8	4.6

Quality traits measured at medium ripe stage were used to estimate when fruit would reach end of shelf life. Fruit were considered at end of shelf life when oversoft (Bareiss firmness of 30 or less) or if rots exceeded 10% flesh volume. Remaining shelf life averaged around 9 days after storage treatments (Table 4). Increasing the delay prior to storage from 2 to 7 days caused a slight loss of shelf life averaging around 0.5 days across all treatments.

Table 4. Remaining shelf life (days at 20°C) of 'Hass' avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	13			
3°C	16	Air		9.2	9.3	8.9
	16	+CA		9.5	9.3	9.3
3°C	21	Air		9.5	8.8	8.7
	21	+CA		9.7	9.1	8.7
5°C	21	Air		8.5	8.6	7.9
	21	+CA		8.7	8.8	8.4

Delays at 5°C did not have any clear or consistent impacts on the development of discrete patches, which occurred at very low levels in this trial (data not shown).

Delays at 5°C prior to storage increased the incidence and volume of diffuse discolouration when fruit were subsequently stored in air (Table 5, Table 6). In contrast, treatments stored in CA showed very low levels of diffuse discolouration that did not differ with delay.

Table 5. Incidence of diffuse discolouration affecting >5% flesh volume in medium ripe 'Hass' avocados after various storage conditions (% of fruit)

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	0			
3°C	16	Air		6.7	3.3	10
	16	+CA		0	0	0
3°C	21	Air		3.3	23	20
	21	+CA		3.3	3.3	3.3
5°C	21	Air		13	30	33
	21	+CA		3.3	6.7	3.3

Table 6. Severity of diffuse discolouration (average % flesh volume affected across all fruit) in medium ripe 'Hass' avocados after various storage conditions

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	0.1			
3°C	16	Air		2.2	0.5	5.4
	16	+CA		0	0	0.2
3°C	21	Air		0.4	4.1	5
	21	+CA		0.7	2.3	0.6
5°C	21	Air		3.6	5.8	7.8
	21	+CA		1.1	1.9	0.7

Differences in rot development were shown due to temperature and CA, however delays at 5°C did not have any clear or consistent impacts on the subsequent development of body rots or stem end rots (data not shown). A large degree of inherent variation occurs in rot data, so effects are difficult to accurately detect without very large sample sizes.

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Overall, the levels of unacceptable internal defects in medium ripe fruit were higher in air than under CA (Table 7). Longer

storage duration and warmer storage temperature also tended to increase the percentage of unacceptable internal defects. However, delays at 5°C prior to storage did not show any strong or consistent effects.

Table 7. Percentage of ‘Hass’ avocados with unacceptable internal defects at medium ripe stage, after various storage conditions.

Temperature	Duration (days)	CA	Delay at 5°C prior to storage treatment (days)			
			0	2	4	7
20°C	0	Air	33			
3°C	16	Air		23	20	33
	16	+CA		10	6.7	27
3°C	21	Air		47	43	53
	21	+CA		33	13	20
5°C	21	Air		50	57	67
	21	+CA		13	10	13

Pre-conditioning effects

The effects of preconditioning could be tested by comparing 5°C storage for 23 days against 3°C storage with pre-conditioning at 5°C for 2 or 7 days. The total duration of these 3 treatments was 23 days. Pre-conditioning treatments did not seem to have any strong impacts on fruit ripening or quality (Table 8). Fruit pre-conditioned for 2 or 7 days prior to 3°C storage were generally similar.

Table 8. Impact of pre-conditioning treatments on fruit ripening and quality traits in ‘Hass’ avocados

Treatment regime	Weight loss at removal (%)	Firmness at removal	Colour score at removal	Diffuse discol. severity (% vol)	Diffuse discol. incidence (% fruit)	Days to firm ripe	Shelf life at removal	Unacceptable fruit (%)
Air stored treatments								
7d 5°C + 16d 3°C	2.2	81.9	2.0	5.4	10	4.3	8.9	33
2d 5°C + 21d 3°C	1.8	82.2	2.0	0.4	3	4.7	9.5	47
2d 5°C + 23d 5°C	3.9	80.2	2.0	3.6	13	3.6	8.5	50
CA stored treatments								
7d 5°C + 16d 3°C	1.9	81.1	1.9	0.2	0	4.6	9.3	27
2d 5°C + 21d 3°C	1.8	82.4	1.9	0.7	3	4.8	9.7	33
2d 5°C + 21d 5°C	3.1	80.7	1.9	1.1	3	4.5	8.7	13

Potential for 3°C market access treatment

A storage regime of 3°C for 16 days was included in the trial design to explore the impacts of a potential market access treatment on ‘Hass’ avocado fruit quality. In this trial, the treatment did not appear to cause any issues with fruit quality, even following delays of 2 or 4 days at 5°C. The combination of 7 days delay at 5°C followed by 16 days at 3°C caused some issues with diffuse discolouration (10% of fruit affected with >5% volume). Treatments incorporating 16 days at 3°C tended to show the most favourable overall outcomes for consumer tolerance thresholds. However, this test was very preliminary in nature. Chilling susceptibility can vary widely due to pre-harvest conditions, so further rigorous testing of this regime would be essential prior to adoption.



4. Summaries and recommendations

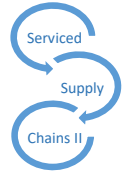
- Increasing the delay prior to storage from 2 to 7 days caused a slight loss of shelf life averaging around 0.5 days.
- For fruit stored in air, longer delays prior to storage increased flesh diffuse discolouration.
- Under CA storage, diffuse discolouration occurred at very low levels and was not affected by 2 to 7 day delays at 5°C.
- Short delays to the commencement of CA caused a very slight reduction in shelf life, but did not result in any substantial differences in ripening or quality.
- Pre-conditioning at 5°C for 2 or 7 days prior to 3°C storage did not affect fruit ripening and quality.
- Preliminary testing of a potential market access treatment (16 days at 3°C) did not cause any quality issues in 'Hass' avocados, except when combined with a delay of 7 days at 5°C.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 26

NQ 'Hass' avocado simulation trials report 2025



2025 North Queensland Grower Report

John Archer, Minh Nguyen, Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

This report presents the findings from the 2025 North Queensland (NQ) post-harvest storage trials on 'Hass' avocados. The study evaluated the impact of controlled atmosphere (CA) storage and temperature on fruit quality, shelf life, and post-harvest disorder development.

Key Performance Indicators (KPIs):

- **Shelf Life (SL):** Days to senescence, defined as the time until fruit reached medium-ripe stage (durometer firmness of 39 or less).
- **Defect Severity (%):** The average percentage of flesh or surface area affected by defects.
- **Diffuse Discolouration (DD):** A specific indicator of chilling injury.
- **Total Severity Volume:** The cumulative volume of all recorded defects.

Treatments resulting in an Average Total Severity > 10% are flagged.

Shelf life, chilling injury, and overall defect responses observed in 2025 were generally similar to those recorded during the 2024 season. The 2025 'Hass' trials primarily focused on the effects of controlled atmosphere storage on chilling injury, post-harvest disorders, firmness retention, and shelf life extension.

Storage at 5°C under controlled atmosphere conditions was effective in extending storage duration, maintaining fruit firmness, and reducing chilling injury compared with fruit stored under air (non-CA) conditions. In contrast, fruit stored under air conditions showed an increased risk of chilling injury and overall quality decline during prolonged storage.

Across all treatments, increasing storage duration was associated with higher levels of defect severity. Comparison of the four seasonal trials did not indicate a consistent trend in shelf life or firmness between harvest periods. However, rot-related defects, particularly body rot and stem-end rot, were generally higher in the mid- and late-season trials compared with the early-season trial.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters, helping maximise product value, reduce claims, and expand trade volume.

This report focuses on export simulation trials conducted during the 2025 'Hass' avocado season on fruit grown in North Queensland (NQ). The primary objective of these trials was to assess the impact of controlled atmosphere (CA) storage on fruit quality, shelf life, firmness retention, and chilling injury development in 'Hass' avocados stored for durations ranging from 10 to 55 days at 5°C.

The trials compared fruit stored under air (non-CA) and controlled atmosphere conditions to evaluate the effectiveness of CA storage in maintaining post-harvest quality during extended storage periods. In addition, the study examined the relationship between storage duration and the development of post-harvest disorders, including body rot, stem-end rot, vascular browning, and diffuse discolouration associated with chilling injury.

2. Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Hass' avocados were harvested during the 2025 season by a commercial picking crew from orchards near Tolga, Queensland. Following harvest, fruit were transported to a nearby packing facility, where they were graded and packed before being transported to Cairns for experimental assessment.

Harvest dates for Trials 1, 2, 3, and 4 were 6 May 2025, 19 May 2025, 20 May 2025, and 16 June 2025, respectively.

Experimental Design

The results presented in this report are based on combined data from three independent trials conducted during the 2025 'Hass' avocado season. Each trial included three replicates per treatment, with each replicate consisting of 8 fruit. This design ensured sufficient statistical power to detect treatment effects while accounting for biological variability.

Dry Matter Content Measurement

Fruit dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values and then sorted by DM content. Fruit were assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of 20 fruits were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

Fruit were stored under storage conditions designed to simulate extended export supply chain scenarios, as detailed in Table 1. Fruit were stored at 5°C under either air (non-CA) or controlled



atmosphere (CA) conditions. Controlled atmosphere storage conditions were maintained at 2% O₂ and 5% CO₂. No ethylene treatments were applied during storage.

Table 1. Trial storage temperature treatments

Storage Temperature (°C)	Controlled Atmosphere	Storage Duration (days)
5	Non-CA	10, 21, 28, 35, 42, 55
5	Controlled Atmosphere	21, 28, 35, 42, 55

At the conclusion of each storage treatment period, fruit were transferred to 20°C and 65% relative humidity for assessment of remaining shelf life. Harvest weather data were incorporated, and fruit temperature was monitored from the time of collection at the packing shed through to removal from cold storage. This enabled the calculation of time × temperature units (TTU), which were used in the development of avocado modelling.

Humidity Control

Relative humidity (RH) during cold storage was maintained at approximately 90% to simulate commercial cold chain conditions. Following removal from storage, fruit were held at 20°C and 65% RH to replicate retail shelf conditions.

Bareiss Firmness and Shelf Life Assessment

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit at the equator. When fruit neared medium ripe (durometer firmness of 39 or less), a final assessment was undertaken. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discoloration were expressed as the percentage of flesh volume affected.

3. Results

The mean dry matter (DM) content for each trial, estimated using near-infrared spectroscopy (NIR), was 27.5%, 27.2%, 29.1%, and 31.3% for Trials 1, 2, 3, and 4, respectively. These values represent the average DM content of all fruit included in each trial. The increase in DM observed in the later trials reflects seasonal progression and increasing fruit maturity over the harvest period.

4. Firmness

Firmness Fruit firmness generally declined with increasing storage duration. However, fruit stored at 5°C under controlled atmosphere (CA) conditions retained higher firmness throughout storage compared with fruit stored under air (non-CA) conditions. Fruit held under CA storage maintained high firmness even after 55 days of storage (approximately 80 Shore units), whereas firmness of fruit stored under non-CA conditions declined progressively over time (Figure 1.). Results from the four successive harvest trials (Trials 1–4) were broadly consistent, with observed differences falling within the normal biological variation expected among fruit. The results demonstrate that controlled atmosphere storage was effective in slowing firmness loss during extended cold storage.

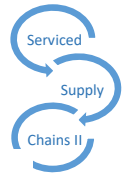
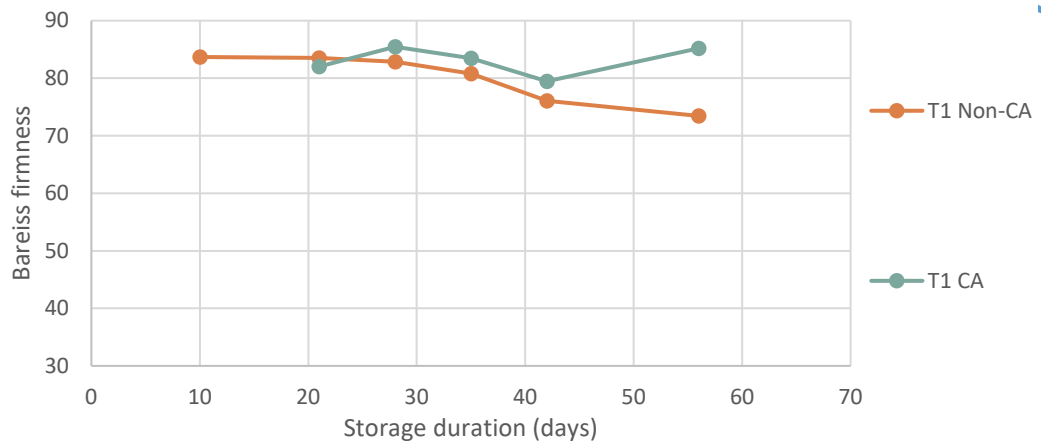
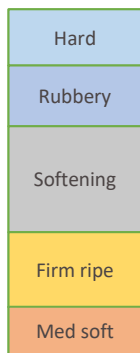
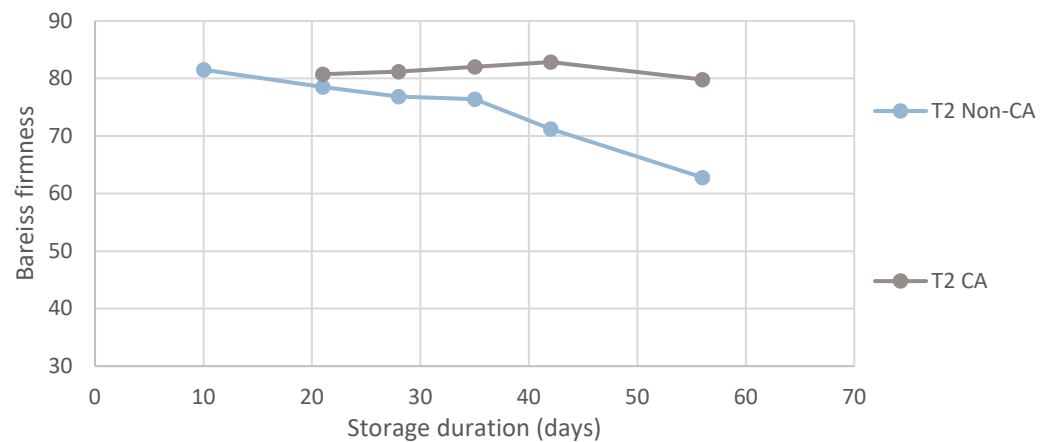
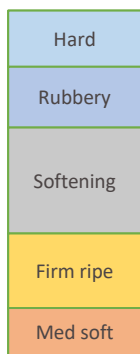
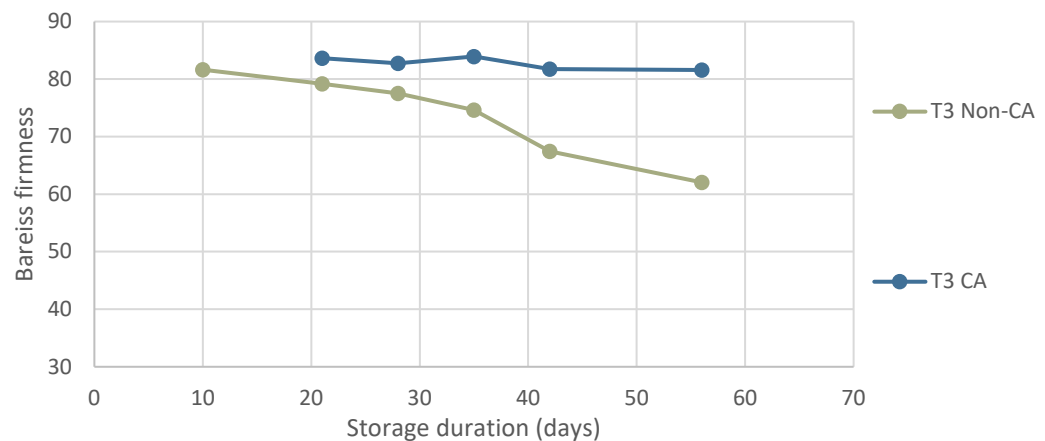
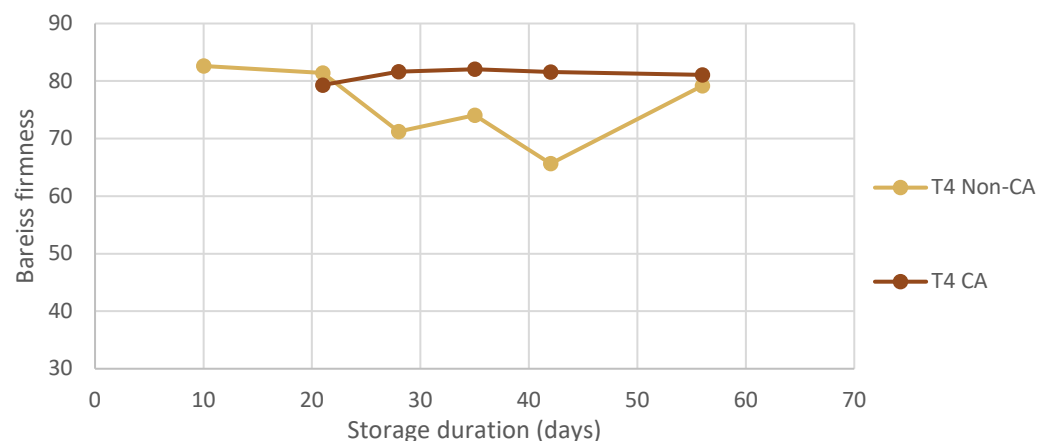
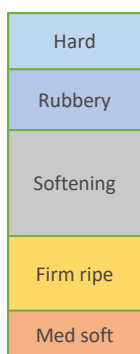
**Trial 1****Trial 2****Trial 3****Trial 4**

Figure 1. Firmness of ‘Hass’ avocados under storage conditions (5°C), CA refers to controlled atmosphere (2% O₂ and 5% CO₂). Four consecutive harvest trials (T1–T4). Side panels indicate the corresponding consumer firmness classes from “Hard” to “Medium-soft.”

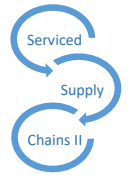
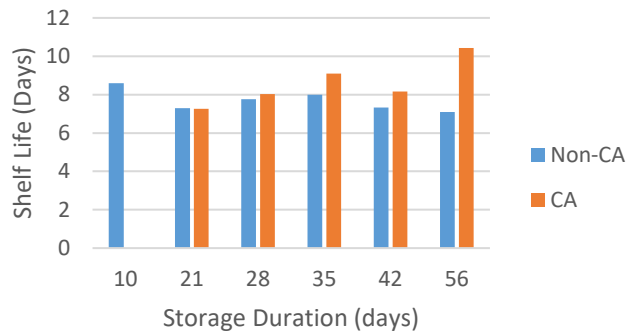
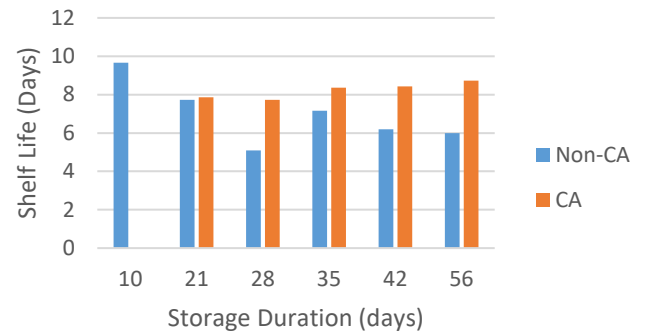
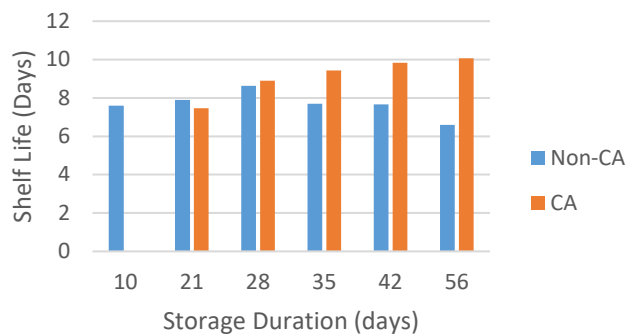
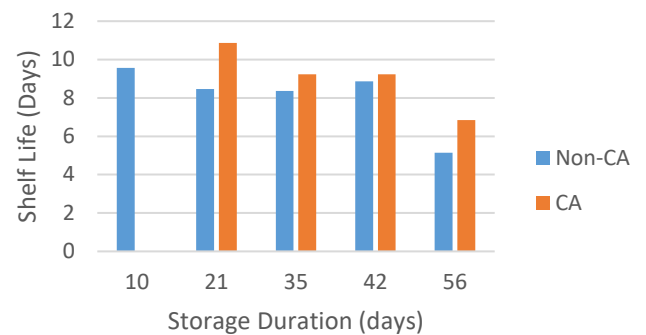
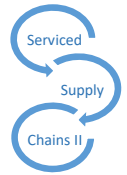
**Trial 1****Trial 2****Trial 3****Trial 4**

Figure 2. Average shelf life of 2025 North Queensland 'Hass' avocados stored at 5°C under air (Non-CA) and controlled atmosphere (CA) conditions across four harvest trials.



5. Shelf Life Performance

The average marketable shelf life for each treatment is presented separately for Trials 1, 2, 3, and 4 in **Figure 2**. Across all four trials, shelf life generally declined with increasing storage duration under air (Non-CA) conditions. In contrast, fruit stored under controlled atmosphere (CA) conditions at 5°C consistently maintained a longer shelf life compared with fruit held under air storage, particularly at extended storage durations.

Although some variation was observed between trials, the overall trend was consistent across the season, indicating that controlled atmosphere storage improved shelf-life outcomes and delayed fruit senescence during prolonged cold storage. The beneficial effects of CA storage became more pronounced after approximately 35 days of storage, where differences between CA and Non-CA fruit were greatest (**Figure 2**).

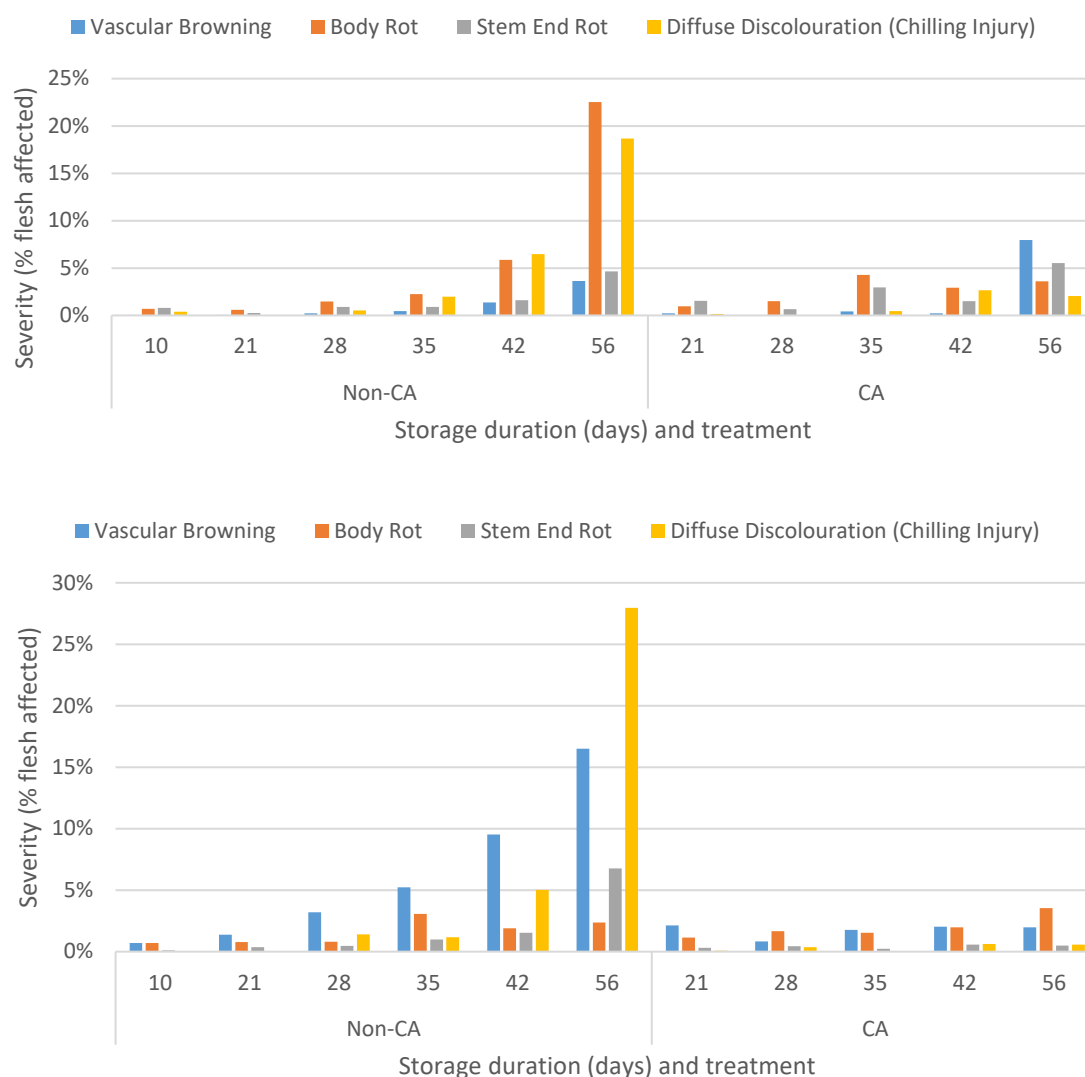


Figure 3. Average defect severity (% flesh affected) of 2025 North Queensland 'Hass' avocados stored at 5°C under air (Non-CA) and controlled atmosphere (CA) conditions. Trial 1 shown top and Trial 2 shown bottom.

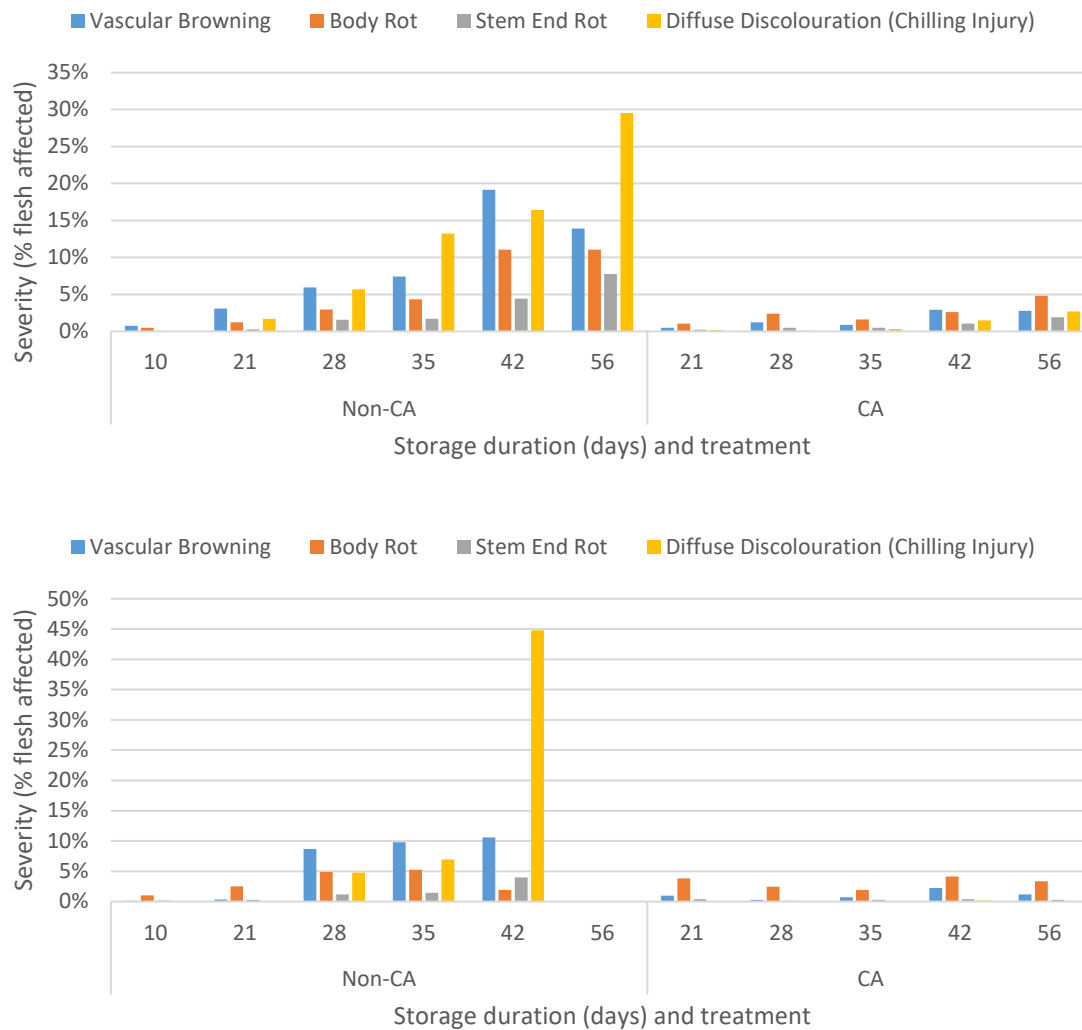
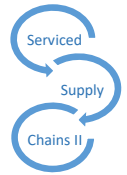
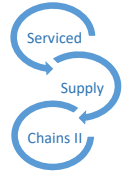


Figure 4. Average defect severity (% flesh affected) of 2025 North Queensland 'Hass' avocados stored at 5°C under air (Non-CA) and controlled atmosphere (CA) conditions. Trial 3 shown top and Trial 4 shown bottom.



6. Chilling Injury: Diffuse Discolouration (DD)

Diffuse discolouration (DD) is a specific manifestation of chilling injury in avocado fruit. The severity of DD and associated post-harvest defects for each treatment is presented for Trials 1 and 2 in Figure 3, and for Trials 3 and 4 in Figure 4.

Across all four trials, DD generally increased with prolonged storage duration under air (Non-CA) conditions. The most severe chilling injury symptoms were observed in fruit stored under Non-CA conditions for 42–56 days, where DD increased markedly and was frequently associated with elevated vascular browning and rot-related defects.

In contrast, fruit stored under controlled atmosphere (CA) conditions consistently showed substantially lower levels of DD across all storage durations. This effect was particularly evident at the longest storage durations, where CA fruit maintained relatively low chilling injury severity compared with the corresponding Non-CA treatments.

The results demonstrate that controlled atmosphere storage at 5°C was effective in reducing the development of chilling injury during extended cold storage. However, some variability was observed between trials, reflecting seasonal and biological variation among fruit.

7. Defect Severity Analysis

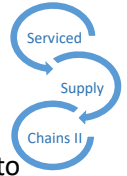
Defect severity reflects the combined impact of storage duration and storage atmosphere on fruit quality. Total defect severity comprised vascular browning, body rot, stem-end rot, and diffuse discolouration associated with chilling injury. The average severity of these defects for Trials 1 and 2 is presented in Figure 3, while Trials 3 and 4 are presented in Figure 4.

Across all four trials, total defect severity generally increased with increasing storage duration, particularly under air (Non-CA) storage conditions. Non-CA fruit stored for 42–56 days showed the highest levels of defect development, with substantial increases in chilling injury, vascular browning, and rot-related disorders.

Controlled atmosphere storage substantially reduced chilling injury severity across all trials and storage durations. In several trials, CA storage also reduced overall defect severity at extended storage durations compared with equivalent Non-CA treatments. Despite this improvement, some long-duration CA treatments still exhibited moderate levels of vascular browning and rot-related defects, particularly at 56 days of storage.

A notable result across all trials was the sharp increase in diffuse discolouration and vascular browning observed in Non-CA fruit after prolonged storage. In contrast, equivalent CA treatments maintained comparatively low levels of chilling injury symptoms, confirming the protective effect of controlled atmosphere storage during extended cold storage at 5°C.

Seasonal conditions during 2025, including periods of high rainfall, may have contributed to increased background defect pressure and variability between trials. Nevertheless, the overall trend across the four trials consistently demonstrated that controlled atmosphere storage improved fruit quality retention and reduced chilling injury risk during long-term storage.



8. Conclusion

A series of export simulation trials were conducted using 2025 North Queensland 'Hass' avocados to assess the effects of controlled atmosphere (CA) storage on fruit quality, firmness retention, shelf life, and post-harvest disorder development during extended storage at 5°C.

Across all four trials, increasing storage duration resulted in higher defect severity and reduced fruit quality under air (Non-CA) storage conditions. The greatest quality decline occurred after 42–56 days of Non-CA storage, where chilling injury, vascular browning, and rot-related defects increased substantially. In contrast, fruit stored under CA conditions maintained improved firmness, reduced chilling injury severity, and longer shelf life throughout storage.

The results demonstrate that controlled atmosphere storage at 5°C is an effective strategy for improving storage performance and reducing chilling injury risk in North Queensland 'Hass' avocados during extended export storage conditions.

Key Findings

1. Controlled Atmosphere Benefits
 - Reduced chilling injury and diffuse discolouration (DD)
 - Improved firmness retention and shelf life
2. Storage Duration Effects
 - Defect severity increased with longer storage duration
 - Non-CA fruit showed substantial quality decline after 35–42 days
3. Defect Development
 - Vascular browning and diffuse discolouration were major defects under prolonged Non-CA storage
 - Rot-related defects increased with extended storage duration

Practical Recommendations

- Use CA storage at 5°C for storage durations exceeding 28 days
- Avoid prolonged Non-CA storage beyond 35–42 days
- Monitor fruit quality closely during extended storage periods

Appendix 27

CQ 'Hass' avocado storage trials report 2025a



Controlled atmosphere storage of Hass avocados

2025 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

As avocado exports grow, supply chain stakeholders increasingly value the ability to predict outcomes of prolonged storage. Predictive models require a sound underlying framework of simulation trial data captured over multiple seasons. In 2025, Hass avocado shelf life and quality were assessed following various storage scenarios to continue to build and improve predictive models. Early and mid-season fruit were stored at 5°C and approximately 90% relative humidity (RH) for periods ranging from 21 to 56 days, with and without controlled atmosphere (CA). Sub-samples of fruit were regularly removed from storage and held at 20°C and approx. 65% RH to evaluate fruit quality and remaining shelf life.

Key observations from the simulation trials:

- Without CA, progressively longer storage durations resulted in:
 - Gradual softening
 - Increasing weight loss, with up to 7% weight lost after 56 days
 - Increasing levels of skin chilling and internal chilling / aging damage
 - More black-toned skin colour development
- For long storage of Hass avocados, CA was highly beneficial in:
 - Maintaining firmness
 - Reducing weight loss
 - Minimising skin chilling and internal chilling / aging damage
 - Promoting purple colour development rather than black-green colour
 - Minimising rots
 - Extending shelf life
- For the early season batch, storage potential was doubled from 21 to 42 days by using CA, with good retention of fruit quality.
- The mid-season batch were less robust and were highly susceptible to internal chilling / aging damage.
- While CA improved outcomes, the mid-season fruit showed quality issues even after short storage durations.
- These results demonstrate the overriding impact of fruit robustness on storage potential.
- Holding at 16°C after long storage resulted in poor fruit quality outcomes compared with warmer retail simulation temperatures.
- Fruit quality and shelf life were only slightly impacted by changing retail conditions from 20 to 24°C.
- A 2-day delay on-farm (in a mix of 10°C and ambient conditions) prior to storage resulted in softer fruit coming out of storage, and poorer fruit quality outcomes in CA treated fruit.



Introduction

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2025 Hass avocado season. The main objective of the trial was to quantify fruit quality and shelf life responses of Hass avocados to long supply chain durations with and without the application of CA. The trial investigated the impacts of time and temperature effects, CA storage, and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

Materials and methods

Commercially mature Hass avocado fruit (targeting dry matter >23%) were sourced for the trials during the 2025 season. Fruit were harvested on 7th May (early season) and 23rd June (mid-season) 2025 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the day of harvest. The following morning they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of premium count 28 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 16-20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to a range of storage regimes designed to reflect potential sea freight conditions, as shown in Table 1. Fruit were stored for 21 to 56 days at 5°C, with or without CA (at 2% O₂ and 5% CO₂). A 10-day treatment at 5°C was added as a baseline indication of quality under a shorter supply chain scenario. All treatments were applied to 3 replicate trays of 10 fruit. Fruit within these trials were not treated with ethylene at any stage. At the end of each treatment storage duration, fruit were shifted to retail simulation at 20°C and 65% RH for ongoing assessment.

In the early season trial, additional trays of fruit were added to test the impact of post-storage temperature on shelf life and quality. Varied post-storage temperatures were tested following 21 and 42 days at 5°C, with or without CA. Fruit were transferred to either 16 or 24°C retail simulation conditions, in addition to the 20°C retail conditions used in the main trial.

In the mid-season trial, additional trays of fruit tested the impact of on-farm delays prior to long storage. Each 35-day treatment had a matching on-farm delay treatment of fruit from the same harvest. These fruit were transferred into an on-farm cool room at 10°C the morning after harvest, until the following

afternoon (approx. 31 hours). The fruit were then shifted into ambient pack shed conditions prior to packing the next day, with temperatures ranging from 12 to 26°C. After packing, the fruit were transferred to the laboratory in an air-conditioned vehicle and were held at approx. 18°C overnight prior to treatment commencement.

Table 1. Storage conditions applied to Hass avocados in 2025 CA trials.

Temperature	CA	Storage duration (days) prior to ongoing 20°C storage					
		10	21	28	35	42	56
5°C	Non-CA	x	x	x	x	x	x
5°C	+CA		x	x	x	x	x

+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

In the early trial some treatment durations were shifted one day earlier due to logistical constraints (34 and 55 days).

The air temperature adjacent to fruit was monitored throughout the trial, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed and firmness was measured on 20 fruit per trial. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury (typically shown as discrete patches) was recorded as the percentage of skin surface area (%SA) affected.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38.5 or less) or if rots were anticipated to exceed 10% of flesh volume. Skin colour was recorded as % SA of green skin, and blackness score (0 = predominantly purple, 50 = mixed purple/black colour, 100 = predominantly black skin tone). Each fruit was cut in half and the seed and skin were removed. The severity of any internal defects, including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration, was expressed as the percentage of flesh volume affected.

Results

Dry matter

Fruit oven dry matter (DM) averaged 25.2% at early harvest, and 27.8% at mid-season. Low DM (less than 23%) was recorded in 19% of fruit in the early harvest and 5% of fruit in the mid-season pick. The relationships between NIR predicted DM and oven DM were good in the early trial, averaging $R^2=0.72$, and weaker in the mid-season trial, averaging $R^2=0.52$ (data not shown).

Weight loss

Fruit weight loss at cold removal increased with longer storage time, with loss of up to 7% of fruit weight occurring in the 56-day treatment (Table 2). Weight loss was higher in the early season fruit than mid-season fruit. CA consistently reduced total weight loss compared with non-CA storage, averaging around 12% less weight loss across all paired treatments.

Table 2. Weight loss (%) from Hass avocados at removal from various storage treatments

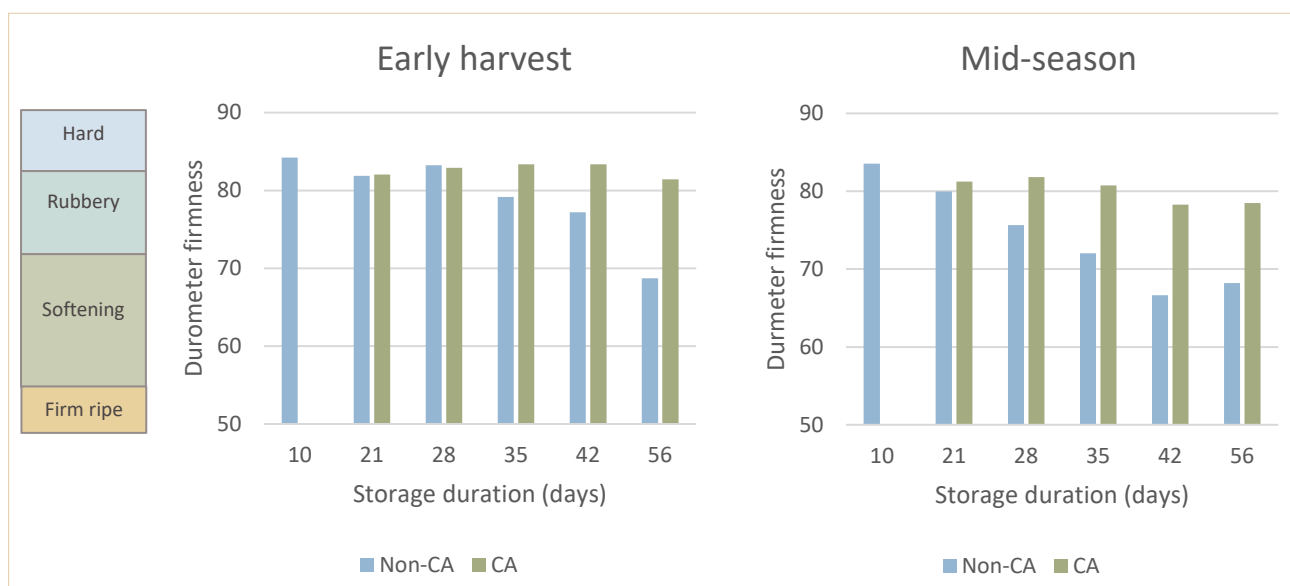
Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	1.1		1.5	
21	2.0	1.9	2.2	2.0
28	3.8	3.2	2.9	2.4
35	4.8	4.0	3.0	2.7
42	5.0	4.2	3.9	3.0
56	7.2	6.6	4.7	4.6

Weight loss occurred more rapidly once fruit were transferred to 20°C, due to the higher temperature and lower RH. Fruit kept at 20°C and 65% RH lost an average 1% of their weight each day. Fruit assessed at medium ripe stage had typically lost around 11% of their original weight.

Firmness changes

CA consistently maintained fruit firmness, even after storage periods of up to 56 days (Figure 1). Almost all fruit stored under CA retained hard to rubbery firmness on removal from storage. In contrast, fruit stored without CA gradually softened during storage.

In early harvest fruit, gradual softening occurred in non-CA fruit stored at 5°C for 35 days or longer. In mid-season fruit, softening occurred earlier in storage and progressed more rapidly.

**Figure 1.** Firmness of Hass avocados at removal from storage treatments at 5°C, with or without application of CA

Once transferred to 20°C, fruit typically took around 4 days to reach firm-ripe, and then another 3 days to reach medium ripe. These processes occurred more rapidly in fruit that had already softened during storage.

Skin chilling damage

Chilling injury on the skin of Hass avocados was typically characterised as discrete dark patches. In some fruit, damage was observed immediately following cold storage. The symptoms could also emerge or worsen in the days following removal.

Skin chilling damage was almost eliminated using CA, as shown in Table 3. Without CA, mid-season fruit developed skin chilling damage after 21 days. The early harvest fruit were slightly more resilient, with the first signs of damage emerging after 28 days. Previous trials have shown the opposite trend (early harvest fruit being more susceptible), so the differences between these batches may relate to factors other than harvest timing. The severity of skin chilling damage tended to progressively worsen with longer storage.

Table 3. Skin chilling damage (%SA) in Hass avocados following various storage treatments

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	0		0	
21	0	0	20	0
28	15	0	43	2
35	20	0	16	0
42	58	0	65	2
56	67	2	75	3



Figure 2. Trays of avocados stored with or without CA for 42 days at 5°C, showing the reduction in skin chilling damage under CA (early season trial)

Skin colour development

CA treated fruit were more likely to develop visually appealing purple colour, while non-CA fruit showed more black-green colour development (Table 4, Figure 3). In non-CA treatments, colour development at ripe tended to become progressively more black-toned with longer storage duration. The mid-season fruit were more prone to black colour development at ripe than early harvest fruit.

Table 4. Black skin colour development in 'Hass' avocados after various storage conditions (where 0 = purple and 100 = black skin colour development)

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	7		32	
21	3	26	82	35
28	62	13	95	25
35	67	7	100	47
42	95	7	100	43
56	100	17	100	63



Figure 3. Black-green skin colour development in non-CA (air) stored fruit compared with purple colour in CA stored fruit. Photos are of mid-season fruit stored for 28 days, then ripened for 5 days.

Some fruit retained green skin colour at ripe, and this was more common in non-CA stored fruit. Across all treatments, non-CA fruit averaged 12% green SA at ripe, while CA stored fruit averaged 2%. There were no obvious trends or patterns in green skin retention relating to storage duration.

Internal chilling / aging damage

Internal damage due to chilling or aging is a key limitation to long storage of Hass avocados. Severe damage is characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed is also considered an early sign of internal chilling / aging deterioration.

In the early season trial, internal damage emerged as an issue after 28 days without CA and progressively worsened with longer storage (Table 5). CA was highly effective at reducing internal chilling and aging damage in the early season fruit. In contrast, the mid-season fruit showed very high susceptibility to internal chilling damage, with some damage shown even after 10 days of storage. While CA reduced the severity, commercially significant damage still occurred in storage treatments of 21 days or longer. In previous trials CA has shown much stronger capacity to eliminate or reduce internal chilling damage. This batch of fruit seemed to have a particularly high susceptibility to damage.

In some previous trials late season fruit have shown greater susceptibility to chilling damage than mid-season fruit. In other seasons, multiple harvest timings across a season have shown similar levels of chilling damage. Chilling sensitivity in fresh produce is complex and can be influenced by numerous pre-harvest variables, so identifying reasons for variation is difficult, particularly with regard to harvest timing.

Table 5. Internal chilling / aging damage (% vol) in Hass avocados at medium ripe, after various storage conditions

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	0		2.9	
21	0.5	0	23.3	12.6
28	6.9	0.2	26.0	4.9
35	18.2	0.2	40.9	13.6
42	22.3	1.6	54.3	13.1
56	26.7	3.9	51.2	17.6

Fruit softening during storage was associated with greater risk of internal chilling / aging damage (Figure 4). Previous research has established that chilling damage is more likely when fruit start to ripen while in cold storage, and this has frequently been reflected in Hass long storage trials.

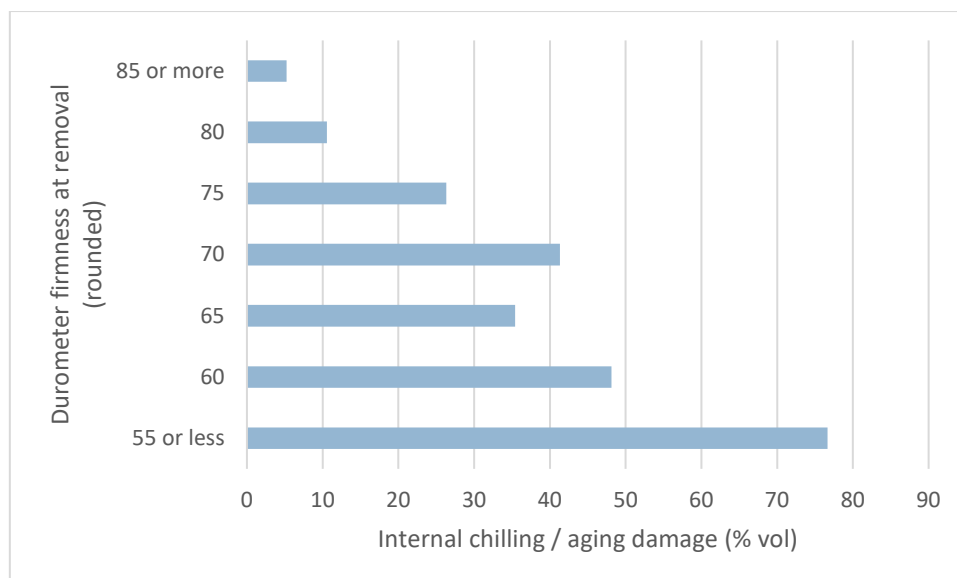


Figure 4. Relationship between fruit firmness at removal from storage and internal chilling / aging damage severity (combined data from early and mid-season trials)

Shelf life

Quality traits measured at medium ripe were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots reached 10% flesh volume. Internal chilling / aging damage of the flesh was a key issue in many treatments. This disorder could not be detected until fruit were destructively assessed at medium ripe. Damage of 10% volume or greater at medium ripe was assumed to have ended shelf life at removal from treatment, giving an effective shelf life of 0 days.

Shelf life was extended by the application of CA (Table 6). The shelf life of control fruit (stored for 10 days) averaged 8.6 days at early harvest. Using CA, similar shelf life could be maintained following storage for up to 42 days. For mid-season fruit, shelf life was impacted by the prevalence of internal chilling damage. While CA improved shelf life in all mid-season treatments, it was not maintained to the same level as the control.

Table 6. Shelf life of Hass avocados at 20°C, following various storage conditions

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	8.6		7.4	
21	9.1	8.8	2.8	5.9
28	7.0	8.1	2.1	6.4
35	2.9	8.2	0.3	5.3
42	3.9	9.3	0.0	5.3
56	2.1	7.7	0.2	5.6

Rots

Body and stem end rots in ripe fruit were an increasing issue as storage durations lengthened (Table 7). The mid-season batch showed greater susceptibility to body rots compared with early season fruit. CA was highly beneficial in reducing the severity of rots.

Table 7. Severity of rots (average % volume) in Hass avocados at medium ripe, after various storage conditions

Duration (days) at 5°C	Early harvest				Mid-season			
	Body rot		Stem end rot		Body rot		Stem end rot	
	Non-CA	CA	Non-CA	CA	Non-CA	CA	Non-CA	CA
10	0		0		0.5		0.1	
21	0.2	0.4	0.1	0	7.8	6.1	0.7	0.3
28	1.6	0.7	0.3	0.1	17.4	1.7	1.9	0.5
35	2.7	0	1.1	0	18.8	2.6	1.2	0.3
42	13.5	0	3.4	0	26.6	7.9	2.6	2.0
56	12.1	0.3	2.3	0.3	24.8	6.6	3.4	0.9

Consumer tolerance

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010¹).

Early harvest fruit retained a high level of quality following up to 21 days in non-CA storage (Table 8). Longer non-CA storage periods resulted in progressively worsening fruit quality. Using CA, the storage potential of the early harvest fruit was extended to 42 days. In contrast, the mid-season batch exceeded consumer tolerance thresholds even after the 10-day storage period. While CA improved outcomes, mid-season fruit quality did not satisfy consumer tolerance thresholds in any of the treatments. These trials demonstrate the overriding impact of fruit robustness on storage potential.

Table 8. Percentage of Hass avocados within acceptable internal defect limits at medium ripe stage, after various storage conditions.

(Green shaded treatments met industry guidelines for consumer tolerance, while orange shaded treatments exceeded these limits)

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	100		77	
21	100	95	17	53
28	67	95	3	73
35	33	100	0	57
42	19	95	0	37
56	10	86	0	20



Figure 5. Internal defects in medium ripe fruit stored without CA (left) and with CA (right). Photos are of early season fruit stored for 42 days at 5°C, then ripened for 10 days.

¹ Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43

Post-storage temperature effects

Retail simulation at 20°C and 65% RH is used as a standard in trials to ensure replicable and consistent conditions. However, actual conditions following storage may vary considerably. In the early season trial, an additional sub-set of trays were shifted to 16 and 24°C retail simulation temperatures after storage to study impacts on shelf life and quality.

Fruit shifted to 16°C after storage retained more green skin colour at ripe compared with warmer temperatures (Table 9). In contrast, black skin colour development was not strongly affected by post-storage temperature.

Table 9. Impact of post-storage temperature on skin colour in long stored Hass avocados

Duration at 5°C (days)	Post-storage temperature (°C)	Green skin %SA at ripe		Skin blackness index	
		Non-CA	CA	Non-CA	CA
21	16	33	11	26	21
	20	4	3	3	26
	24	0	0	12	38
42	16	15	15	93	24
	20	9	0	95	7
	24	2	0	95	33

Holding at 16°C after long storage increased the risk of internal chilling / aging damage compared with warmer retail simulation temperatures (Table 10). This was particularly striking in 21-day non-CA stored fruit, where half of all fruit developed 10% or greater damage volume when transferred to 16°C. In contrast, fruit held at 20 or 24°C did not develop any substantial damage.

Table 10. Impact of post-storage temperature on internal chilling / aging damage in Hass avocados

Duration at 5°C (days)	Post-storage temperature (°C)	Internal chilling / aging damage severity (%vol)		Incidence of internal chilling / aging damage ≥10% volume	
		Non-CA	CA	Non-CA	CA
21	16	20.2	1.2	52	5
	20	0.5	0.0	0	0
	24	1.0	0.0	0	0
42	16	26.9	8.3	90	24
	20	22.3	1.6	62	5
	24	22.1	0.8	67	0

Rot development was not a major issue following 21 days of storage and was not strongly affected by post-storage temperature (Table 11). However, after 42 days non-CA storage, warmer post-storage temperatures increased rot development. The increase in body rot severity was primarily driven by larger rots developing, while stem end rot was driven more by increased incidence (data not shown).

Table 11. Impact of post-storage temperature on rot development at medium ripe in Hass avocados

Duration at 5°C (days)	Post-storage temperature (°C)	Body rot severity (average %vol)		Stem end rot severity (average %vol)	
		Non-CA	CA	Non-CA	CA
21	16	1.0	0.3	0.2	0.9
	20	0.2	0.4	0.1	0
	24	0.3	0.3	0.5	0
42	16	4.0	0.2	1.0	0
	20	13.5	0	3.4	0
	24	20.4	0.3	5.3	0.6

Fruit transferred to 16°C took longer to reach firm ripe, averaging around 9 days, compared with 5.6 days at 20°C and 4.6 days at 24°C (Table 12). While this resulted in longer shelf life following CA storage, it was at the expense of fruit quality. Post-storage exposure to 16°C tended to result in the poorest fruit quality outcomes.

Fruit quality and shelf life were only slightly impacted by the change from 20 to 24°C. Across all treatments, shelf life averaged around 1 day shorter at 24°C compared with 20°C. Following CA storage, internal quality did not notably vary due to post-storage temperature at 20 or 24°C. Fruit in these trials were not tested for sensory qualities, which may also have been affected by post-storage temperatures.

Table 12. Impact of post-storage temperature on days to reach firm ripe, shelf life and consumer tolerance at medium ripe in Hass avocados following long storage

Duration at 5°C (days)	Post-storage temp (°C)	Days to firm ripe		Shelf life		Consumer tolerance (% fruit)	
		Non-CA	CA	Non-CA	CA	Non-CA	CA
21	16	8.3	9.2	5.5	13.7	48	86
	20	4.9	5.6	9.1	8.8	100	95
	24	4.0	4.6	8.3	7.9	86	100
42	16	8.7	9.6	1.3	10.4	10	76
	20	5.5	6.4	3.9	9.3	19	95
	24	4.9	4.9	2.4	8.4	10	95

On farm delays

A 2-day delay on-farm (under a mix of 10°C and ambient conditions) caused a slight decrease in firmness, from 85.1 at trial start, to 82.3 in delayed fruit. This difference widened after fruit were subsequently stored for 35 days at 5°C (Table 13). Two-day delayed fruit were around 6 shore units softer at the end of the storage treatment. The delayed fruit reached firm ripe around 0.5 - 1 day earlier. Differences in quality due to delay mostly occurred in the CA treated fruit, where delay resulted in slightly more black colour development, increased body rots and more internal chilling / aging damage. Shelf life in CA treated fruit was shortened by delay, and consumer tolerance declined from 57 to 14%. Non-CA fruit were strongly chill damaged in this trial after 35 days, and differences due to the added delay were not as evident.

Previous trials tested delays prior to CA commencement without any breaks in the cool chain, and these delays had only incremental impacts on shelf life and quality. The current trial shows that exposure to ambient conditions during delay can be more detrimental.



Table 13. Impact of a 2-day on-farm delay prior to storage on Hass avocado fruit shelf life and quality, following storage for 35 days at 5°C

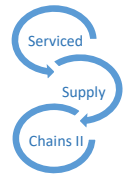
On-farm delay duration	Non-CA		CA	
	0 day	2 day	0 day	2 day
Durometer firmness at removal from storage	72.0	66.2	80.7	74.5
Blackness index	100	100	47	65
Body rot severity (average % vol)	18.8	20.2	2.6	12.6
Body rot incidence (% fruit with body rot)	100	100	23	73
Internal chilling / aging severity (%vol)	40.9	43.0	13.6	35.4
Incidence of internal chilling $\geq 10\%$ vol	97	90	33	76
Days to firm ripe	4.9	3.7	4.9	4.5
Shelf life (days)	0.3	0.7	5.3	2.1
Consumer tolerance (% fruit)	0	0	57	14

Directions for further research

The current trials highlighted the impact of inherent robustness on storage outcomes. Chilling susceptibility is a critical factor limiting storage potential in Hass avocados. Smaller trials with greater repetition could improve the ability of shelf-life models to predict chill sensitivity. Monitoring chill sensitivity through a library tray style system could allow factors such as weather prior to harvest, fruit maturity, harvest timing, farm and block effects to feed into chill risk modelling.

Summaries and recommendations

- Without CA, fruit quality outcomes progressively worsened as storage duration increased.
- Long non-CA storage resulted in:
 - Gradual softening and weight loss
 - Increased risk of skin chilling damage, black skin colour development and internal damage
- CA was highly beneficial in:
 - Maintaining firmness
 - Limiting weight loss
 - Reducing the risk of skin chilling and internal chilling / aging damage
 - Promoting purple colour development rather than black-green colour
 - Minimising rots
 - Prolonging shelf life
- CA doubled storage potential from 21 to 42 days for inherently robust fruit.
- For less robust fruit, CA improved outcomes and reduced quality issues.
- Fruit held at 16°C after long storage showed worse fruit quality outcomes than fruit stored under warmer retail simulation conditions.
- Changing retail simulation from 20 to 24°C had minimal impact on fruit quality and reduced shelf life by around 1 day.
- A 2-day delay on-farm prior to storage, under mixed 10°C and ambient conditions, was associated with softer fruit coming out of storage, and poorer fruit quality outcomes in CA-treated fruit.
- These results highlight the importance of maintaining a constant cool chain in maximising quality.



Acknowledgments

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Appendix 28

CQ 'Hass' avocado storage trials report 2025b

Controlled atmosphere storage of Hass avocados

2025 season Central Queensland grower report

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Department of Primary Industries

Summary

As avocado exports increase, supply chain stakeholders have a growing interest in predicting the outcomes of prolonged storage. Predictive models require a sound underlying framework of simulation trial data captured over multiple seasons. In 2025, Hass avocado shelf life and quality were assessed following various storage scenarios to continue to build and improve predictive models. Early and mid-season fruit were stored at 5°C and approximately 90% relative humidity (RH) for periods ranging from 21 to 56 days, with and without CA. Sub-samples of fruit were regularly removed from storage and held at 20°C and approx. 65% RH to evaluate fruit quality and remaining shelf life.

Key observations from the simulation trials:

- Without CA, progressively longer storage durations resulted in:
 - Gradual softening
 - Increasing weight loss
 - Increasing levels of skin chilling and internal chilling / aging damage
- For long storage of Hass avocados, CA was highly beneficial in:
 - Maintaining firmness
 - Reducing weight loss
 - Minimising skin chilling and internal chilling / aging damage
 - Minimising body rot severity
 - Extending shelf life
- CA improved fruit quality outcomes and reduced risk.
- However, the inherent robustness of the fruit had an overriding impact on storage potential.
- Compared with 20°C retail simulation, a lower temperature of 16°C resulted in fruit taking longer to reach firm ripe and prolonged shelf life.
- A higher retail simulation temperature of 24°C slightly hastened ripening and reduced shelf life by around 1 day.
- Overall internal defects did not consistently vary due to post-storage temperature.
- Delays of 3 to 6 days at 5°C prior to storage caused small incremental impacts on shelf life and fruit quality.



Introduction

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2025 Hass avocado season on fruit grown in Central Queensland. The main objective of the trial was to quantify fruit quality and shelf life responses of Hass avocados to long supply chain durations with and without the application of CA. The trial investigated the impacts of time and temperature effects, CA storage, and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

Materials and methods

Commercially mature Hass avocado fruit (targeting dry matter >23%) were sourced for the trials during the 2025 season. Fruit were harvested on 7th May (early season) and 25th June (mid-season) 2025 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the day of harvest. The following morning they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. The early harvest fruit used in the trial were count 28 size, while mid-season fruit were count 25. Packed trays of premium fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 16-20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to a range of storage regimes designed to reflect potential sea freight conditions, as shown in Table 1. Fruit were stored for 21 to 56 days at 5°C, with or without CA (at 2% O₂ and 5% CO₂). A 10-day treatment at 5°C was added as a baseline indication of quality under a shorter supply chain scenario. All treatments were applied to 3 replicate trays of 10 fruit. Fruit within these trials were not treated with ethylene at any stage. At the end of each treatment storage duration, fruit were shifted to retail simulation at 20°C and 65% RH for ongoing assessment.

In the early season trial, additional trays of fruit were added to test the impact of post-storage temperature on shelf life and quality. Varied post-storage temperatures were tested following 21 and 42 days at 5°C, with or without CA. Fruit were transferred to either 16 or 24°C retail simulation conditions, in addition to the 20°C retail conditions used in the main trial.

In the mid-season trial, additional trays of fruit tested the impact of non-CA delays at 5°C, prior to 35 days of storage (both with or without CA). Delay durations of 3 and 6 days were tested.

**Table 1.** Storage conditions applied to Hass avocados in 2025 CA trials.

Temperature	CA	Storage duration (days) prior to ongoing 20°C storage					
		10	21	28	35	42	56
5°C	Non-CA	x	x	x	x	x	x
5°C	+CA		x	x	x	x	x

+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

Some treatment durations were shifted one day earlier due to logistical constraints (34 and 55 days).

The air temperature adjacent to fruit was monitored throughout the trial, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

At trial commencement all fruit were weighed and firmness was measured on 10-20 fruit per trial. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury (typically shown as discrete patches) was recorded as the percentage of skin surface area (%SA) affected.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 54 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38.5 or less) or if rots were anticipated to exceed 10% of flesh volume. Skin colour was recorded as % SA of green skin, and blackness score (0 = predominantly purple, 50 = mixed purple/black colour, 100 = predominantly black skin tone). Each fruit was cut in half and the seed and skin were removed. The severity of internal defects, including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration, was expressed as the percentage of flesh volume affected.

Results

Dry matter

Fruit oven dry matter (DM) averaged 23.3% at the early harvest, and 32.6% at mid-season. Half of the oven-dried fruit samples from the early harvest had low DM (less than 23%). However, considering all trial fruit, NIR-predicted DM values suggested an average dry matter of 25%, and around 17% of fruit with low DM. It seems likely that the 16 oven-dried DM fruit were not representative of the whole trial, and were slightly skewed towards low DM. The relationships between NIR predicted DM and oven DM were good, averaging $R^2=0.73$ (data not shown).

Weight loss

Fruit weight loss at cold removal increased with longer storage time, with loss of up to 6.7% of fruit weight occurring in the 56-day treatment (Table 2). CA typically reduced total weight loss compared with non-CA storage, averaging around 11% less weight loss across all paired treatments.

Table 2. Weight loss (%) from Hass avocados at removal from various storage treatments

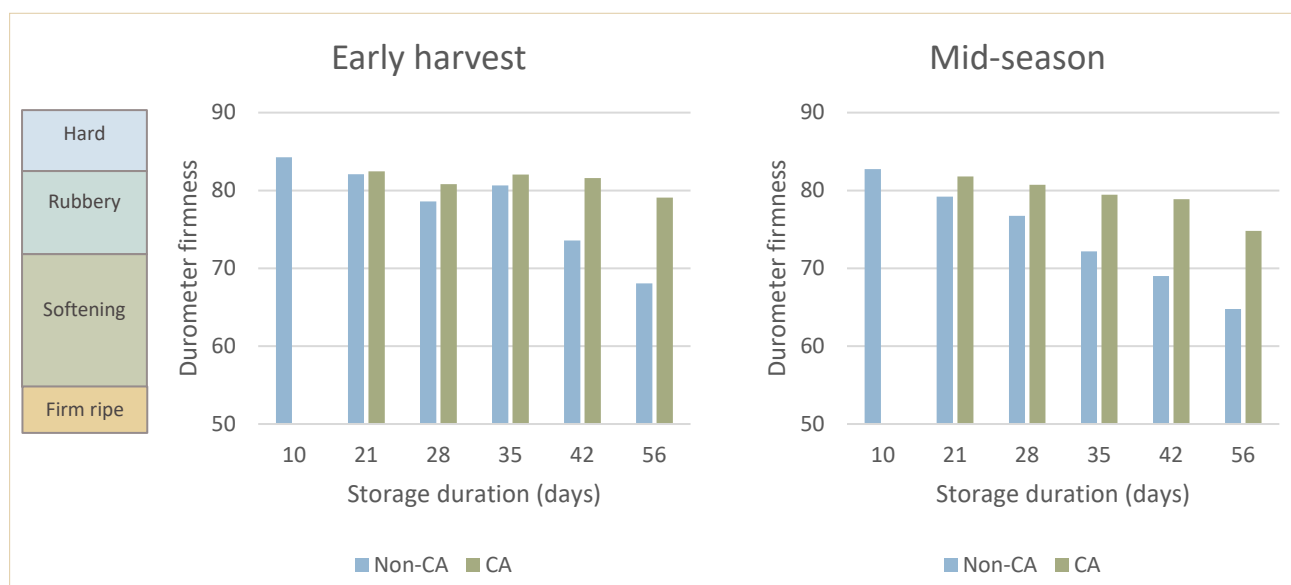
Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	1.0		1.1	
21	2.1	2.0	2.3	2.1
28	4.1	3.0	3.8	3.3
35	3.9	3.9	4.6	3.9
42	5.0	4.2	5.0	4.4
56	6.5	6.7	6.3	5.3

Weight loss occurred more rapidly once fruit were transferred to 20°C, due to the higher temperature and lower RH. Fruit kept at 20°C and 65% RH lost an average 0.8% of their weight each day. Fruit assessed at medium ripe stage had typically lost around 10% of their original weight.

Firmness changes

CA maintained fruit firmness, even after prolonged storage periods (Figure 1). Most fruit stored under CA retained hard to rubbery firmness on removal from storage. In mid-season fruit slight softening occurred in CA storage after 56 days. Fruit stored without CA gradually softened during storage.

In the early harvest fruit, gradual softening occurred in non-CA fruit stored at 5°C for 42 days or longer. In mid-season fruit, softening occurred earlier in storage and progressed more rapidly.

**Figure 1.** Firmness of Hass avocados at removal from storage treatments at 5°C, with or without application of CA

Once transferred to 20°C, fruit typically took around 4-5 days to reach firm-ripe, and then another 3 days to reach medium ripe. These processes occurred more rapidly in fruit that had already softened during storage.

Skin chilling damage

Chilling injury on the skin of Hass avocados was typically characterised as discrete dark patches. In some fruit, damage was observed immediately following cold storage. The symptoms could also emerge or worsen in the days following removal.

Skin chilling damage was almost eliminated using CA, as shown in Table 3. Without CA, mid-season fruit developed skin chilling damage after 35 days (Figure 2). The early harvest fruit were slightly more resilient, with substantial damage emerging after 42 days. The severity of skin chilling damage tended to progressively worsen with longer storage.

Table 3. Skin chilling damage (%SA) in Hass avocados following various storage treatments

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	0		0	
21	0	0	0	0
28	2	0	7	0
35	5	0	44	0
42	57	0	28	0
56	58	2	64	2



Figure 2. Trays of avocados stored with or without CA for 35 days at 5°C, showing difference in skin chilling damage (mid-season trial)

Skin colour development

In non-CA treatments, colour development at ripe tended to become progressively more black-toned with longer storage duration (Table 4). CA treated fruit tended to show slightly more purple colour tone, but this response was not as strong as seen in previous CA trials.

Table 4. Black skin colour development in 'Hass' avocados after various storage conditions (where 0 = purple and 100 = black skin colour development)

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	43		25	
21	62	71	62	53
28	67	86	67	57
35	76	69	98	73
42	90	62	98	67
56	100	83	83	62

Internal chilling / aging damage

Internal damage due to chilling or aging is a key limitation to long storage of Hass avocados. Severe damage is characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed is also considered an early sign of internal chilling / aging deterioration.

Internal damage occurred at low levels following storage periods of 21 days or longer (Table 5). CA was highly effective at reducing internal chilling / aging damage. Mid-season fruit stored without CA showed progressively greater severity of internal chilling damage with increasing storage duration.

The mid -season fruit were more sensitive to chilling / aging damage than the early harvest batch. In some previous trials late season fruit have shown greater susceptibility to chilling damage than mid-season fruit. In other seasons, multiple harvest timings across a season have shown similar levels of chilling damage. Chilling sensitivity in fresh produce is complex and can be influenced by numerous pre-harvest variables, so identifying reasons for variation is difficult.

Table 5. Internal chilling / aging damage (% vol) in Hass avocados at medium ripe, after various storage conditions

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	0		0	
21	0	0	1.4	0
28	4.0	0	0.8	0.5
35	1.5	0.1	8.5	1.4
42	4.3	0.5	13.2	0
56	7.6	1.1	19.3	0.6

Fruit softening during storage was associated with greater risk of internal chilling / aging damage (Figure 3). Previous research has established that chilling damage is more likely when fruit start to ripen while in cold storage, and this has frequently been reflected in Hass long storage trials.

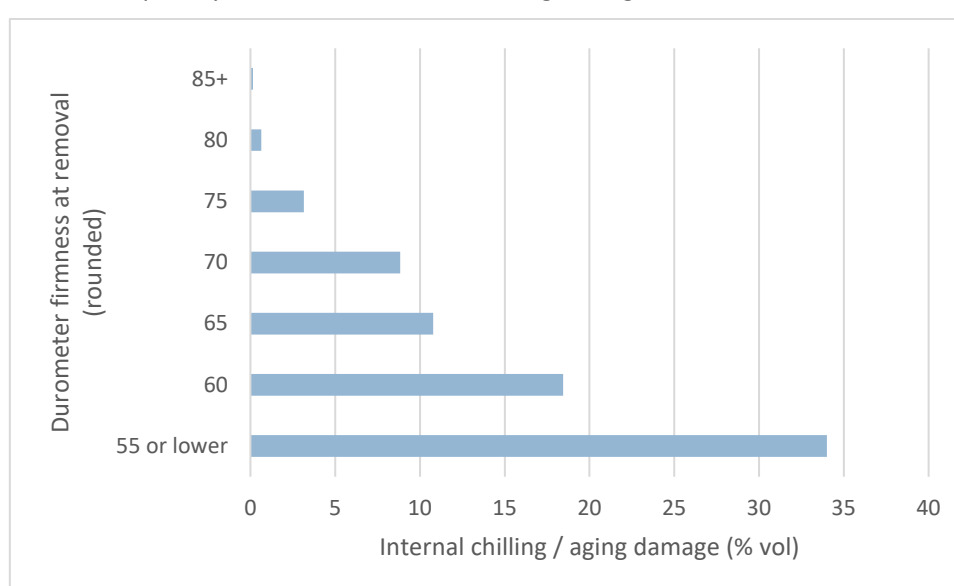


Figure 3. Relationship between fruit firmness at removal and internal chilling / aging damage severity (combined data from early and mid-season trials)



Shelf life

Quality traits measured at medium ripe were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots reached 10% flesh volume. Internal chilling / aging damage was a key issue in many treatments. This disorder could not be detected until fruit were destructively assessed at medium ripe. Damage of 10% volume or greater at medium ripe was assumed to have ended shelf life at removal from treatment, giving a shelf life of 0 days.

Using CA, storage treatments of up to 56 days retained similar shelf life to the controls (Table 6). In contrast, non-CA treatments showed progressive loss of shelf life as storage duration increased.

Table 6. Shelf life of Hass avocados at 20°C, following various storage conditions

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	10.2		8.8	
21	9.3	9.7	7.3	9.5
28	7.3	9.9	8.0	8.4
35	7.0	8.8	3.9	8.0
42	6.3	9.6	2.5	8.6
56	3.7	9.0	1.2	8.4

Rots

Both early and mid-season fruit had significant issues with rot development when at medium ripe. Body rots were increasingly severe as storage durations lengthened (Table 7). CA was beneficial in reducing the average severity of body rots, but did not show a strong impact on stem end rots.

Table 7. Severity of rots (average % volume) in Hass avocados at medium ripe, after various storage conditions

Duration (days) at 5°C	Early harvest				Mid-season			
	Body rot severity		Stem end rot severity		Body rot severity		Stem end rot severity	
	Non-CA	CA	Non-CA	CA	Non-CA	CA	Non-CA	CA
10	1.3		0.7		1.1		0.9	
21	3.4	1.2	3.0	1.5	6.6	7.2	1.9	3.3
28	5.3	2.2	0.9	2.6	9.1	2.9	2.7	3.4
35	9.7	5.3	7.0	5.7	21.4	6.2	2.4	3.9
42	21.4	7.0	3.0	8.3	26.8	7.6	3.4	4.6
56	23.7	5.4	3.3	8.4	30.2	7.3	7.2	1.1

Consumer tolerance

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010¹).

The only treatment that stayed within consumer tolerance thresholds was storage of early season fruit for 10 days (Table 8). Body rots were the key issue contributing to poor internal quality. Using CA generally

¹ Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43

improved quality outcomes compared with non-CA storage. Fruit quality progressively worsened as storage duration increased, but this effect was minimised by using CA. These results demonstrate the overriding impact of fruit robustness on storage potential.

Table 8. Percentage of Hass avocados within acceptable internal defect limits at medium ripe stage, after various storage conditions.

(Green shaded treatments met industry guidelines for consumer tolerance, while orange shaded treatments exceeded these limits)

Duration (days) at 5°C	Early harvest		Mid-season	
	Non-CA	CA	Non-CA	CA
10	90		87	
21	76	81	63	57
28	76	81	43	80
35	38	52	7	70
42	0	48	0	60
56	5	43	0	67



Figure 4. Internal defects in medium ripe fruit stored without CA (left) and with CA (right).

Photos are of mid-season fruit stored for 28 days at 5°C, then ripened for 8 days.

More body rot development can be seen under the skin in the non-CA fruit, while stem end rots are similar.

Post-storage temperature effects

Retail simulation at 20°C and 65% RH is used as a standard in trials to ensure replicable and consistent conditions. However, actual conditions following storage may vary considerably. In the early season trial, an additional sub-set of trays were shifted to 16 and 24°C retail simulation temperatures after storage to study impacts on shelf life and quality.

There were no substantial differences in skin colour, rot development, or internal chilling / aging damage due to the variation in retail simulation temperature (data not shown). Fruit transferred to 16°C took longer to reach firm ripe, averaging around 9 days, compared with 5.8 days at 20°C and 4.7 days at 24°C (Table 9). This slower softening also resulted in longer shelf life following CA storage. Across all treatments, shelf life averaged around 1 day shorter at 24°C compared with 20°C. Overall internal quality did not consistently vary due to post-storage temperature. Fruit in these trials were not tested for sensory qualities, which may also have been affected by post-storage temperatures.

Table 9. Impact of post-storage temperature on days to reach firm ripe, shelf life and consumer tolerance at medium ripe in Hass avocados following long storage

Duration at 5°C (days)	Post-storage temp (°C)	Days to firm ripe		Shelf life		Consumer tolerance (% fruit)	
		Non-CA	CA	Non-CA	CA	Non-CA	CA
21	16	8.3	10.1	14.5	16.0	71	43
	20	5.5	6.5	9.3	9.7	76	81
	24	4.1	5.5	8.1	9.3	57	67
42	16	6.2	11.3	10.0	16.0	0	62
	20	4.2	7.0	6.3	9.6	0	48
	24	2.7	6.5	4.5	9.5	5	33

On farm delays

Delays at 5°C prior to long storage had minimal impacts on shelf life and fruit quality (Table 10). Fruit delayed at 5°C for 6 days were around 2-3 shore units softer at removal from cool storage and showed very slight increases in body rot severity and internal chilling / aging damage. These incremental differences would be expected due to the lengthening of total storage duration due to delays. Days to firm ripe and shelf life were not notably affected by delays. For CA-treated fruit, consumer tolerance was higher in fruit stored without delay, compared with 3 and 6-day delay treatments.

Table 10. Impact of cool delays prior to storage on Hass avocado fruit shelf life and quality, following subsequent storage for 34-35 days at 5°C

Delay duration at 5°C	Non-CA			CA		
	0 days	3 days	6 days	0 days	3 days	6 days
Durometer firmness at removal from storage	72.2	70.4	68.8	79.5	75.1	76.9
Body rot severity (average % vol)	21.4	25.7	25.1	6.2	7.2	11.3
Internal chilling / aging severity (%vol)	8.5	6.2	11.0	1.4	1.4	4.8
Days to firm ripe	3.3	3.6	3.3	4.7	4.5	4.8
Shelf life (days)	3.9	5.1	4.1	8.0	8.9	7.3
Consumer tolerance (% fruit)	7	0	7	70	43	47

Possible directions for further research

The current trials highlighted the impact of inherent robustness on storage outcomes. Chilling and rot susceptibility are critical factors limiting storage potential in Hass avocados. Smaller trials with greater repetition could improve the ability of shelf-life models to predict chill and rot sensitivity. Monitoring robustness through a library tray style system could allow factors such as weather prior to harvest, fruit maturity, harvest timing, farm and block effects to feed into quality modelling.



Summaries and recommendations

- Without CA, fruit quality outcomes progressively worsened as storage duration increased.
- Long non-CA storage resulted in:
 - Gradual softening and weight loss
 - Increased risk of skin chilling damage and internal chilling / aging damage
- CA was highly beneficial in:
 - Maintaining firmness
 - Limiting weight loss
 - Reducing the risk of skin chilling and internal chilling / aging damage
 - Minimising rots
 - Prolonging shelf life
- CA consistently improved outcomes and reduced quality issues.
- Changing retail simulation conditions from 20 to 24°C had minimal impact on fruit quality and reduced shelf life by around 1 day.
- Retail simulation at 16°C slowed ripening, prolonged shelf life and did not strongly affect overall fruit quality. However, sensory qualities were not assessed in this trial.
- Delays of 3 to 6 days at 5°C before storage caused small incremental impacts on shelf life and fruit quality.

Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support. This work was part of the broader Serviced Supply Chains II project (AM21000) that was funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland, Department of Energy, Environment and Climate Action, Victoria, Department of Agriculture and Fisheries, Northern Territory, Department of Primary Industries and Regional Development, Western Australia, Piñata Farms Pty Ltd and Summerfruit Australia Ltd.



Appendix 29

WA 'Hass' avocado storage trials report 2023-2025



Hass avocado storage in WA: local fruit under different temperatures, storage duration and fruit sizes.

Declan McCauley and Dario Stefanelli

Western Australia Department of Primary Industries and Regional Development

The following document details summaries of five air storage trials carried out in Western Australia from February 2023 to November 2025. The five air storage trials were carried out as part of Serviced Supply Chains II.

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

Five air storage trials carried out in Western Australia from February 2023 to November 2025 investigated how storage duration, storage temperature and fruit size affect fruit quality and shelf life. The last three trials included assessments of ethylene production as well. Ethylene is discussed further in 'WA ethylene assessments 2024' and 'WA ethylene assessments 2025'. The trials showed that temperatures above 5°C cause shorter shelf life and greater fruit quality problems after shorter storage durations. Cooler storage temperatures did not necessarily impact fruit quality but reduced shelf life. Smaller fruit were found to consistently have better fruit quality outcomes than larger fruit, even if it was not reflected in shelf life. Finally, the maximum storage duration for WA grown 'Hass' avocados stored at 5°C is more than 14 days, but less than 21 days.

1. Air storage trials of Hass avocados: February 2023

Declan McCauley, Milan Patel, Dario Stefanelli

Introduction

Storage of 'Hass' avocados is essential for transport to distant export markets. While controlled atmosphere is currently deemed essential for very long export supply chains shorter chains to close markets such as Indonesia and Singapore are still suitable for air storage. While chains are expected to be short, interruptions to shipments and oversupply in the market can increase supply chains. When fruit are exposed to increasing supply chains and have not been stored in controlled atmospheric conditions it becomes important to understand the possible shelf life 'Hass' avocados can cope with, without causing great detriment to fruit quality.

Also, substantial research in avocado shelf life under air storage conditions has been done on fruit grown in Queensland, but not from fruit from Western Australia. The following air storage trial was carried out to determine shelf life of WA 'Hass' avocados under relatively long conditions of storage.

Methods

On the 21st of February 2023 'Hass' avocados in the 16 count size were obtained. The avocados were harvested from a local Pemberton orchard the day before and had already been treated with 'Sportak' fungicide (FMC Ag Australia). Once fruits were delivered to the lab at the Manjimup Horticultural Research Institute the fruits were allocated to one of nine treatments (Table1). Each treatment was represented by one tray of 16 fruit. Fruits were assessed firmness with a durometer (Turon round tip durometer-TR Turoni srl, Copernico Italy) and weighed when allocated to treatments.

Table 1. Storage conditions applied to 'Hass' avocados in February 2023 air storage trials.

Temperature	Storage duration (days) prior to ongoing 20°C storage				
	0	7	14	21	28
5°C		x	x	x	x
7°C		x	x	x	x
20°C	x				

One tray was immediately ripened at 20°C, four trays were stored at 5°C and the other four trays at 7°C. The eight trays which were stored were progressively removed after 7, 14, 21, and 28 days. At the end of each storage period one tray each from each temperature was removed and transferred to the lab to ripen at 20°C.

When each tray was removed from storage the fruits were assessed for firmness and weighed. Fruits were assessed a further two times before being dissected. The 20°C fruits were assessed one extra time due to their long ripening time.



Dissection of the fruits involved cutting fruits into four quarters, peeling the fruits and visually assessing fruits for the volume of body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD). The sum of all types of internal disorder was calculated for each fruit and the proportion of fruits with total damage over 10% was calculated to determine consumer acceptance. The Australian industry uses a standard whereby fruit are acceptable for consumers as long as only less than 10% of fruit have more than 10% total internal disorders/damage.

After dissection the 20°C fruits were sampled for a small piece of flesh which was dried to determine dry matter.

Results

Dry matter

Oven derived dry matter is only reported for the 20°C treatment. 38.4%.

Weight loss

Fruits were large and in the 16 count class. Average weight was 341 grams. Fruit stored at 7°C lost the most weight with an average loss of 6.3% lost as compared to 5.7% lost in the 20°C control and 5.3% in the 5°C treatment. Longer storage increased weight loss. For 7°C weight loss ranged from 5.4% after seven days storage to 7.5% after 28 days storage. For 5°C weight loss ranged from 4.7% lost after seven days storage to 5.4% moisture loss after 28 days storage.

For fruits stored for fewer days the weight lost after storage (during ripening) was the most substantial, for both treatments. At five degrees storage loss was 13% of the total weight lost while for the 7°C treatment the storage loss was 30% of the total lost. After longer storage the weight loss started to become more significant during storage, as compared to after storage. After 28 days of storage the 5°C treatment had 48% of weight lost in storage and the 7°C treatment had 59% of weight loss during storage.

Firmness

Firmness at dissection was similar across treatments at an average 36.9. Firmness at harvest was also virtually identical across treatments at 85. Firmness after storage varied due to both storage duration and storage temperature. On the day the fruit were removed from cool storage the firmness of the 5°C fruits was an average of 80.1 and was firmer after a longer storage duration. Firmness was 83 after 28 days of storage but only 75 after seven days of storage. Firmness of the 7°C fruit was an average of 73.8. Firmness was similar for all storage times bar the 28 days, which was only 63.

Table 2. Firmness (Turoi) of 'Hass' avocados immediately after removal from storage at either 5 or 7°C.

Storage duration (days)	Storage temperature (°C)	
	5	7
7	75.8	76.6
14	78.9	77.1
21	82.9	78.6
28	83.2	63.1

Shelf life

Shelf life was seven days for all treatments and storage duration combinations except for the 14 day removal, and the 20°C control. The shelf life of the 14-day removal for both temperatures was six days instead of seven, and the 20°C control had a shelf life of nine days.

Internal quality

Fruit quality was generally good, with most internal issues being represented in the fruit stored at 7°C (Figure 1). Very little internal damage was found, with most of the damage being from body rots and bruising. Diffuse discolouration was not reported at all from the 5°C treatment and 20°C control and only a few times from the 7°C treatment. Total damage was less overall for the 5°C treatment as compared to the 7°C temperature treatment. Damage increased as storage duration was increased. There was no damage reported after seven days of storage with most damage being reported after 28 days of storage (0.04% at 5°C and 0.12% at 7°C).

Consumer acceptance

Fruits with more than 10% total damage were found after 28 days of storage at 5°C (6.25% of fruit) and after 21 (6.25%) and 28 days of storage (31.25%) at 7°C (Figure 2). No fruit in the control had more than 10% damage. Based off these results the least fruit damage can be achieved by air storing 'Hass' avocados for a maximum of 21 days at 5°C. Longer storage at 28 days was still possible and did not breach the industry accepted consumer standard but was not as good as the 21 day treatment. Storage at 7°C resulted in a shorter safe storage duration with the 'best bet' being the 14 day storage duration, as no damage exceeding the industry standard was found after this storage time.

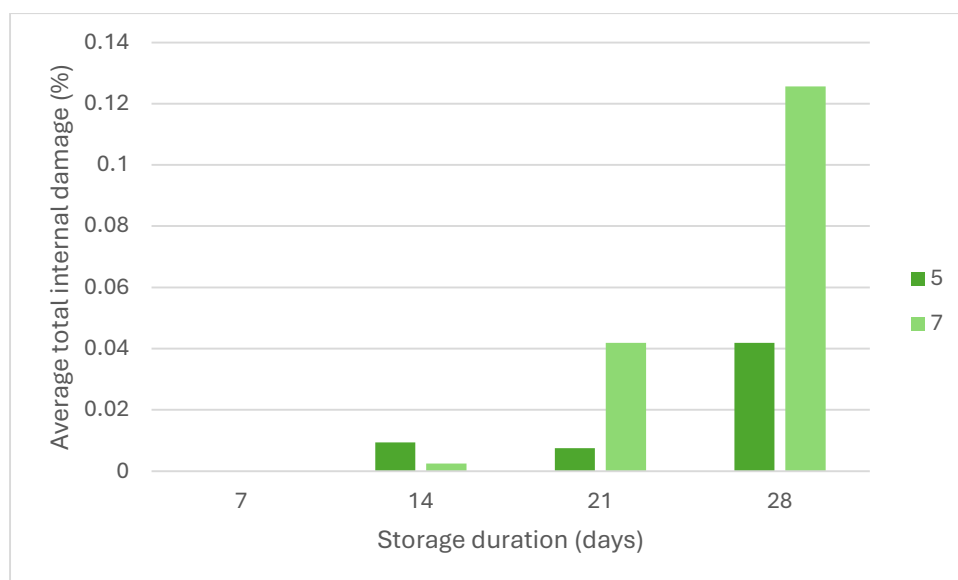


Figure 1. The average internal damage of 'Hass' avocados stored at 5 or 7°C for 7, 14, 21, or 28 days and then stored at 20°C until soft ripe.

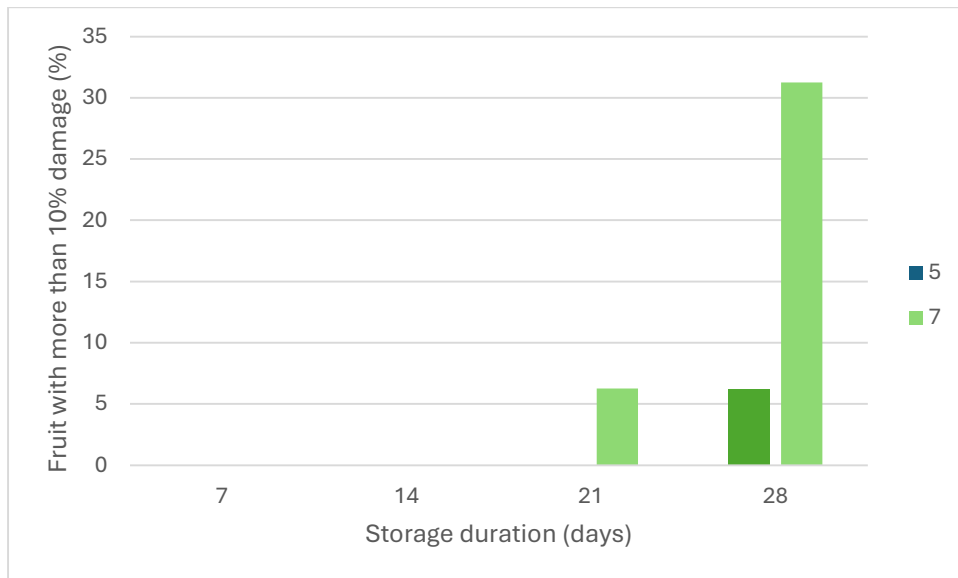


Figure 2. The proportion of ‘Hass’ fruits with more than 10% internal damage after storage at 5°C or 7°C for 7, 14, 21, or 28 days and then stored at 20°C until soft ripe.

General conclusion

Fruit quality was surprisingly good for the harvest time of February, and the high dry matter of 38.4%. Storage at 5°C did not exceed the industry’s consumer quality standard up to 28 days of storage, with no single fruit exceeding the quality standard up to 21 days of storage. Storage at 7°C was acceptable up to 21 days in terms of the industry standard, but as per the 5°C treatment, there were no single fruit exceeding the standard up to 14 days.

2. Air storage trials of two Hass avocados sizes at multiple temperature combinations: February 2024

Declan McCauley, Muhammad Asad Ullah, Dario Stefanelli

Introduction

Air storage was shown to be okay at storing avocados for up to 28 days in the previous storage trial, more so for the standard 5°C storage temperature. The 7°C temperature increased fruit damage but only very slightly. It remains to be seen how a warmer temperature of 10°C will affect internal fruit quality of WA grown 'Hass' avocados under air storage conditions. In addition, colder storage temperatures have been evaluated on 'Hass' avocados grown in QLD, but not in WA. The storage temperature of 3°C was included, with and without a precooling period, to assess how avocados grown in WA conditions are affected by lower storage temperatures over long durations of air storage.

Avocado fruits in this trial were also represented over two fruit sizes. Avocados are produced from trees in a range of different sizes, with different sizes being exclusively available depending on the production year. For example, in years when there is an abundance of fruit, fruits are generally smaller. In years when fruit set has been poor due to climate or alternate bearing fruit are normally very large. We aimed to determine how fruit in different sizes responded to storage conditions.

Methods

'Hass' avocado fruits were retrieved from a local packing shed on the 15th of February. The fruit were picked from a local orchard the day before and were treated with Sportak fungicide at the packing shed. Fruit sizes retrieved from the packing shed were 18 and 23 count trays. The numbers refer to the number of fruit that can fit into a 5.5 kg tray. A smaller number indicates larger fruits. A total of 17 trays of 18 count fruit and 17 trays of 23 count fruit were collected from the packing shed and transported to the lab at the Manjimup Horticultural Research Institute.

During allocation to treatments the fruits were weighed and assessed for firmness. Trays were allocated to the storage and temperature treatments as outlined in Table 3. In each individual combination of treatment and temperature there was one tray for each size. Fruits were placed into the coolroom on the same day the fruit were retrieved from the packing shed. The 5+3°C fruits were placed into the 5°C coolroom for five days before being moved into the 3°C coolroom. There was only one room set up for each storage temperature.

Table 3. Storage duration and storage temperatures applied to two sizes of ‘Hass’ avocados in February 2024 air storage trials. Each ‘x’ marks one single tray of fruits.

		Storage duration (days) prior to ongoing 20°C storage				
Temperature		0	14	21	28	35
18 count fruit	5°C		x	x	x	x
	10°C		x	x	x	x
	5+3°C		x	x	x	x
	3°C		x	x	x	x
	20°C	x				
25 count fruit	5°C		x	x	x	x
	10°C		x	x	x	x
	5+3°C		x	x	x	x
	3°C		x	x	x	x
	20°C	x				

Trays were removed from the coolroom after their planned storage durations and transferred to the 20°C laboratory to ripen. Fruits were weighed and assessed for firmness upon entry to the lab, and then every second day. Fruits were progressively dissected as fruits reached the soft ripe stage (firmness<40) until no fruits were left.

Ethylene Assessments

Ethylene assessments were included in the February 2024 storage trials. In each treatment combination except the 20°C treatment three fruit from each tray was designated as an ethylene fruit. These fruits, in addition to the normal weight and firmness assessments, were also assessed for ethylene production. Ethylene assessments were done on the same day as the weight and firmness assessments. Ethylene production results are reported elsewhere in the separate appendix ‘WA ethylene assessments 2024’.

Dissection of the fruits involved cutting fruits into four quarters, peeling the fruits and visually assessing fruits for the volume of body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD). The sum of all types of internal disorder was calculated for each fruit and the proportion of fruits with total damage over 10% was calculated to determine consumer acceptance. The Australian industry uses a standard whereby fruit are acceptable for consumers as long as less than 10% of fruit have more than 10% total internal disorders/damage.

During dissection a disc of flesh was removed with an apple corer, weighed, dried at 65°C and then weighed again to determine dry matter for all fruits. The following equation was used to determine dry matter:

$$\text{Dry matter \%} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

Results

Dry matter

Oven dry matter of all fruits was an average of 30.5%.

Storage temperatures

The 3°C coolroom was maintained at an average temperature of 3.06°C and relative humidity of 90.8%. The 5°C coolroom had an average temperature of 5.01°C and a relative humidity of 84.7%. The 10°C coolroom had an average temperature of 11.05°C and a relative humidity of 88.1%. Finally, the laboratory used for ripening was maintained at an average temperature 18.6°C and a relative humidity of 67.5%.

Weight loss

The 18 count fruits had a starting weight of 301 grams and the 25 count fruits had a starting weight of 211 grams. The 25 count fruits lost a greater proportion of weight due to storage than the 18 count fruits (Figure 3). There wasn't a noticeable trend in weight loss due to storage temperatures. The least weight loss was from the fruits stored at 10°C in the 18 count size (6.4%) and the most weight loss was from the 5 + 3°C treatment in the 25 count fruit size (8.6%).

Weight loss over time was high when fruit were ripened immediately at 20°C for both sizes (7.6% for 18 count and 8.6% for 25 count fruit). (Figure 5). Weight loss during storage showed a trend of increasing as the storage duration was increased, for both fruit sizes. Weight loss was smallest after only 14 days (6.3% for 18 count and 7.2% for 25 count) and was highest after 35 days (7.8% for 18 count and 9.6% for 25 count). Weight loss for the 25 count fruit was higher than the 18 count fruit for all storage durations.

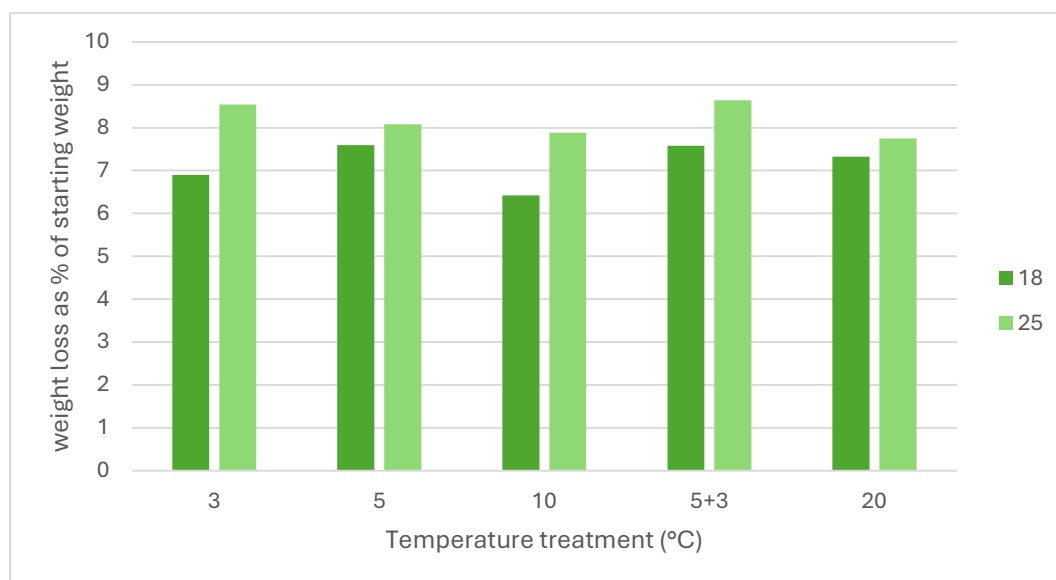


Figure 3 Weight loss of two sizes of 'Hass' avocados (18 and 25 count) as a percentage of starting weight shown according to storage temperature (3,5,10,20, 3+5°C).

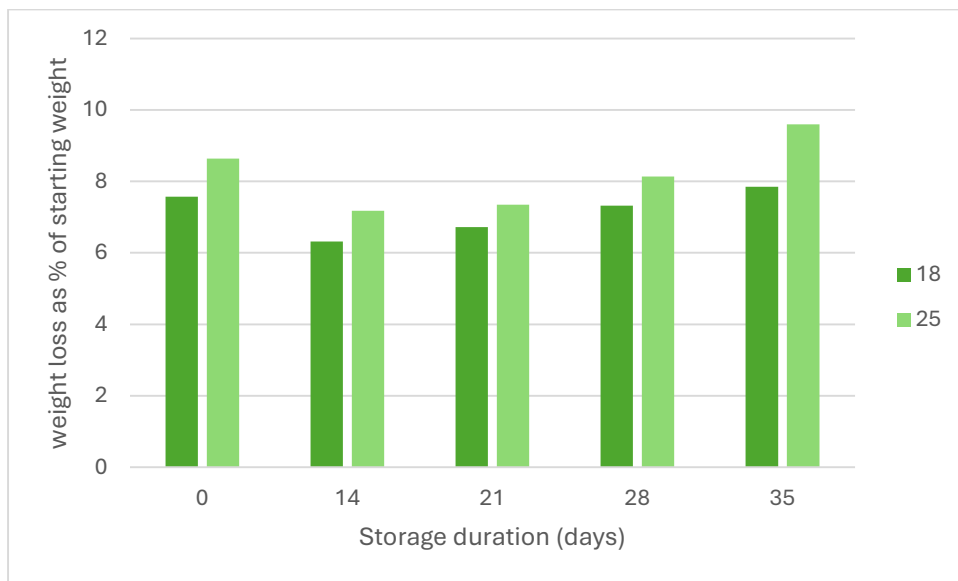


Figure 4 Weight loss of two sizes of ‘Hass’ avocados (18 and 25 count) as a percentage of starting weight shown according to storage duration (0, 14, 21, 28 and 35 days).

Shelf life

Shelf life was similar between the two different fruit sizes, with the longest shelf life from the fruits which were not stored (Figure 5). Once storage was applied to fruits shelf life was substantially decreased in comparison to the un-stored fruits. While the un-stored 18 count fruit had a shelf life of 15.61 days the 18 count fruits stored for 14 days at 5°C had a shelf life of only 10.83 days. Shelf life of the different fruit sizes at different temperatures was mostly similar, except for the 10°C treatment. Both sizes of fruits stored at 10°C had the shortest overall shelf lives. Shelf life decreased rapidly with longer storage durations under the 10°C storage temperature with the shelf life after 35 days being only 0.66 days for the 18 count fruit and only 0.48 days for the 25 count fruit.

There was also a reduction in shelf life for the 3, 5+3 and 5°C treatments as storage duration was increased. However, shelf life of the fruits stored for 35 days at all temperature and sizes was increased as compared to the fruits stored for 28 days. The only exception was the 18 count fruit stored at 5+3°C. The increase in shelf life for the 35 day storage duration was particularly notable in the 3°C temperature as shelf life increased from 7.88 days in the 18 count fruits to 9.5 days. The 25 count fruit had a similar magnitude of change.

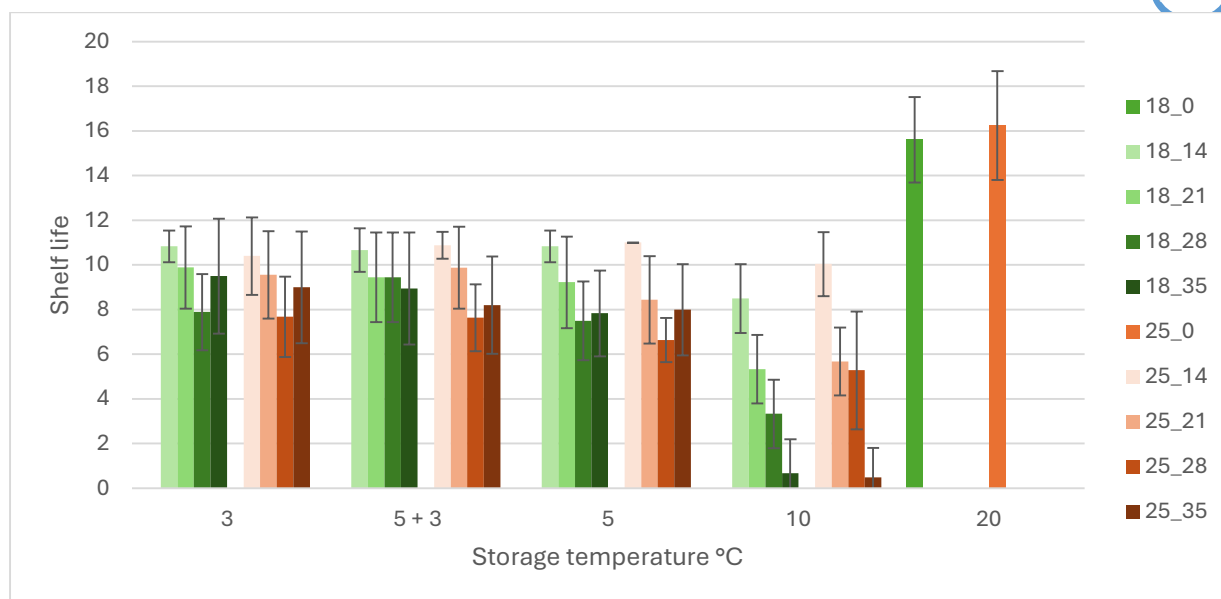


Figure 5. Shelf life of two sizes of ‘Hass’ avocados (18 and 25 counts) under increasing air storage duration (0, 14, 21, 28, 35 days) and five storage temperatures (3, 5, 10, 20, 3+5°C) in February 2024. Bars with green hue are the 18 count fruit and bars with orange hue are 25 count fruit. Standard deviation of shelf life is shown with the black up down bars.

Firmness

Turoni derived firmness started at an average of 90.5 for the 18 count fruits, and 88.8 for the 25 count fruits. At assessment the average firmness value was 38.2 for 18 count fruits, and 39.8 for 25 count fruits. There was no clear trend in firmness with increasing storage durations and different storage temperatures. All fruits stored at 10°C had the lowest overall firmness at assessment, particularly those fruit stored for 28 and 35 days. Fruit stored for 35 days at 5+3°C were notable for being dissected at a firmness of 43.4. The lowest overall firmness of 32.7 was from the 28 days fruits stored at 10°C.

Internal quality

Fruit quality was not exemplary with relatively high levels of internal damage from body rots, SER, and VB. Body rots contributed the most damage, followed by SER and then VB (Figure 6). Both fruit sizes had body rots, SER and VB but there was substantially less SER and VB damage in the 25 count fruit size. Body rots were very high after no storage with an average severity of 50% or higher in both sizes. After 14 days of storage the 18 and 25 count fruits had less body rots with an average severity of 38.9% for the 18 count fruits and 20% for the 25 count fruits. Body rots increased in the 18 count fruits up to 44.4% after 28 days of storage before decreasing to 36.1% after 35 days of storage. The severity of body rots for the 25 count fruits increased gradually with increasing storage time up to 29% body rots in the 35-day storage treatment. The magnitude of SER was less than body rots in all fruit sizes, storage durations, with most SER occurring in the 18 count fruits after either no storage or after 28 days of storage. VB also occurred in the 18 count fruits after 0, 28 and 35 days of storage, but at a very low level, relative to the level of body rots and SER. SER and VB occurred at low levels in both fruit sizes in the 14-35 day storage duration but was most notable in the 28 and 35 day storage duration.

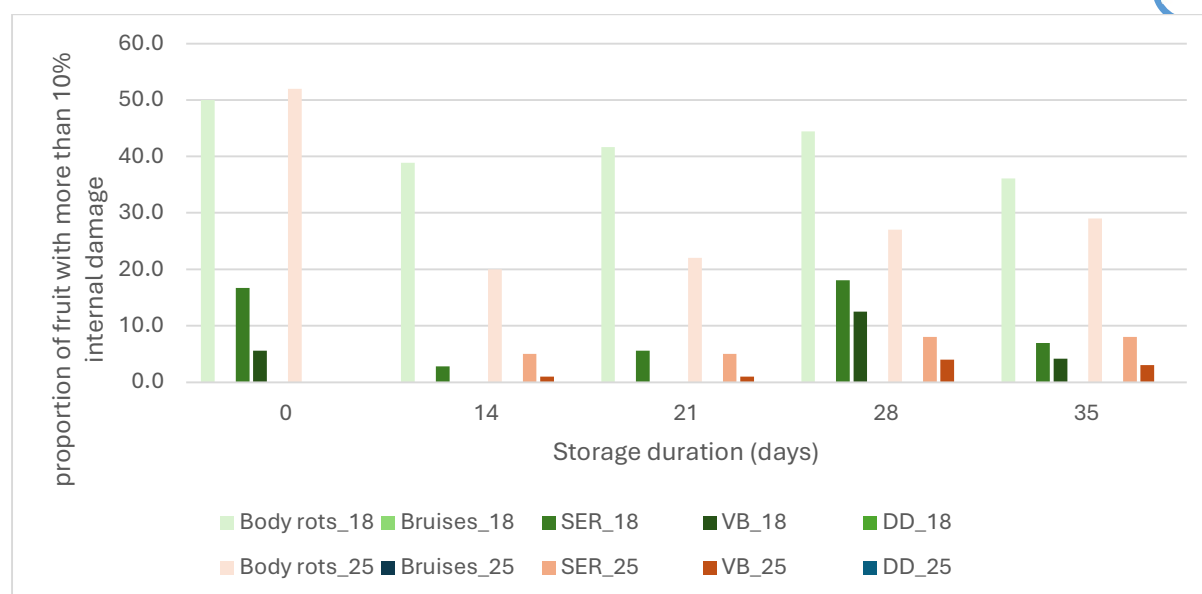


Figure 6. The proportion of two sizes of ‘Hass’ avocado fruits (18 count, green hue and 25 count-orange hue) stored for five durations (0, 14, 21, 28 and 35 days) at five temperatures (3, 5, 10, 20, 3+5°C) with more than 10% damage caused by body rots, bruises, stem end rots (SER), vascular browning (VB), and diffuse discolouration (DD).

There were some combinations of storage duration and storage temperature which successfully met the consumer standard, but none were in the size 18 fruits (Figure 7). Size 25 fruits stored for 14 and 35 days at 5+3°C, and stored for 28 days at 5°C all had 8% of fruits with less than 10% total internal damage. The 10°C storage temperature resulted in the most damage overall with up to 67% of fruit with more than 10% damage after 28 days of storage in the 18 count size, and 56% of 25 count fruit with more than 10% damage after 35 days. Fruits stored at 20°C were extensively damaged as well with 61% of 18 count fruit and 52% of 25 count fruit having more than 10% internal damage.

The proportion of fruit exceeding the consumer standard did not consistently increase as storage duration was increased. Notably, the proportion of fruits exceeding the consumer standard decreased with increasing storage duration in the 18 count fruit stored at 3°C. Count 18 size fruits stored for 14 days had 38.9% of fruit exceeding the consumer standard, while after 28 and 35 days 27.8% of fruits were exceeding the consumer standard. The proportion of fruits exceeding the consumer standard in the 18 count fruit stored at 10°C did increase for the 21 and 28 day storage durations, but then decreased slightly after 35 days of storage. The other storage duration, size and temperature combinations resulted in the percentage of fruits exceeding the consumer standard either decreased then increased or increased then decreased as storage duration increased. There was no consistent pattern.

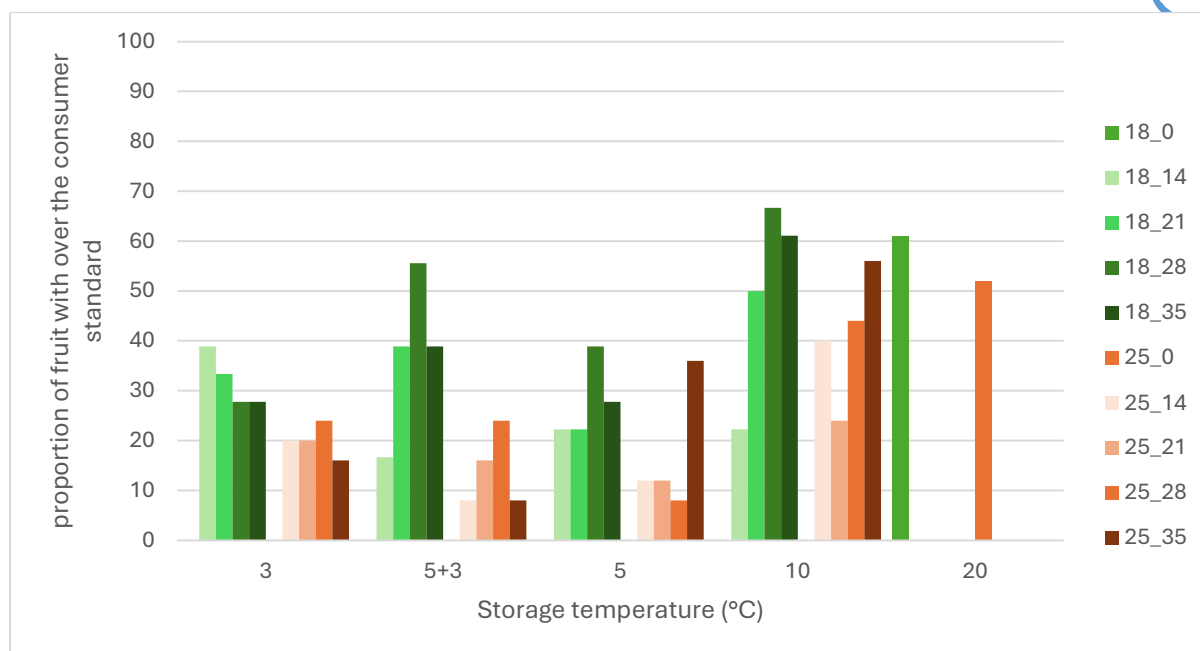


Figure 7. The proportion of two sizes of ‘Hass’ avocados (18 and 25 counts) exceeding the consumer standard under increasing air storage duration (0, 14, 21, 28, 35 days) and five storage temperatures (3, 5, 10, 20, 3+5°C) in February 2024. Bars with green hue are the 18 count fruit and bars with orange hue are 25 count fruit.

General conclusions

While fruit quality was not as good as the storage trial from last year, there was a trend of decreasing shelf life with increasing storage time, and with increasing storage temperatures. The 3 and 5+3°C storage temperatures did not appear to provide any benefit as compared to the 5°C standard. In fact, total damage was slightly elevated by the 3°C storage temperature as compared to 5°C. 10°C resulted in a short shelf life, especially after 21 days of storage, and caused substantial fruit damage as well. Fruits in the 25 count size did not have very different shelf life times as compared to the 18 count fruits, but did have fewer fruits with internal damage exceeding the consumer standard. Curiously the 25 count fruit lost more weight over time, presumably due to the larger surface area to volume ratio of the smaller fruit. The weight loss over time does not appear to have affected fruit quality.

3. Air storage of two sizes of ‘Hass’ avocados over extended storage durations: September and November 2024.

Declan McCauley, Amit Khanal, Muhammad Asad Ullah, Dario Stefanelli

Introduction

Simulation trials were carried out on WA fruit in air storage conditions for another season to replicate the trial work of the last two seasons. In particular, the trials focussed on the industry standard cooling temperature of 5°C, long storage durations of up to 45 days, and the effect of fruit size.

Methods

Two identical trials were run during this season of air storage trials. For the first trial ‘Hass’ avocado fruits were retrieved from a local packshed on the 4th of September 2024. For the second trial fruits were collected on the 12th of November 2024. The trial design was completely identical. The fruits were harvested the day before from a farm located near Capel, WA. The fruits collected were from two sizes, 18 and 23 count fruit. All fruits were treated with Sportak in the packshed. Fruits were transported to the laboratory at the Manjimup Horticultural Research Institute where they were sorted into treatments. All fruits were individually numbered, weighed and assessed for firmness with a Turoni durometer. Dry matter was determined using a Felix 751 NIR device (Felix instruments, Washington USA).

Fruits were allocated to one of eight treatments as outlined in Table 5. For each size, 24 fruit were allocated to the storage durations of 0, 5, 10, 15, 20, 25, 30 and 45 days. The 24 fruit were split into three separate trays with eight fruit per tray. Each tray was placed into one of three separate coolrooms. All coolrooms were set to 5°C. The second fruit size was identical so for each removal time there was a total of 48 fruit spread over six trays in three coolrooms. The fruits held at 20°C (0 days storage duration) were also spread over three trays but all placed into one ripening room.

At the end of each storage duration the three trays of each size (six trays total) were removed and transferred to 20°C to ripen. Weight and firmness were immediately assessed at removal and regularly as the fruit ripened. Fruits were progressively dissected as fruits reached the soft ripe stage (firmness<40) until no fruits were left.

Ethylene Assessments

Additional fruits were added to the main trial design for ethylene assessments. These fruits are included separately in this trial report as these fruits were treated with Graduate A+ fungicide (Syngenta, USA), in addition to the Sportak fungicide. Ethylene fruits were included as an extra five fruit per size and storage duration. Ethylene assessments were done at the same time as the weighing and firmness assessments. In addition the 35 and 47 days storage treatments were assessed in the coolroom a total of three times, twice for the 30 day fruits and all three times for

the 47 day storage fruits. The three assessments were done at 14, 27 and 42 days. Further details on the ethylene assessments can be found in the separate appendix 'WA ethylene assessments 2024' and 'WA ethylene assessments 2025'. Identical ethylene assessments were done for the September and November 2024 trials.

Dissection of the fruits involved cutting fruits into four quarters, peeling the fruits and visually assessing fruits for the volume of body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD). The sum of all types of internal disorder was calculated for each fruit and the proportion of fruits with total damage over 10% was calculated to determine consumer acceptance. The Australian industry uses a standard whereby fruit are acceptable for consumers as long as less than 10% of fruit have more than 10% total internal disorders/damage.

Table 4. Storage conditions applied to 'Hass' avocados in September 2024 and replicated in the November 2024 air storage trials.

Fruit size	Storage duration (days) prior to ongoing 20°C storage								
	Temperature	0	5	10	15	20	25	30	45
18	5°C		x	x	x	x	x	x	x
	20°C	x							
23	5°C		x	x	x	x	x	x	x
	20°C	x							

Results

Dry matter

Dry matter was determined with felix NIR machine and was 29.65% for the 18 count fruit, and 29.13% for the 23 count fruit. The total average was 29.39%.

Weight loss

As with the previous trials 'Hass' avocado fruits lost weight during storage. The 18 count avocado fruits started the trial with an average weight of 295.7 grams and ended with an average of 266.8 grams. The 23 count fruit started with a weight of 234.7 grams and were dissected at an average weight of 211 grams. As per previous trials, the smaller fruits lost a greater proportion of their initial fresh weight with 9.8% lost from the 18 count fruit and 10.1% from the 23 count fruit. Most of the weight loss occurred after the fruits were removed from the coolroom with an average of 3.7% of weight lost during storage for the 18 count fruit compared to 7.1% of pre storage weight lost during the ripening period. The 23 count fruit had similar values. The proportion of weight lost during storage increased as longer storage durations were applied. 7.9% of weight was lost during 47 days of storage as compared to 0.6% of weight after only five days in the 18 count fruits.

Firmness

When fruits were received from the packshed the fruit had an average firmness (Turon) of 88.8 for the 18 count fruit, and 90.2 for the 23 count fruit. After removal from storage firmness was similar between the different storage times at around 83-84, except for the 47 day treatment which had a firmness of 67-68 when removed from the coolroom. Firmness at dissection was an average of 37 for the 0-29 day storage durations for the 28 count fruit. For the 23 count fruit the average firmness was 36.9 for 0-29 days of storage. Firmness at dissection after 47 days of storage was unusually high at 49.9 for the 18 count fruit and 46 for the 23 count fruit.

Skin hardening after long storage

While average firmness decreased as the 47 day storage fruits ripened, many of the fruits in both sizes softened initially before becoming firm again (Table 6). The 47 day fruits were assessed for firmness at the point of being removed from the coolroom, three days later, and then again for a final time four days later. From the total 48 fruits, 15 were dissected at the second time, and the final 33 were dissected at the third time. Of the total of 33 fruits which were dissected at the third time 13 (39%) of these 'abnormal' fruits increased in firmness from 54.5 to 58.6. The remaining 'normal' fruits reduced in firmness from 55.8 to 43.7. Of these abnormal fruits the majority (69%) were from the 18 count fruits. These abnormal fruits were associated with slightly more total damage (87.5%) than the normal fruits (77.8%). There were no 'abnormal' fruits in the 29 day storage treatment.

Table 5. The change in firmness over time for 'Hass' avocado fruits in two sizes (18 and 23 count) after 47 days of 5°C air storage, as well as the quality outcome for the fruits which softened normally over time, and fruits which didn't soften normally over time (abnormal).

	Firmness	
	24/10/2024	28/10/2024
Abnormal	54.5	58.6
Normal	55.8	43.7
Quality outcome (total damage %)		
Abnormal	0	87.5
Normal	32.72	77.8

Shelf life

While shelf life dropped initially after 12 days of storage it remained stable for both fruit sizes until 47 days (Figure 8). Shelf life was variable in certain treatment combinations, notably in both fruit sizes for fruits not stored, stored for 15, 26, and 47 days. For storage durations of 5 and 12 days only the 23 count fruit size had variable fruit size with all 18 count fruit maturing on one day. Fruits from both sizes from the 20 and 30 day storage durations all ripened on one day as well. The longest shelf life was for the fruits which were ripened immediately (0 days) with an average of 9.8 days for the 18 count fruits and 11.5 days for the 23 count fruits. After five days of storage shelf life dropped to 7 days for the 18 count fruit and 8.1 days for the 23 count fruit. Shelf life remained similar for 12 days but dropped again by 15 days of storage. By 15 days shelf life for the 18 count fruit had dropped to 5.5 days and to 6 days for the 23 count fruit. While the

23 count fruit had a longer shelf life up until the 15 days of storage the smaller fruit did not have a longer shelf life than the 18 count fruit from days 20 to 47.

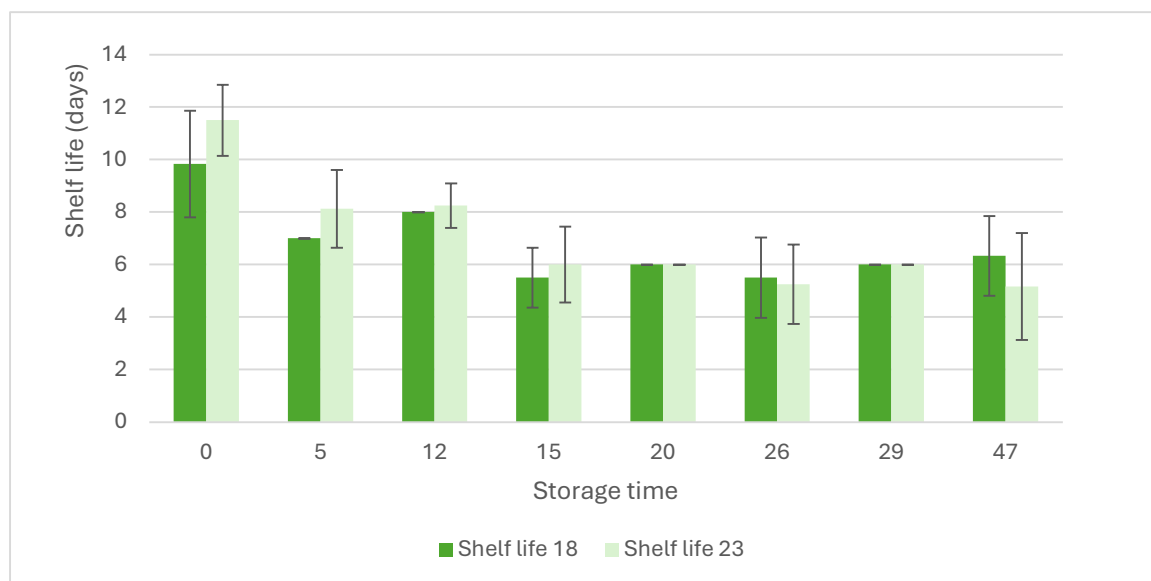


Figure 8. Shelf life of ‘Hass’ avocados stored in air for up to 47 days from September 2024. Standard deviation of shelf life is shown with the black up down bars.

Internal quality and consumer acceptance

Fruit quality was good with fruits with more than 10% damage only appearing after 12 days of storage (Figure 9). However, the amount of fruit exceeding the standard was very small at only 4.7% for the 23 count size, which is not actually over the official definition of the consumer standard. It was only after 29 days of storage that more than 10% of fruits in the 18 count size only had more than 10% damage (37.5%). At 29 days of storage the 23 count fruit were also over the consumer standard limit with 12.5% of avocados with more than 10% of flesh affected by a disorder. By 47 days of storage both 23 and 18 count fruits were well over the consumer standard with 100% of 18 count fruit with more than 10% damage and 79% of 23 count fruit with more than 10% damage. The 23 count fruit had better quality in the long term and had consistently lower levels of damage throughout the storage trial.

Unlike in previous trials where body rots dominated, the primary issue in the September 2024 storage trials was diffuse discolouration, which largely appeared in the fruits stored for 29 days and over. Body rots and bruises were however still present throughout fruits, along with stem end rot.

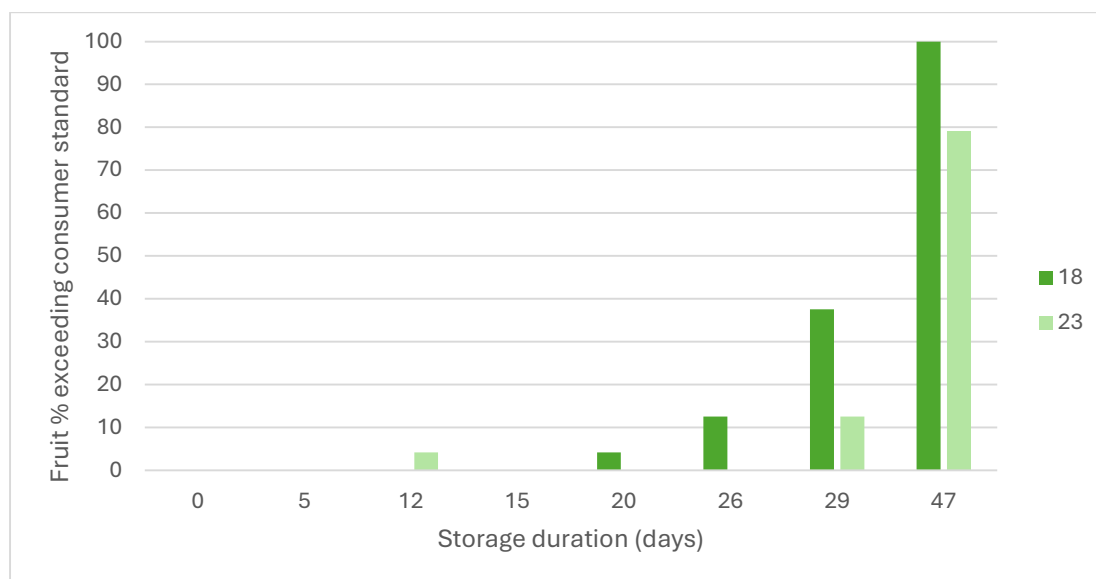


Figure 9. Consumer acceptance of 'Hass' avocados stored in air for up to 47 days from September 2024. Consumer acceptance is shown as the percentage of fruits with more than 10% total internal damage.

Ethylene fruit shelf life and consumer acceptance

The ethylene specific fruit-which had an extra fungicide treatment-had very good fruit quality with the consumer standard being met in both fruit sizes up to 26 days of storage. After 26 days of storage there was 60% of fruits with more than 10% damage after 29 days and 100% after 47 days. The 23 count fruit were unaffected at 29 days and it was only after 47 days that 100% of fruits had more than 10% damage.

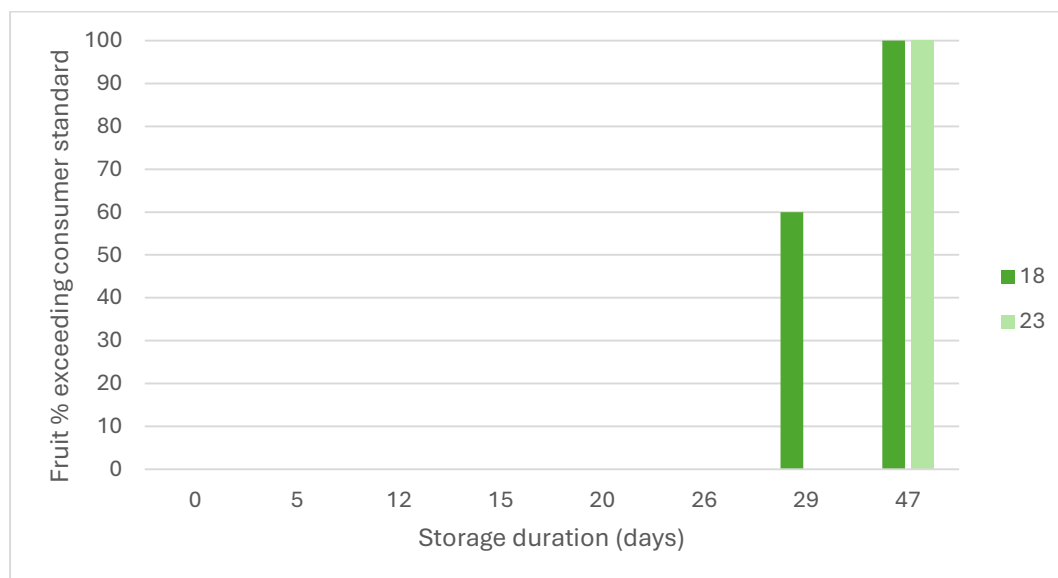


Figure 10. Consumer acceptance of 'Hass' avocados intended for ethylene assessments stored in air for up to 47 days from September 2024. Consumer acceptance is shown as the percentage of fruits with more than 10% total internal damage.

Conclusion:



As per the February 2024 fruit storage trials, smaller fruits had a better overall fruit quality and better consumer acceptance at soft ripe stage, particularly after longer storage durations. While these fruits were stored in air storage they still met the consumer standard in both sizes after 26 days of storage, and the 23 count fruit met the consumer standard after 29 days. Firmness abnormally stopped decreasing after 47 days of storage, and was associated with more body rots. It is not clear if the abnormal firmness either allowed more time for body rots to develop, or if greater body rots caused the skin to begin hardening as a side effect. The addition of Graduate A+ to the ethylene fruits caused slightly better fruit quality. The same overall trends remained for Graduate A+ treated fruits: smaller fruit had fewer internal damage and longer storage durations caused more internal damage

November 2024 storage trial results

Dry matter

The November 2024 storage trial was carried out 69 days after the start of the September 2024 trial. Dry matter was determined with the felix NIR. The 18 count fruits had a dry matter of 31.3% and the 23 count fruits had a dry matter of 30.1%.

Weight loss

The 'Hass' avocados collected in November started with an average weight of 303.9 grams for the 18 count size and 243 grams for the 23 count size. Fruit weight dropped during storage with more weight lost with longer storage durations. The 18 count fruits stored for five days lost 1.3% of their starting weight while the 47 day fruits lost 5.8% of their starting weight after storage (Figure 10). Similarly the 23 count fruits lost 2.1% weight after five days of storage and 6.2% after 47 days of storage. While the amount of weight lost during storage increases as storage duration increased the amount of weight lost after storage was more likely to decrease with longer storage duration. The 23 count fruits showed this best with weight loss after storage initially increasing to 7.9% after 12 days storage then decreasing to 4.8% after 47 days of storage. In the 18 count fruit the amount of weight lost after 47 days was very large at 22.4%, much larger than the 4.4% weight loss of the 30 day fruits.

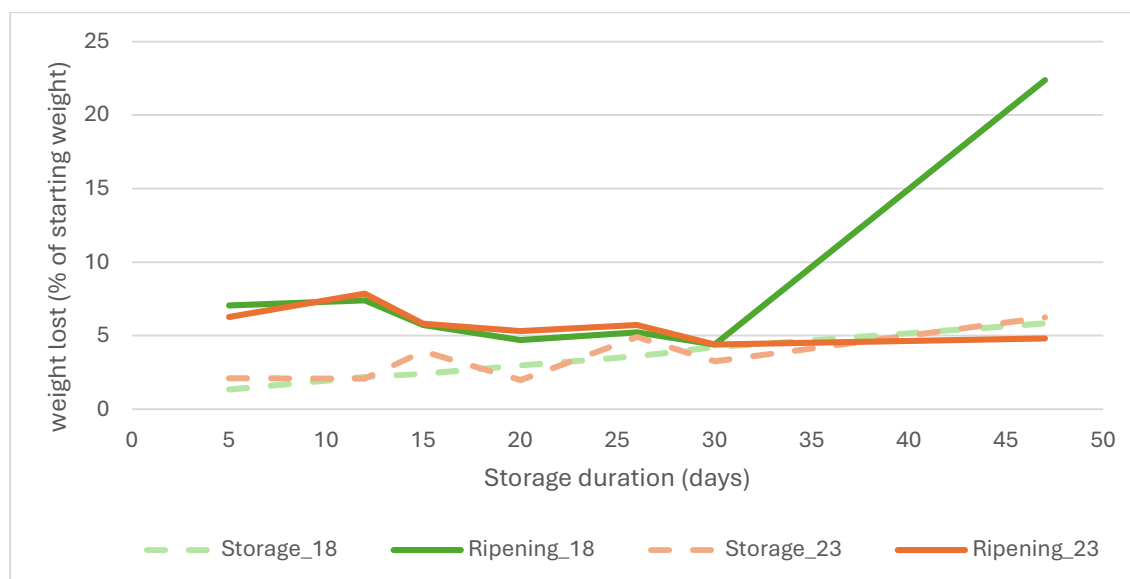


Figure 11. The proportion of weight loss of two sizes (18 and 23 count) of ‘Hass’ avocados stored for seven storage durations (5, 12, 15, 20, 26, 30, and 47 days) at 5°C in November 2024. Weight loss is expressed as either weight lost during storage (dashed line) or during ripening (solid line).

Firmness

‘Hass’ avocados received from the packing shed had an average firmness of 86.5 for the 18 count fruit and 88.2 for the 23 count fruit. After storage firmness had reduced to an average of 79.5 for the 18 count fruit and 80.7 for the 23 count fruit. Fruits removed from storage from 5 to 30 days had variable but similar firmness values. The day 15 storage duration resulted in the second lowest firmness values of 73.9 for the 18 count fruit. The 20 day storage treatment had the second lowest firmness of 78.4 for the 23 count fruit. The lowest firmness after storage was from the 47 day fruits for both sizes, with a firmness of 72.8 for the 18 count fruit, and 73.3 for the 23 count fruit.

At dissection firmness was an average of 38.9 for the 18 count fruit and 40.3 for the 25 count fruit. Firmness of the 18 count fruit was below 40 for all removal times except the 30 and 47 days storage durations. Firmness of the 23 count fruit was below 40 for all storage durations except days 15, 30 and 47.

Abnormal fruits which became more firm after initially softening were found in the storage durations of 12, 15, 20, 26, 30 and 47 days, with the most occurrence after 30 days of storage (56.3%), followed by 15 days of storage (40.6%). There were more occurrences of 23 count fruit undergoing abnormal softening than the 18 count fruits with up to 100% of identified abnormal fruits being in the 23 count size at 20 days of storage. Only after 47 days of storage did the 18 count fruits have more occurrences of abnormal ripening. The fruits which ripened abnormally did not have more damage than fruits which ripened normally with an average damage of 16.8% in the abnormally ripening fruit, and 27.5% total damage in normally ripening fruits.

Table 6. The sum proportion of two sizes (18 and 23 counts) of ‘Hass’ avocado fruits under storage of 5°C in November 2024 which ripened abnormally. The proportion of presence of abnormal ripening between the two fruit sizes is shown in the bottom two rows of the table.

	Storage duration (days)					
	12	15	20	26	30	47
Total	33.3	40.6	18.8	38.2	56.3	12.5
18	25	30.8	0	46.2	40.7	66.7
23	75	69.2	100	53.8	59.3	33.3

Shelf life

Shelf life during the November 2024 storage trial was notable for starting highly variable, and becoming less variable over time (Figure 12). All dissections of the fruits stored for 30 and 47 days were dissected on one day. In general shelf life decreased over time but fluctuations in shelf life during the middle of the storage trial means the trend is not well defined. Fruits stored for 15 days had the shortest overall shelf life of 6.7 days for both fruit sizes. The longest shelf life 10.25 days and was for the 18 count fruits that were immediately ripened. At some storage durations the larger fruits had shorter shelf life, and at other storage durations the smaller fruits had a shorter shelf life. The 18 count fruits had a shorter shelf life after 20 and 26 days of storage, while the 23 count fruit had a shorter shelf life with no storage, 5, 12 and 15 days of storage. All of these differences between shelf life of the different sizes of fruit were very slight.

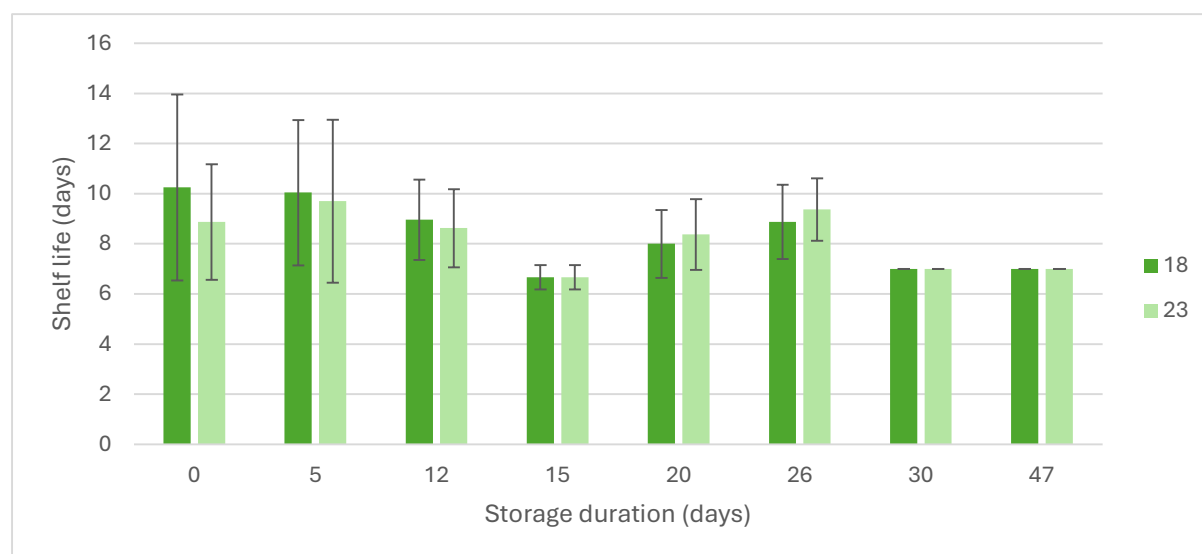


Figure 12. Shelf life of two sizes of ‘Hass’ avocados (18 and 23 counts) stored at 5°C during November 2024 for seven different storage durations (5, 12, 15, 20, 26, 30, and 47 days) along with the control of no storage (0 days).

Internal quality and consumer acceptance

Only one of the storage durations and fruit sizes met the consumer standard in the storage trial (Figure 13). The lowest amount of fruit with less than 10% total damage was from the 23 count fruit ripened immediately, with 8.3% of fruit having more than 10% damage. The 18 count fruit

ripened immediately had 45.8% of fruit with more than 10% damage. 100% of fruits, regardless of size, had more than 10% damage after 47 days of storage. At five of the storage durations the 18 count fruits had much greater numbers of fruit exceeding the consumer standard than the 23 count fruit. The exceptions were 15 days storage, 20 days storage and 47 days storage.

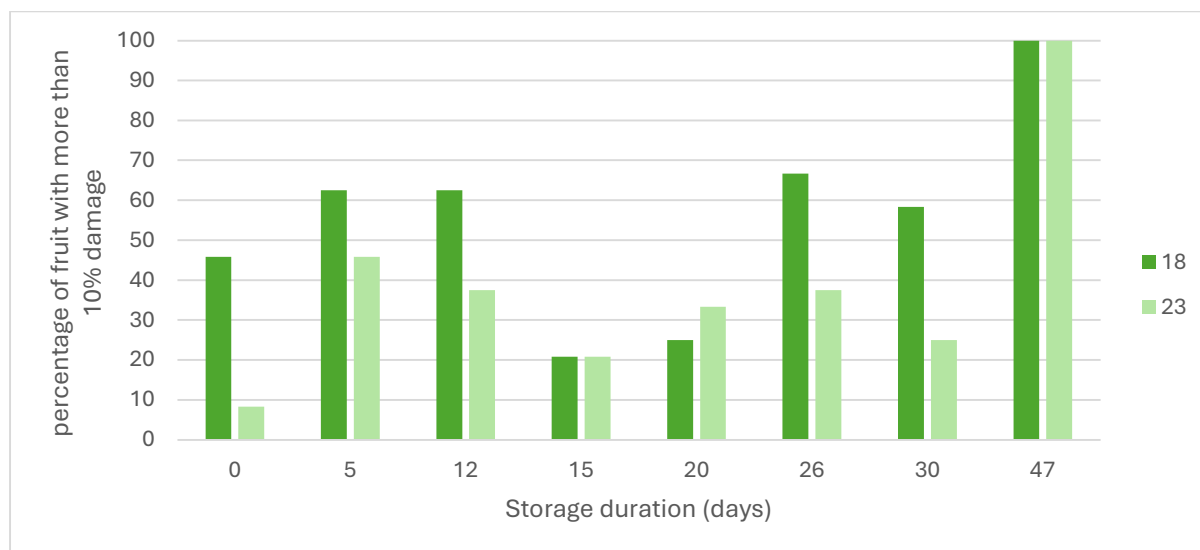


Figure 13. The percentages of two sizes (18 and 23) of ‘Hass’ avocado fruit with more than 10% damage over eight storage durations (0, 5, 12, 15, 20, 26, 30 and 47 days) in air storage trials during November 2024.

The cause of the internal damage for both fruit sizes (Figure 13 and Figure 14) was mostly body rots with a small amount of bruises and stem end rots (SER). Vascular browning (VB) was scarcely present in both sizes. Diffuse discolouration was scarcely present except for after 47 days of storage when an average of 56% of the 18 count fruits, and 54% of the 23 count fruits were affected. Body rots were generally more severe in the 18 count fruit size with an average volume of 14.7%, as compared to the average body rot volume of 10.5% for the 23 count fruit. Both bruises (3.32%>2.49%) and SER (1.79%>1.17%) were also more severe in the 18 count fruit size. VB was slightly worse in the 23 count fruits (1.46%>0.62%), mostly due to high severity in the 23 count fruits that were stored for 26 days.

The presence of body rots did not show an obvious trend driven by storage duration (Figure 11 and Figure 12). In fact body rots began low at a severity of 3.5% in the 23 count fruit ripened immediately, but high in the 18 count fruit at 18.5% then increased to 15.5% in the 23 count fruit and to 23.17% in the 18 count fruit stored for five days. Body rots then declined slightly in the fruit stored for 12 days before decreasing substantially in the fruit stored for 15 and 20 days in both fruit sizes. Body rots then increased again in both fruit sizes for the fruit stored for 26 days, decreased again for the 30 day fruits before increasing again for the 47 day fruits.

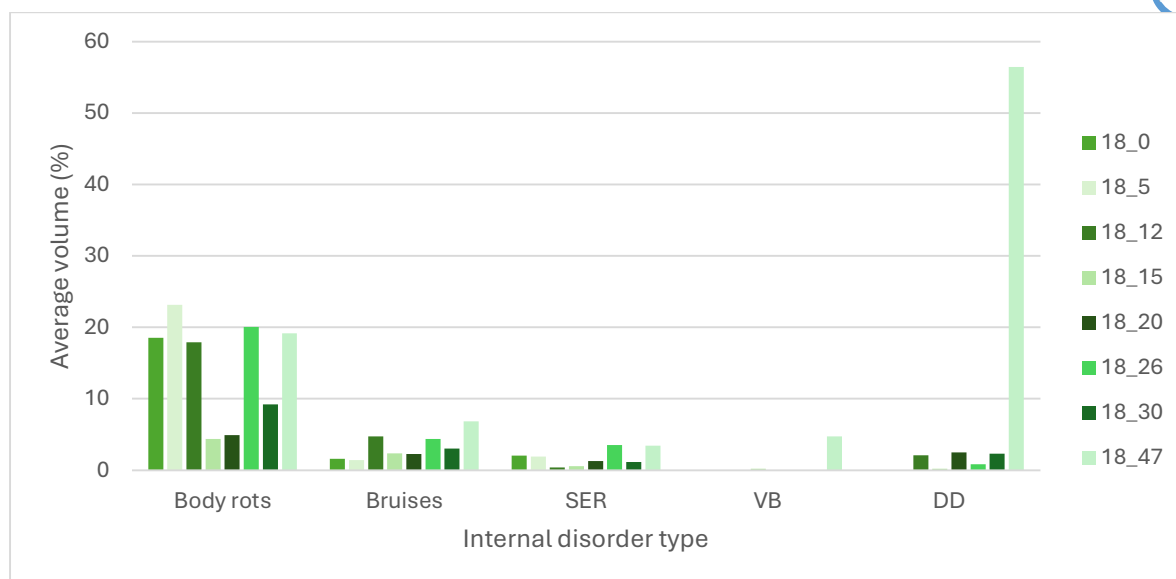


Figure 14. The average volume of internal defects in size 18 'Hass' avocado fruits stored for eight storage durations (0, 5, 12, 15, 20, 26, 30 and 47 days) in air storage trials during November 2024. Internal defects are body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD).

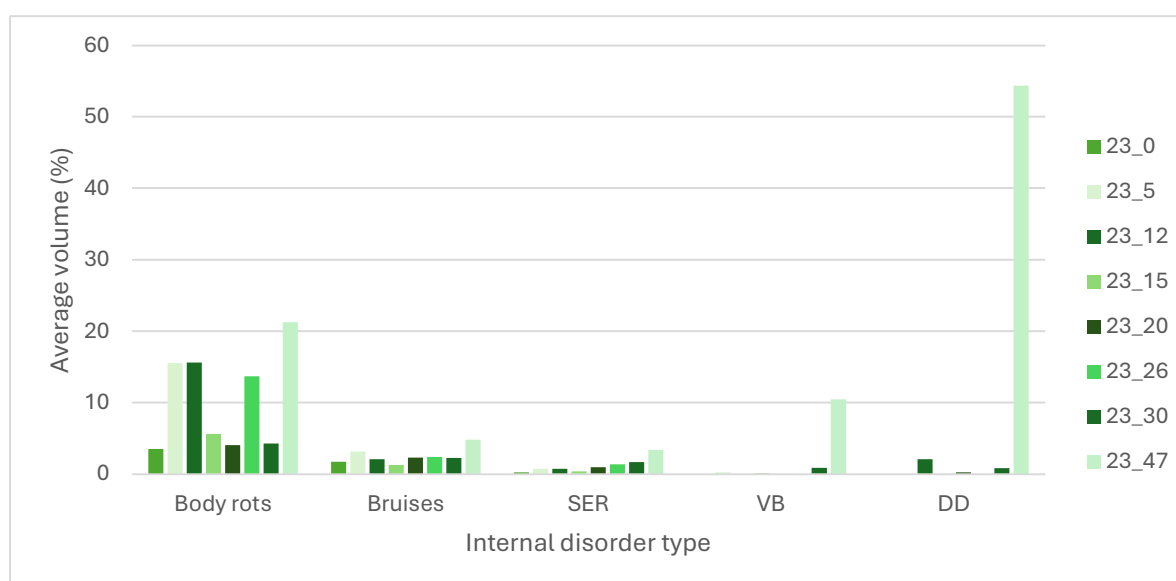


Figure 15. The average volume of internal defects in size 23 'Hass' avocado fruits stored for eight storage durations (0, 5, 12, 15, 20, 26, 30 and 47 days) in air storage trials during November 2024. Internal defects are body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD).

Ethylene fruit consumer acceptance

Except for fruits from the 20 day storage duration, no fruits achieved the consumer standard (Figure 16). The lowest proportion of fruits with more than 10% damage was 20% in the 0, 5, 15, 26 and 30 day storage durations. There is a limit to reporting in this regard as there were only five

fruit per storage duration, hence it is not mathematically possible for the value to be less than 20%, unless there are no fruit reported with more than 10% damage.

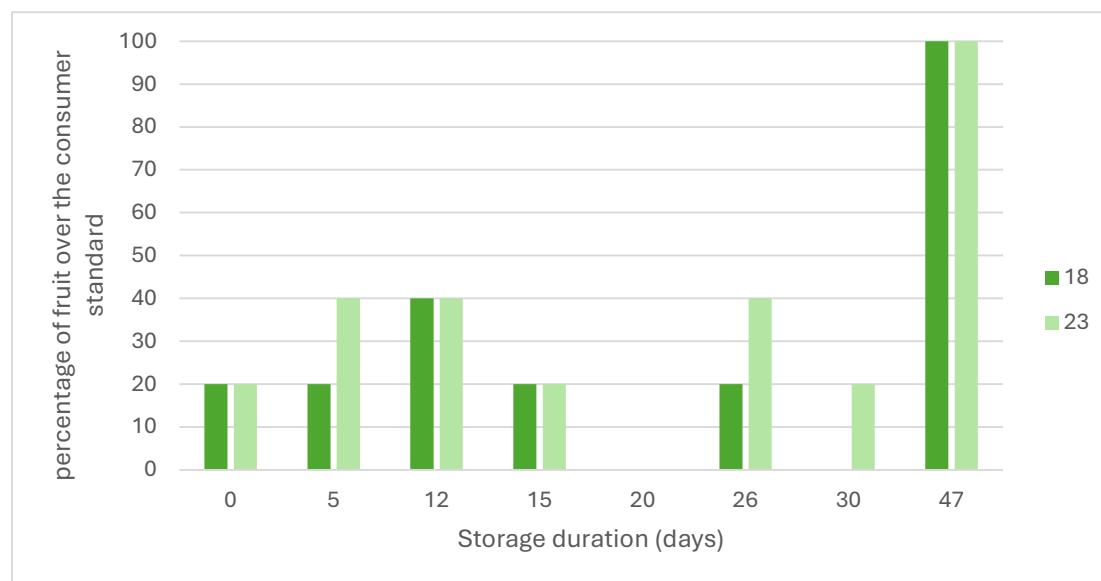


Figure 16. Percentage of ‘Hass’ avocados with more than 10% damage intended for ethylene assessments stored in air for up to 47 days from November 2024. Consumer acceptance is shown as the percentage of fruits with more than 10% total internal damage.

Conclusion

Fruit quality was notably poor during the November 2024 storage trial with no combinations of fruit size and storage duration producing fruit acceptable to consumers. Even the addition of graduate A+ to the ethylene assessment fruits did not result in very good fruit quality, however there were statistical limitations with those fruits due to the use of low replicate numbers. The longest storage duration of 47 days was the worst with up to 100% of fruit exceeding the consumer standard. The smaller 23 count fruit had less internal damage than the larger 18 count fruit. Most fruit issues were due to body rots with diffuse discolouration being a serious issue only for the 47 day storage duration. Bruises, SER and VB were all minor issues. Shelf life was highly variable under shorter storage durations and became more consistent with longer durations. All fruit had the same shelf life after 30 and 47 days of storage. Abnormal fruit softening occurred again in November and was observed in more fruit and over more storage treatments. Fruit with abnormal softening were not more likely to have more internal damage, unlike the earlier September trial. The results would seem to suggest that fruit over 30% in dry matter are less suitable for long term storage, however given that even the fruit with no storage failed the consumer standard, it may be that these fruit had other issues. As the smaller fruit had relatively fewer issues this trial has supported the results of previous trials showing that smaller fruit are less prone to internal damage after long term storage.

4. Air storage of 'Hass' avocados-focus on ethylene; November 2025

Declan McCauley, Amit Khanal, Dario Stefanelli

Introduction

The final storage trial held in WA reduced the trial size and scope down to focussing on only one fruit size with the same storage temperature and similar storage durations to previous trials. 30 count fruits were used for the first time, largely due to availability in a season with high supply of smaller fruits. Multiple storage durations were used, including ultra along storage durations to determine how fruit shelf life and fruit quality changes over time at a relatively high 'resolution'. The main goal of the November 2025 storage trial was to further replicate previous trials, as well as carry out ethylene assessments on larger numbers of fruit than the previous trials.

Methods

'Hass' avocado fruits grown near Vasse, WA, were collected from a local packshed on the 11th of November 2025. Fruits were treated with Sportak at the packing shed. Fruits were transported to the laboratory at the Manjimup Horticultural Research Institute. Fruits were treated further with Graduate A+ fungicide before being allocated to different storage durations. The storage durations used are outlined in table 8. All fruit were weighed and assessed for firmness before storage (Turon durometer).

Fifteen fruit were used for each storage duration with a total of 120 fruits. Fruits removed from the 5°C storage were transferred to 20°C and ripened. Weight and firmness were measured at removal and regularly afterwards as the fruit ripened. Fruits were progressively dissected as fruits reached the soft ripe stage (firmness<40) until no fruits were left.

Dissection of the fruits involved cutting fruits into four quarters, peeling the fruits and visually assessing fruits for the volume of body rots, bruises, stem end rots (SER), vascular browning (VB) and diffuse discolouration (DD). The sum of all types of internal disorder was calculated for each fruit and the proportion of fruits with total damage over 10% was calculated to determine consumer acceptance. The Australian industry uses a standard whereby fruit are acceptable for consumers as long as less than 10% of fruit have more than 10% total internal disorders/damage.

Ethylene studies were carried out during this storage trial, with further details in the separate appendix 'WA ethylene assessments 2024' and 'WA ethylene assessments 2025'.

Table 7. Storage conditions applied to 'Hass' avocados in November 2025.

Temperature	Storage duration (days) prior to ongoing 20°C storage							
	0	6	13	15	17	20	27	34
5°C		x	x	x	x	x	x	x
20°C	x							

Results

Dry matter

Dry matter ranged from 17.2 to 34% with an average of 24.6%.

Shelf life

Shelf life of avocados was consistent for storage durations of 0 to 6 days at 10.8 to 11.1 days (Figure 17). Shelf life declined after 13 days of storage to 8.2 days, then remained relatively steady at 8.8 days at 15 days, 9 days at 17 days, and 7.9 days after 20 days of storage. Shelf life dropped to a low of 6.4 days after 27 days of storage and then increased slightly to a shelf life of 7 days after 34 days of storage. Variability in shelf life as shown by standard deviation was variable between the different storage durations with the smallest variation in shelf life after 34 days of storage as all fruits were dissected on one day and the most variation in shelf life after 17 days of storage.

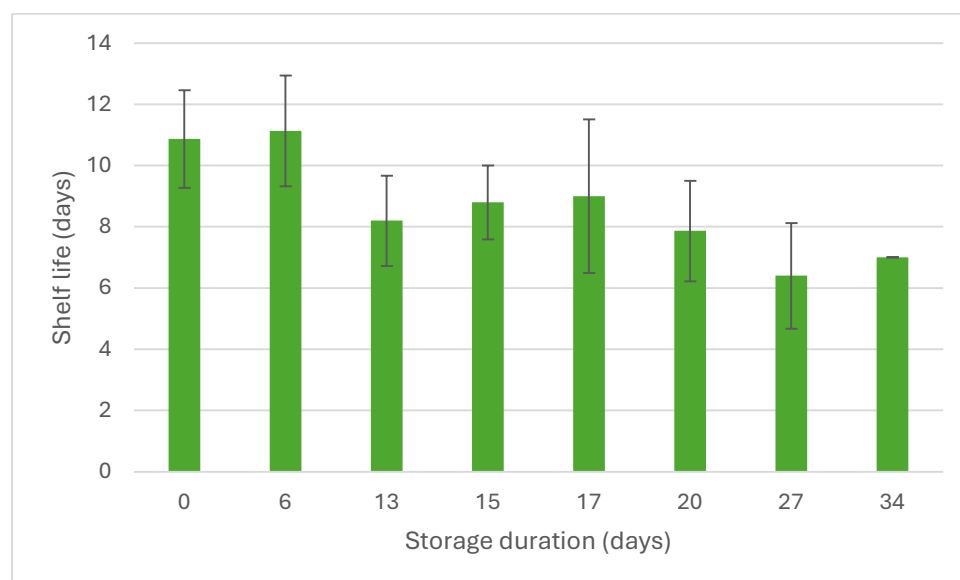


Figure 17. Shelf life of 'Hass' avocados according to eight storage durations applied during November 2025.

Internal quality and consumer acceptance

Internal fruit quality was very good during this storage trial, with fruits only exceeding the consumer standard after 20 days of storage (13.3%). There were some fruits with more than 10% damage at 17 days of storage but not enough to exceed the consumer standard. After 27 days of storage fruits with more than 10% damage had increased to 20% of all fruits, and after 34 days 60% of all fruits had more than 10% internal damage. No fruits had more than 10% damage up to 17 days of storage.

While no fruits had more than 10% internal damage there was still a small amount of damage in the shorter storage times. The main form of damage was bruising, followed by body rots. At 15 days of storage a minor amount of stem end rots was present and after 17 days of storage diffuse discolouration appeared in fruits. After 27 days of storage diffuse discolouration became

the largest cause of disorder in the avocado fruits, followed by bruises, stem end rots, and then body rots. After the longest storage duration of 34 days diffuse discolouration occurred at an average incidence of 18.8% with vascular browning being the next most severe disorder at only 6.1%. The next most severe form of flesh damage was body rots, followed by bruising and then stem end rots.

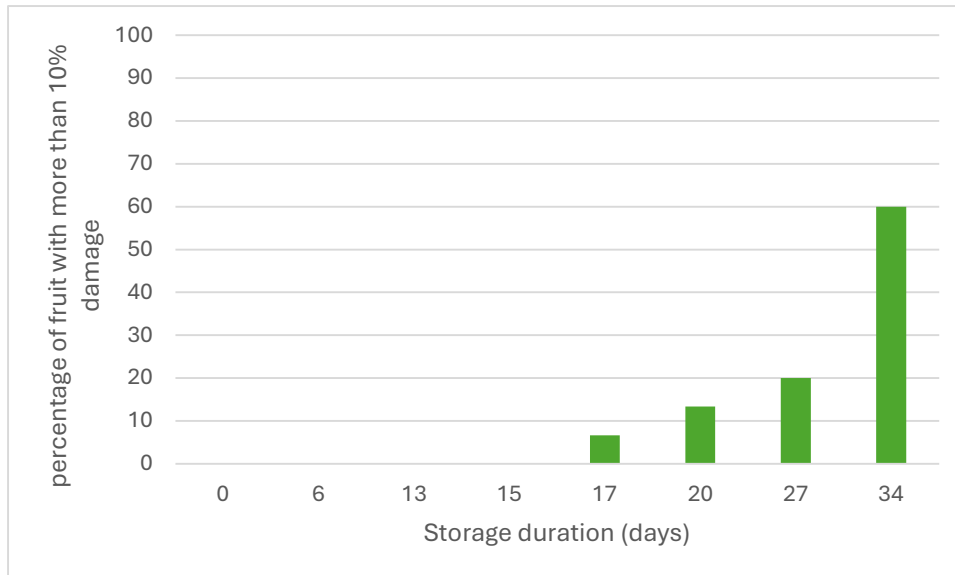


Figure 18. The percentage of 'Hass' avocados with more than 10% internal damage over eight different storage durations from the November 2025 storage trial.

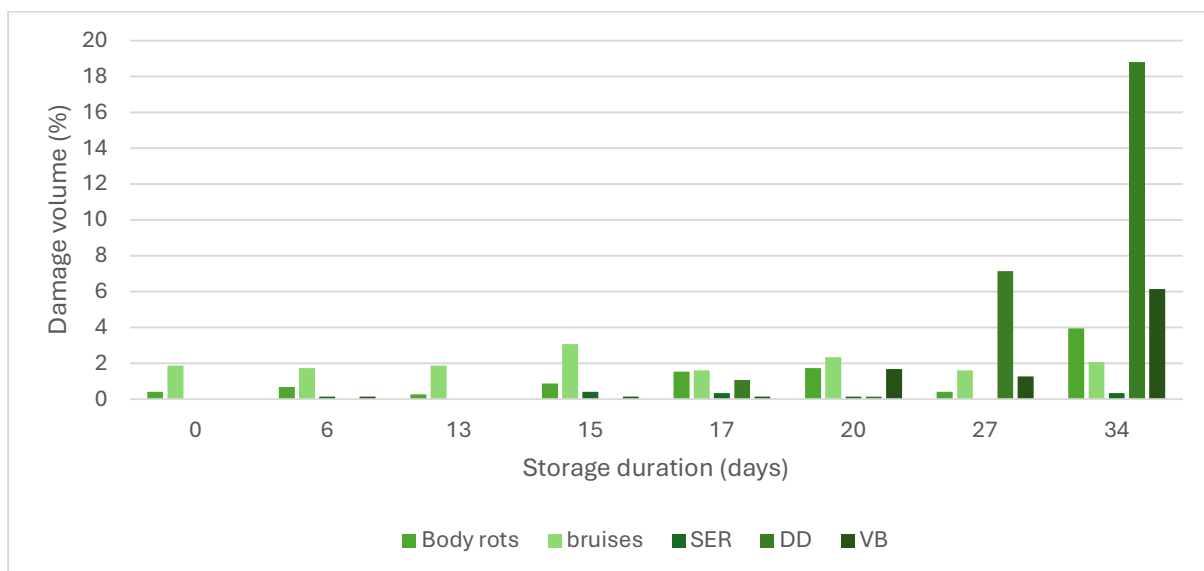


Figure 19. The average volume of individual forms of flesh damage of 'Hass' avocados stored for eight storage durations during November 2025.



Conclusion

Fruit quality was good during this trial, likely due to the low dry matter of the fruit, small fruit size and the use of the extra fungicide application of Graduate A+. Fruit quality gradually decreased over time with fruit failing to meet the accepted industry standard after 20 days of storage. Shelf life gradually decreased in tandem with fruit quality. The damage present in the fruit was mostly minor amounts of bruises and body rots but in the longer storage durations diffuse discolouration and vascular browning became the most severe fruit issues. The increase in diffuse discolouration can be attributed to the long storage time.



5. Conclusions for all storage trials

‘Hass’ avocados stored for up to 21 days at 5°C avoided failing the industry standard in the February 2023 and September 2024 storage trials. The November 2025 was acceptable in terms of the consumer standard up to 17 days, but not 20 days. In the other two storage trials, virtually all fruit failed the consumer standard regardless of fruit size, storage temperature and storage duration. Consequently, the air storage limit for ‘Hass’ avocado fruits grown in Western Australia and stored at 5°C is likely longer than 14 days, but less than 21 days. The assumptions for this storage limit is that Sportak has been used as a minimum.

Smaller fruit size was consistently associated with less internal fruit damage than larger fruit, as well as slightly longer shelf life. Storage temperatures above 5°C resulted in shorter shelf life poorer fruit quality outcomes as well. Cooler storage outcomes did not yield a benefit over the 5°C storage temperature.

**Table 9. Summary of air storage trials held on ‘Hass’ avocados grown in Western Australia.**

Number	Date	Short name	Temperature treatments (°C)	Fruit size treatments	Dry matter	Storage treatments (days)	Fruit quality outcome
1	21/02/2023	Feb-23	5 and 7	16	38.4	7, 14, 21, 28	Good quality, consumer standard failure of 5°C treatment after 28 days, and 21 days for 7°C treatment.
2	15/02/2024	Feb-24	3, 5+3, 5, 10	18, 25	30.5	14, 21, 28, 35	Low fruit quality. Only fruits from 25 size achieved consumer standard at temperatures of 5+3°C after 14 and 35 days and 5°C after 28 days. Even the unstored fruit failed the consumer standard. 10°C caused the worst fruit quality, especially after longer storage durations. Larger fruits had worse quality outcomes than the smaller fruit.
3	4/09/2024	Sep-24	5	18, 23	29.39	5, 10, 15, 20, 25, 30, 45	Good fruit quality. Failure of consumer standard for 18 size fruits at 26 days, and 29 days for 23 size fruit. Very poor fruit quality after 47 days storage. Larger fruits had worse quality outcomes than the smaller fruit.
4	12/11/2024	Nov-24	5	18, 23	30.7	5, 10, 15, 20, 25, 30, 45	Low fruit quality, only the 23 count fruit ripened immediately achieved the consumer standard. The larger fruit had worse fruit quality outcomes.
5	11/11/2025	Nov-25	5	30	24.6	7, 11, 16, 21, 25, 30, 42	Very good fruit quality. Fungicide use, small fruit and low dry matter may be responsible. Consumer standard was failed after 25 days of storage. Quality after 42 days was very bad, with no shelf life either.

Appendix 30

WA 'Hass' avocado storage trials report 2024

Predicting the shelf life of 'Hass' avocado fruit

2024 Western-Australian grower report

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Summary

A series of export simulation trials were conducted with 'Hass' avocados to assess the impact of different supply chain handling and storage conditions on fruit quality and shelf life. The trials involved commercially mature fruit harvested from farms in Western Australia (WA). Fruit from three 2024 harvests entered storage with progressively higher dry-matter (DM) content (29.4 % → 31.6 %) and high initial firmness (≈ 81 Shore units). Controlled atmosphere (CA) storage experiments (0–65 days) showed that Time $\times$ Temperature explains most of the variation in post-treatment shelf life (ESL) and chilling-injury risk. Diffuse discolouration (DD; internal chilling injury) spiked only after very long air storage at 5 °C (> 30 days) but was largely suppressed by CA.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters, helping them maximize product value, reduce claims, and expand trade volume.

The primary objectives of the project are:

- Develop predictive shelf-life models for a wide range of fresh horticultural produce.
- Apply these models to create decision aid tools and update handling guidelines for improved quality and consistency.
- Establish an information portal to facilitate access to these decision aid tools, making them readily available to stakeholders.

This report focuses on the export simulation trial work conducted during the 2024 'Hass' avocado season on fruit grown in WA. The central objective of these trials was to assess the fruit quality and shelf-life response of 'Hass' avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, such as CA storage and fruit maturity (dry matter content). The data generated from these trials will contribute to the development of accurate predictive models for avocado quality and shelf life, enhancing decision-making for exporters and stakeholders.



2. Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Hass' avocados were harvested between September and November 2024 by a commercial picking crew on a farm located near Busselton, WA. After harvest, the fruit were transferred to a nearby packing house, packed, and then air-transported to Cairns for trial work.

Experimental Design

The results presented in this report are based on combined data from three independent trials conducted during the 2024 harvest season. Each trial included three replicates per treatment, with each replicate consisting of 8 fruit. This design ensured sufficient statistical power to detect treatment effects while accounting for biological variability.

Dry Matter Content Measurement

At the laboratory, the dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the center. All trial fruit were grouped according to their NIR-predicted DM values and then sorted by DM content. Fruit were assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of 20 fruits were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

The fruit were assigned to different storage temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. A subset of fruit was stored under CA conditions at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

Table 1 Trial storage temperature treatments

Storage Temperature (°C)	Controlled Atmosphere (+/-)	Storage Duration (days)
5	-	5, 10, 15, 20, 26, 30, 44
5	+	20, 26, 30, 44, 65
7	-	5, 10, 20, 30, 44
10	-	5, 10, 15, 20
15	-	5, 10, 15
20	-	0, 5

At the conclusion of each treatment storage period, the fruit were moved to 20°C for further assessment of their remaining shelf life. The air temperature adjacent to the fruit was monitored from the time of collection at the packing shed through to removal from the cold storage treatments. This allowed for the calculation of time × temperature units (TTU), which helped quantify the effects of storage duration and temperature.

Humidity Control

Relative humidity (RH) inside the cold storage rooms was maintained at approximately 90% to simulate typical cold storage conditions. Once removed from storage, the fruit were placed in a controlled environment at 20°C, with the RH held at 65% to replicate retail conditions.

Bareiss Firmness Measurement

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit at equator. A firmness value of <39 was defined end of shelf life (ESL). These benchmarks provided consistent criteria for assessing ripeness and the remaining usability of the fruit during the trials.

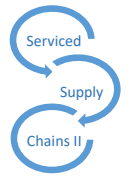
3. Results

Fruit from the three harvests increased in DM from 29.4% to 31.6%, with consistent high intake firmness ($\approx$ 83 Shore units) and moderate skin colour (score 2.0–2.2).

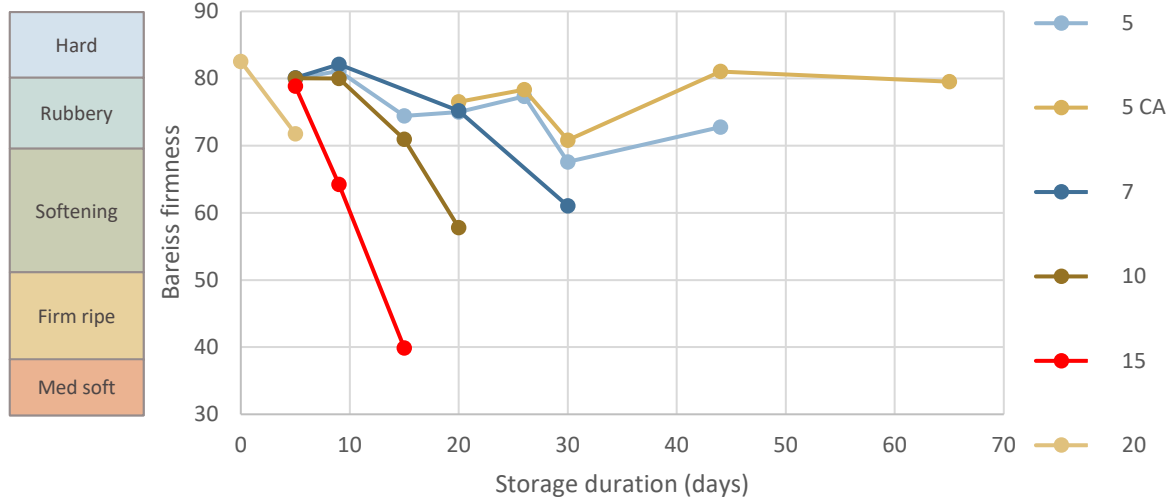
Table 2 Baseline fruit quality for each harvest used in export simulation trials. Numbers in parentheses indicate the corresponding standard deviations.

Trial ID	Size	Harvest Date	Dry-matter (%)	Mean Fruit Weight (g)	Skin Colour Score	Intake Firmness (Shore units)
1	30	3/09/2024	29.4 (2.10)	234.2 (9.61)	2.0 (0.13)	82.4 (3.76)
2	23	1/10/2024	30.1 (1.94)	239.7 (11.41)	2.0 (0.09)	83.0 (4.08)
3	23	11/11/2024	31.6 (1.48)	242.1 (11.11)	2.2 (0.7)	82.9 (4.74)

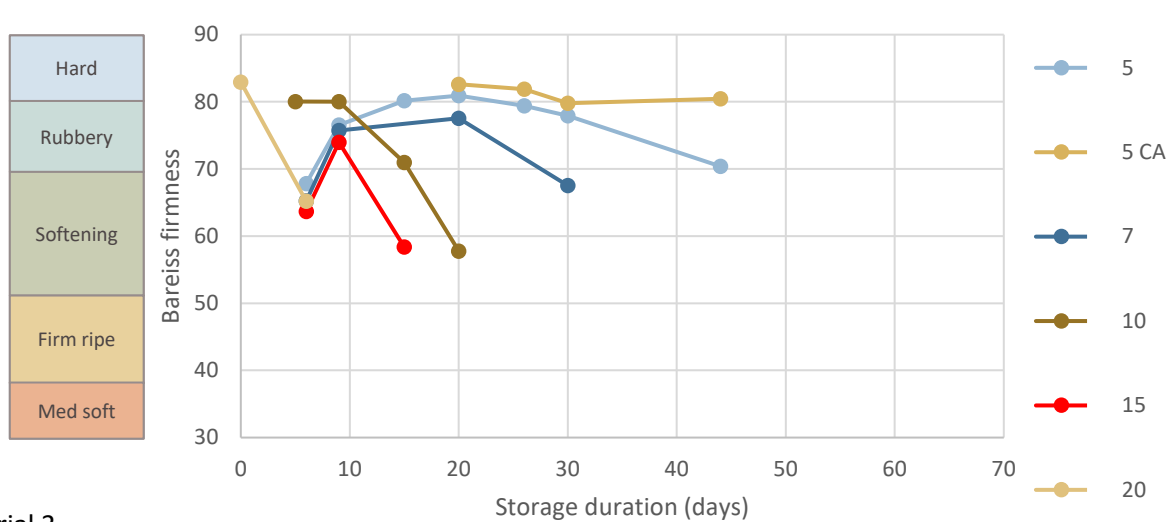
Firmness generally declined with longer storage and higher temperatures. Fruit held at 5 °C in CA retained high firmness even after 65 days ($\approx$ 80 Shore units), while fruit stored at 15 °C for 15 days dropped to 46 Shore units (Figure 1). Results from the three successive harvests (Trials 1–3) were broadly consistent; any differences fell well within the normal, expected variation among individual fruit (Figure 1).



Trial 1



Trial 2



Trial 3

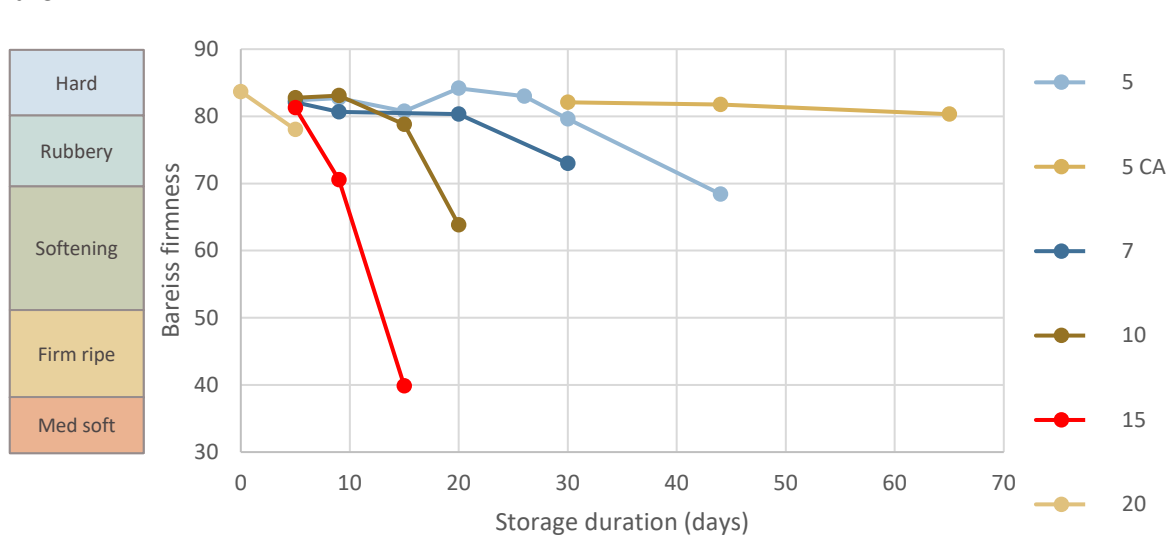


Figure 1 Firmness of 'Hass' avocados under storage conditions (5, 7, 10, 15 and 20 °C), CA refers to controlled atmosphere (2% O₂ and 5% CO₂). Three consecutive harvest trials (Trials 1–3). Side panels indicate the corresponding consumer firmness classes from "Hard" to "Medium-soft."

From Table 3 the longer fruit were stored in air, and the warmer the storage temperature, the fewer days of marketable life remained once they were transferred to 20 °C. In extreme cases (e.g., 15 °C for 15 days), some fruit actually crossed the firm ripe (FR) threshold (firmness < 50 Shore units) before the cold-storage period had even finished, yielding negative “days to FR” values (Table 3). By contrast, fruit held at 5 °C retained a useful buffer of “days to FR” even after 65 days, making this temperature highly advantageous for long-haul uses such as sea freight. Results were consistent across all three trials.

Table 3 Days to firm ripe (FR) at 20°C after storage treatment. Values are the mean of treated fruit; numbers in brackets are the corresponding standard deviations. Three consecutive harvest trials (Trials 1–3). Numbers in parentheses indicate the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Trial 1 (days to FR)		Trial 2 (days to FR)		Trial 3 (days to FR)	
5	-	5	5.8	(0.93)			5.1	(0.45)
5	-	6			6.8	(1.23)		
5	-	9	4.3	(1.00)	5.6	(0.71)	4.3	(0.74)
5	-	15	3.6	(0.68)	4.6	(1.17)	7.0	(0.83)
5	-	20	3.6	(1.55)	3.9	(1.14)	3.3	(0.70)
5	-	26	2.5	(0.45)	3.4	(0.49)	3.8	(0.44)
5	-	30	3.2	(0.82)	4.0	(1.14)	3.2	(0.51)
5	-	44	2.7	(0.48)	3.8	(0.38)	4.3	(1.43)
5	+	20	3.8	(1.24)	5.5	(0.59)	5.0	(1.84)
5	+	26	3.1	(0.61)	4.0	(0.20)	4.9	(1.02)
5	+	30	3.3	(0.00)	4.9	(0.28)	4.1	(0.28)
5	+	44	2.6	(0.44)	4.8	(0.41)	5.2	(0.88)
5	+	65	4.0	(0.65)	9.6	(0.77)	4.9	(0.93)
7	-	5	5.8	(1.02)			4.8	(0.48)
7	-	6			6.2	(0.59)		
7	-	9	4.0	(1.50)	5.3	(0.61)	4.0	(0.00)
7	-	20	1.9	(1.25)	3.0	(0.46)	2.1	(1.12)
7	-	30	2.1	(1.85)	3.0	(0.00)	2.6	(1.10)
10	-	5	5.7	(1.01)			4.9	(0.61)
10	-	6			6.0	(0.20)		
10	-	9	3.1	(1.02)	4.8	(0.44)	3.8	(0.44)
10	-	15	2.5	(1.40)	3.4	(0.50)	6.5	(1.91)
10	-	20	0.7	(1.27)	1.0	(0.42)	1.7	(1.20)
15	-	5	3.3	(1.47)			3.8	(1.03)
15	-	6			5.8	(1.11)		
15	-	9	1.4	(1.40)	4.8	(0.64)	2.4	(1.17)
15	-	15	-0.7	(0.00)	0.6	(0.65)	-1.5	(0.51)
20	-	0	6.5	(2.21)	9.5	(1.74)	8.0	(1.16)
20	-	5	2.0	(1.20)			3.2	(1.14)
20	-	6			2.8	(1.36)		

Table 4 tracks the days each lot still had before reaching end-of-shelf-life (ESL) once fruit were at 20 °C. Across all three trials, ESL steadily declined as storage temperature and time increased. Fruit held at 5 °C for ≤ 10 days still ripened slowly, retaining 7–13 days of ESL. By contrast, fruit stored at 15 °C for 15 days or at 20 °C for 5 days had only 2–7 days left, and some lots dipped even lower. When CA (2 % O₂ and 5 % CO₂) was used, fruit stored at 5 °C maintained or even modestly improved ESL compared with air controls of the same duration. For instance, after 26 days, CA fruit in Trial 2 still had 10.8 days of ESL versus 11.4 days for air-stored fruit, but after 65 days CA fruit in the same trial still showed 14.1 days—almost double the 8.8 days recorded for the longest air treatment.

Table 4 Days to ESL at 20°C after storage treatment. Values are the mean of treated fruit;. Three consecutive harvest trials (Trials 1–3). Numbers in parentheses indicate the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Trial 1 (days to ESL)		Trial 2 (days to ESL)		Trial 3 (days to ESL)	
5	-	5	7.8	(1.77)			11.1	(3.31)
5	-	6			13.1	(3.76)		
5	-	9	7.3	(1.82)	13.0	(3.57)	11.3	(3.74)
5	-	15	5.8	(2.00)	9.7	(2.22)	12.8	(2.70)
5	-	20	7.0	(2.63)	9.0	(2.13)	10.7	(3.06)
5	-	26	7.9	(2.84)	11.4	(3.73)	10.1	(3.89)
5	-	30	9.4	(3.75)	10.6	(2.83)	10.7	(2.94)
5	-	44	8.1	(2.80)	8.8	(2.19)	7.4	(2.04)
5	+	20	5.8	(1.31)	10.2	(2.81)	10.4	(2.89)
5	+	26	9.1	(3.41)	10.8	(3.17)	11.5	(2.77)
5	+	30	7.3	(3.87)	9.0	(2.18)	10.3	(2.66)
5	+	44	8.4	(2.89)	11.0	(2.80)	10.2	(2.57)
5	+	65	6.2	(2.49)	14.1	(3.83)	10.9	(2.44)
7	-	5	8.2	(1.75)			12.2	(3.07)
7	-	6			13.3	(3.47)		
7	-	9	6.9	(2.12)	12.3	(3.26)	11.5	(4.11)
7	-	20	6.8	(3.37)	11.2	(3.16)	7.2	(4.05)
7	-	30	8.1	(4.25)	9.4	(3.10)	8.2	(2.73)
10	-	5	7.7	(1.27)			12.0	(3.46)
10	-	6			12.5	(3.12)		
10	-	9	5.5	(1.78)	12.3	(3.44)	11.8	(2.70)
10	-	15	6.8	(3.60)	9.5	(2.54)	10.7	(2.90)
10	-	20	6.5	(4.24)	7.3	(2.91)	6.1	(3.08)
15	-	5	6.5	(1.34)			8.2	(2.60)
15	-	6			12.5	(2.98)		
15	-	9	4.9	(3.30)	10.7	(2.18)	6.3	(3.08)
15	-	15	2.0	(2.85)	7.4	(2.63)	1.9	(2.63)
20	-	0	10.8	(2.55)	15.8	(3.66)	13.8	(3.74)
20	-	5	5.6	(1.70)	(0.00)		7.0	(2.86)
20	-	6			9.8	(3.09)		

Post-storage disorders became more severe with longer storage durations. Disorders such as stem-end rot (SER) and body rot remained low during short-term storage but increased markedly after extended periods, particularly under air storage conditions. For example, fruit stored at 5 °C in air for 44 days exhibited an average 8.3% body rot volume, while the same treatment under CA showed 2.1% body rot (Table 5). This highlights the protective effect of CA storage in suppressing disease incidence during prolonged cold storage. Table 6 and

Table 7, which report the other two trials, show the same pattern of increasing disorders in air and consistent suppression under CA.

Table 5 Post storage disorders after storage treatment and End of shelf life (ESL) at 20°C Trial 1. Values are the mean of treated fruit; numbers in brackets are the corresponding standard deviations. Numbers in parentheses indicate the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Body Rot (% vol)		Bruise (% vol)		Vascular Browning (% vol)		Stem-end Rot (% vol)	
5	-	5	0.3%	(0.01)	0.3%	(0.01)	0.0%	(0.00)	0.0%	(0.00)
5	-	9	0.3%	(0.01)	0.3%	(0.01)	0.3%	(0.01)	0.6%	(0.02)
5	-	15	0.0%	(0.00)	0.1%	(0.00)	0.2%	(0.01)	0.5%	(0.02)
5	-	20	0.0%	(0.00)	0.5%	(0.01)	0.5%	(0.02)	0.5%	(0.01)
5	-	26	0.3%	(0.01)	0.2%	(0.01)	1.2%	(0.02)	0.9%	(0.02)
5	-	30	2.9%	(0.07)	0.9%	(0.03)	1.3%	(0.02)	1.8%	(0.03)
5	-	44	8.3%	(0.19)	0.2%	(0.01)	1.5%	(0.03)	2.5%	(0.04)
5	+	20	0.0%	(0.00)	0.3%	(0.01)	0.0%	(0.00)	0.1%	(0.00)
5	+	26	1.8%	(0.06)	0.3%	(0.01)	0.9%	(0.02)	3.6%	(0.05)
5	+	30	1.1%	(0.03)	1.4%	(0.05)	0.2%	(0.01)	1.4%	(0.03)
5	+	44	2.1%	(0.04)	0.5%	(0.02)	2.0%	(0.04)	4.2%	(0.08)
5	+	65	1.8%	(0.03)	0.0%	(0.00)	2.3%	(0.05)	4.2%	(0.08)
7	-	5	0.5%	(0.02)	0.3%	(0.01)	0.0%	(0.00)	0.6%	(0.02)
7	-	9	0.0%	(0.00)	0.3%	(0.01)	0.1%	(0.00)	0.0%	(0.00)
7	-	20	1.3%	(0.05)	0.6%	(0.01)	0.7%	(0.02)	1.0%	(0.02)
7	-	30	4.0%	(0.11)	0.6%	(0.02)	5.7%	(0.10)	3.4%	(0.05)
10	-	5	0.2%	(0.01)	0.0%	(0.00)	0.1%	(0.00)	0.3%	(0.01)
10	-	9	0.0%	(0.00)	0.0%	(0.00)	0.2%	(0.01)	0.1%	(0.00)
10	-	15	1.0%	(0.03)	0.8%	(0.02)	0.7%	(0.01)	0.9%	(0.02)
10	-	20	3.0%	(0.07)	2.9%	(0.04)	1.0%	(0.03)	1.1%	(0.02)
15	-	5	0.1%	(0.00)	0.4%	(0.01)	0.0%	(0.00)	0.4%	(0.01)
15	-	9	0.6%	(0.02)	1.1%	(0.02)	0.6%	(0.01)	0.8%	(0.01)
15	-	15	0.4%	(0.01)	0.4%	(0.01)	0.7%	(0.01)	1.5%	(0.02)
20	-	0	0.3%	(0.01)	0.5%	(0.02)	0.0%	(0.00)	1.0%	(0.02)
20	-	5	0.3%	(0.01)	0.8%	(0.01)	0.0%	(0.00)	0.2%	(0.01)

Table 6 Post storage disorders after storage treatment and End of shelf life (ESL) at 20°C Trial 2. Values are the mean of treated fruit. Numbers in parentheses indicate the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Body Rot (% vol)		Bruise (% vol)		Vascular Browning (% vol)		Stem-end Rot (% vol)	
5	-	6	6.5%	(0.09)	2.0%	(0.04)	0.4%	(0.01)	0.0%	(0.00)
5	-	9	11.1%	(0.14)	2.3%	(0.04)	1.2%	(0.02)	0.0%	(0.00)
5	-	15	1.0%	(0.03)	0.5%	(0.01)	0.1%	(0.00)	0.0%	(0.00)
5	-	20	1.3%	(0.04)	0.5%	(0.01)	0.3%	(0.01)	0.0%	(0.00)
5	-	26	10.1%	(0.12)	2.2%	(0.03)	2.1%	(0.04)	0.0%	(0.00)
5	-	30	7.9%	(0.08)	2.2%	(0.03)	2.8%	(0.05)	0.7%	(0.03)
5	-	44	4.6%	(0.06)	2.5%	(0.04)	2.3%	(0.03)	34.2%	(0.30)
5	+	20	2.6%	(0.06)	2.0%	(0.04)	0.3%	(0.01)	0.0%	(0.00)
5	+	26	5.3%	(0.10)	1.3%	(0.02)	0.3%	(0.01)	0.0%	(0.00)
5	+	30	0.6%	(0.01)	3.0%	(0.06)	1.2%	(0.03)	0.0%	(0.00)
5	+	44	7.2%	(0.09)	2.8%	(0.04)	1.2%	(0.02)	0.0%	(0.00)
5	+	65	6.3%	(0.10)	7.0%	(0.08)	3.9%	(0.06)	1.0%	(0.03)
7	-	6	9.7%	(0.11)	2.8%	(0.03)	0.5%	(0.01)	0.0%	(0.00)
7	-	9	4.3%	(0.06)	1.5%	(0.03)	0.3%	(0.01)	0.0%	(0.00)
7	-	20	9.7%	(0.09)	3.3%	(0.04)	2.9%	(0.03)	0.1%	(0.01)
7	-	30	14.0%	(0.12)	3.8%	(0.04)	3.8%	(0.04)	1.8%	(0.05)
10	-	6	6.8%	(0.08)	2.9%	(0.04)	0.2%	(0.01)	0.0%	(0.00)
10	-	9	9.4%	(0.11)	3.0%	(0.03)	0.7%	(0.01)	0.0%	(0.00)
10	-	15	9.2%	(0.12)	2.6%	(0.03)	0.8%	(0.01)	0.0%	(0.00)
10	-	20	4.0%	(0.05)	2.2%	(0.03)	2.0%	(0.04)	0.0%	(0.00)
15	-	6	8.9%	(0.08)	3.8%	(0.05)	0.3%	(0.01)	0.0%	(0.00)
15	-	9	4.2%	(0.06)	3.3%	(0.04)	0.4%	(0.01)	0.0%	(0.00)
15	-	15	12.0%	(0.18)	4.6%	(0.09)	1.3%	(0.02)	0.0%	(0.00)
20	-	0	9.4%	(0.11)	3.3%	(0.04)	1.0%	(0.02)	0.0%	(0.00)
20	-	6	5.5%	(0.07)	5.9%	(0.06)	1.0%	(0.02)	0.0%	(0.00)

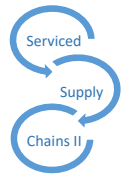
Table 7 Post storage disorders after storage treatment and End of shelf life (ESL) at 20°C Trial 3. Values are the mean of treated fruit; numbers in brackets are the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Body Rot (% vol)		Bruise (% vol)		Vascular Browning (% vol)		Stem-end Rot (% vol)	
5	-	6	4.9%	(0.09)	1.4%	(0.03)	0.0%	(0.00)	0.0%	(0.00)
5	-	9	4.5%	(0.05)	0.5%	(0.01)	0.0%	(0.00)	0.0%	(0.00)
5	-	15	12.8%	(0.11)	2.8%	(0.04)	0.5%	(0.01)	0.1%	(0.00)
5	-	20	6.3%	(0.06)	2.3%	(0.03)	1.1%	(0.03)	0.0%	(0.00)
5	-	26	7.8%	(0.08)	1.3%	(0.02)	1.0%	(0.02)	0.0%	(0.00)
5	-	30	8.0%	(0.08)	2.1%	(0.02)	2.0%	(0.03)	3.3%	(0.11)
5	-	44	5.9%	(0.07)	0.6%	(0.02)	3.9%	(0.06)	60.2%	(0.22)
5	+	20	6.3%	(0.07)	2.4%	(0.03)	0.1%	(0.01)	0.0%	(0.00)
5	+	26	5.3%	(0.06)	3.8%	(0.04)	0.7%	(0.01)	0.0%	(0.00)
5	+	30	3.6%	(0.04)	2.6%	(0.03)	0.6%	(0.01)	1.5%	(0.07)
5	+	44	4.7%	(0.05)	2.4%	(0.03)	1.0%	(0.02)	0.0%	(0.00)
5	+	65	8.5%	(0.09)	8.7%	(0.09)	4.5%	(0.08)	3.0%	(0.06)
7	-	6	6.6%	(0.08)	4.6%	(0.07)	0.1%	(0.00)	0.0%	(0.00)
7	-	9	3.0%	(0.07)	2.3%	(0.04)	0.0%	(0.00)	0.0%	(0.00)
7	-	20	3.5%	(0.06)	2.4%	(0.05)	0.3%	(0.01)	0.0%	(0.00)
7	-	30	4.1%	(0.06)	2.1%	(0.03)	1.5%	(0.03)	2.3%	(0.05)
10	-	6	5.9%	(0.10)	2.0%	(0.03)	0.0%	(0.00)	0.0%	(0.00)
10	-	9	7.4%	(0.09)	1.2%	(0.02)	0.0%	(0.00)	0.0%	(0.00)
10	-	15	7.1%	(0.08)	4.5%	(0.09)	0.0%	(0.00)	0.0%	(0.00)
10	-	20	2.8%	(0.05)	0.6%	(0.01)	0.3%	(0.01)	1.4%	(0.04)
15	-	6	2.5%	(0.05)	0.6%	(0.01)	0.0%	(0.00)	0.0%	(0.00)
15	-	9	2.3%	(0.03)	1.0%	(0.02)	0.2%	(0.01)	0.0%	(0.00)
15	-	15	1.7%	(0.04)	0.6%	(0.01)	0.0%	(0.00)	0.1%	(0.00)
20	-	0	5.2%	(0.11)	1.8%	(0.03)	0.1%	(0.00)	0.0%	(0.00)
20	-	6	1.7%	(0.02)	1.4%	(0.02)	0.1%	(0.00)	0.0%	(0.00)

Table 8 shows that DD, which is the visible sign of chilling injury, developed only after prolonged cold storage and intensified with time, with incidence varying markedly between harvests. In air at 5 °C, DD remained negligible up to 26 days but leapt to 14 % volume after 30 days and to 38 % after 44 days in Trial 1. Switching the same 5 °C treatment to a CA (2 % O₂, 5 % CO₂) slashed DD to below 4 % at 30 days and kept it under 1 % at 44 days. Raising the storage temperature above 5 °C had a similar protective effect: across all three trials, fruit stored at 7, 10, 15, or 20 °C rarely exceeded 3 % volume. DD levels differed greatly between harvests, highlighting the natural variability in fruit susceptibility to chilling injury.

Table 8 Diffuse Discolouration / chilling injury after storage treatment and End of shelf life (ESL) at 20°C.
 Values are the mean of treated fruit Three consecutive harvest trials (Trials 1–3). Numbers in parentheses indicate the corresponding standard deviations.

Storage Temperature (°C)	CA	Storage Duration (days)	Trial 1 Diffuse Discolouration (% area)		Trial 2 Diffuse Discolouration (% area)		Trial 3 Diffuse Discolouration (% area)	
5	-	5	0.1%	(0.01)			0.0%	(0.00)
5	-	6			1.3%	(0.06)		
5	-	9	0.0%	(0.00)	0.0%	(0.00)	0.0%	(0.00)
5	-	15	0.0%	(0.00)	0.3%	(0.01)	0.1%	(0.00)
5	-	20	1.3%	(0.06)	0.0%	(0.00)	0.0%	(0.00)
5	-	26	0.3%	(0.01)	0.0%	(0.00)	0.0%	(0.00)
5	-	30	14.3%	(0.25)	0.0%	(0.00)	0.0%	(0.00)
5	-	44	38.3%	(0.29)	0.3%	(0.01)	0.0%	(0.00)
5	+	20	0.0%	(0.00)	0.1%	(0.00)	0.0%	(0.00)
5	+	26	0.4%	(0.01)	0.0%	(0.00)	0.0%	(0.00)
5	+	30	3.5%	(0.17)	0.0%	(0.00)	0.0%	(0.00)
5	+	44	0.7%	(0.02)	0.0%	(0.00)	0.0%	(0.00)
5	+	65	1.3%	(0.03)	0.0%	(0.00)	0.1%	(0.01)
7	-	5	0.0%	(0.00)			0.0%	(0.00)
7	-	6			0.8%	(0.03)		
7	-	9	0.0%	(0.00)	0.6%	(0.02)	0.0%	(0.00)
7	-	20	0.0%	(0.00)	0.0%	(0.00)	0.0%	(0.00)
7	-	30	8.1%	(0.15)	0.4%	(0.01)	0.0%	(0.00)
10	-	5	0.0%	(0.00)			0.0%	(0.00)
10	-	6			0.0%	(0.00)		
10	-	9	0.0%	(0.00)	1.3%	(0.05)	0.0%	(0.00)
10	-	15	0.2%	(0.01)	0.5%	(0.02)	0.0%	(0.00)
10	-	20	0.3%	(0.01)	1.8%	(0.03)	0.0%	(0.00)
15	-	5	0.0%	(0.00)			0.3%	(0.01)
15	-	6			0.0%	(0.00)		
15	-	9	1.0%	(0.05)	1.5%	(0.04)	0.0%	(0.00)
15	-	15	3.6%	(0.11)	2.0%	(0.04)	0.1%	(0.00)
20	-	0	0.0%	(0.00)	0.1%	(0.01)	0.1%	(0.00)
20	-	5	0.0%	(0.00)			0.1%	(0.00)
20	-	6			0.0%	(0.00)		



4. Summaries and recommendations

- Fruit dry matter content only slightly increased as the season progressed.
- Cold air versus cold CA. At 5 °C, CA extended both “days to firm-ripe” and ESL. Fruit in CA still had >6 days of ESL after 65 days; air-stored fruit at the same temperature fell below 8 days of ESL by 44 days.
- Severe chilling injury and stem-end rot were only seen in extended air storage conditions (> 30 days at 5 °C).
- Harvest variability, Absolute disorder levels fluctuated among trials, yet the performance ranking of treatments (cold air worst > warmer air > cold CA best) never changed.

Recommendation: For export handling, use CA storage at 5 °C to mitigate the risk of delays and ensure air-stored consignments are moved within 20 days to avoid quality loss.

5. Acknowledgments

The authors thank the grower, farm staff and the WA Department of Agriculture and Food team for their assistance. This work was funded by Hort Innovation through the Serviced Supply Chains II (AM21000) project.

Appendix 31

WA 'Hass' avocado controlled atmosphere storage trials report 2024

Controlled atmosphere storage of WA 'Hass' avocados

Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

'Hass' avocados grown in Western Australia (WA) were stored in air or under controlled atmosphere (CA) for periods of 21, 26 or 30 days. Following storage, fruit were held at 20°C and 65% RH to evaluate remaining shelf life and quality at medium ripe.

- CA storage showed strong benefits in:
 - retaining fruit firmness
 - reducing moisture loss
 - reducing retention of green skin colour
 - reducing rots and chilling damage
 - improving internal quality

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report focusses on CA trial work completed at MRF during the 2024 'Hass' avocado season. The main objective of the trial was to quantify the fruit quality and shelf life response of WA grown 'Hass' avocados to long storage under air and CA.

2. Materials and methods

Commercially mature 'Hass' avocado fruit (targeting dry matter >23%) grown in WA were sourced for trials during the 2024 season.

Fruit were stored at 5°C either in air or CA for 21, 26 or 30 days. CA was maintained at 2% O₂ and 5% CO₂ and relative humidity (RH) inside cold rooms was maintained near 90%. At the end of each storage treatment, fruit were shifted to 20°C and 65% RH for ongoing assessment. An additional control treatment was kept constantly at 20°C and 65% RH. Each treatment was applied to 3 replicate trays of 9 fruit.

At trial commencement all fruit were weighed. In addition, skin colour score and firmness were recorded for control fruit. Skin colour score was recorded according to the scale below:

Skin colour score

- 1 = Emerald green
- 2 = Forest green
- 3 = Approx 25% colour development
- 4 = Approx 75% colour development
- 5 = Full colour development (<10% green), with purple colour
- 6 = Full colour development, with black colour

Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, skin colour score, weight and firmness were recorded for all fruit.

After each storage treatment, fruit were shifted to 20°C for ongoing shelf life assessment, with fruit quality monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Fruit quality under controlled atmosphere (CA) versus air

CA storage (2% O₂ and 5% CO₂) slightly reduced weight loss compared with air over durations of 21 to 30 days at 5°C (Table 1).

Table 1. Weight loss in 'Hass' avocados stored under air or CA at 5°C for various durations

Storage temperature	Storage duration (days)	Weight loss after storage (%)	
		Air	CA
5°C	21	2.4	2.1
	26	2.7	2.6
	30	2.8	2.7

CA maintained fruit firmness, with fruit remaining hard when stored under CA for up to 30 days (Table 2). In contrast, fruit firmness slightly declined after 30 days in fruit held at 5°C in air.

Table 2. Firmness of 'Hass' avocados at removal from various storage treatments, with and without CA (higher values indicate firmer fruit)

Storage temperature	Storage duration (days)	Firmness	
		Air	CA
5°C	21	83.7	84.0
	26	81.8	84.3
	30	75.0	82.9

Dark skin colour development started to occur after 30 days at 5°C in air, while fruit stored under CA storage remained green (Table 3).

Table 3. Skin colour score of 'Hass' avocados at removal from various storage treatments under air or CA

Storage temperature	Storage duration (days)	Skin colour score (1-6)	
		Air	CA
5°C	21	2.0	2.0
	26	2.1	2.0
	30	2.9	2.0

The retention of green skin colour after ripening was greatest in fruit transferred immediately to 20°C (Table 4). Fruit stored in air at 5°C for long periods also retained green skin colour at ripe, but this did not occur under CA.

Table 4. Green skin colour at ripe in 'Hass' avocados following storage under air or CA

Storage temperature	Storage duration (days)	Green skin colour (% SA) at ripe	
		Air	CA
5°C	21	1.4	0.5
	26	3.8	0.0
	30	7.3	0.3
20°C	-	23.7	

Rots occurred at low levels in fruit transferred immediately to 20°C and worsened with storage (Table 5). Particularly high levels of rot incidence and severity were observed following 30 days storage in air. Rots were substantially reduced by the use of CA.

Table 5. Severity and incidence of rots in 'Hass' avocados at medium ripe following storage for various periods with or without CA

Temp	Storage duration (days)	Body rot severity (% vol)		Body rot incidence (% fruit)		Stem end rot severity (% vol)		Stem end rot incidence (% fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA
5°C	21	5.2	1.2	70	22	1.4	0.6	37	15
	26	3.8	2.0	59	22	0.5	0.4	19	19
	30	11.9	3.7	85	52	2.7	1.4	74	33
20°C	-	0.3		15		0.4		4	

Storage under CA reduced the incidence and severity of diffuse flesh discolouration symptomatic of chilling injury (Table 6). Vascular browning emerged as an issue in fruit stored for 30 days, and was a particular issue in fruit stored under CA. Compared with air, CA reduced the total defect volume in ripe fruit after 21 and 26 days. However, following 30 days storage the total volume of internal defects was very high under both CA and air.

Table 6. Severity and incidence of internal defects in 'Hass' avocados at medium ripe following storage for various periods with or without CA

Temp	Storage duration (days)	Diffuse discolouration severity (% vol)		Diffuse discolouration incidence (% fruit)		Vascular browning severity (% vol)		Total internal defect volume (%)	
		Air	CA	Air	CA	Air	CA	Air	CA
5°C	21	0.7	0.2	11	4	4.3	1.0	16.1	6.3
	26	1.6	0.1	22	4	4.9	0.3	13.5	4.8
	30	5.5	1.8	63	19	5.8	12.6	30.1	21.3
20°C	-	0.0		0		0.0		1.0	

Fruit stored under CA took slightly longer than air-stored fruit to reach firm ripe after being transferred to 20°C, averaging 1.6 days longer (Table 7). However, air stored fruit took around 1.7 days longer than CA stored fruit to ripen from firm ripe to medium ripe. As a result, CA stored fruit tended to spend less time at ideal eating firmness. The total shelf life averaged around 11 days following all long storage treatments under both CA and air.

Table 7. Ripening and shelf life of 'Hass' avocados following storage for various periods with or without CA

Temp	Storage duration (days)	Days to reach firm ripe		Days from firm ripe to medium ripe		Shelf life (days)		Unacceptable fruit (%)	
		Air	CA	Air	CA	Air	CA	Air	CA
5°C	21	4.9	6.1	5.9	4.1	11.4	11.1	74	22
	26	4.0	6.1	6.1	4.0	10.7	11.0	48	11
	30	4.7	6.1	6.0	4.9	10.5	11.8	81	52
20°C	-	9.5		3.2		13.6		4	

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, Harker et al. 2010).

Flesh quality declined with prolonged cool storage, particularly in air. Most fruit stored in air for 21 to 30 days developed unacceptable internal defects when ripened to medium soft. The use of CA reduced the loss of internal quality. However, following 30 days under CA, greater than half of the fruit showed unacceptable internal defects. The high levels of internal defects in this trial may have resulted from harvest delays of 3-4 weeks due to rain.

The original trial design included removals at 45 and 60 days. Due to the high levels of defects after 30 days, these longer treatments were not fully assessed. Fruit stored for 45 days were cut open to observe and photograph internal defects at firm ripe and medium ripe. Air stored fruit were in very poor condition when cut open at firm ripe after 45 days. CA stored fruit were in good condition at firm ripe, but internal quality declined at medium ripe.

4. Summaries and recommendations

CA storage provided strong benefits in long duration storage, maintaining fruit firmness, reducing defects and improving internal quality.

For fruit used in these trials, storage durations of up to 26 days could be achieved using CA, however longer storage resulted in poor internal quality at medium ripe.

5. Acknowledgments

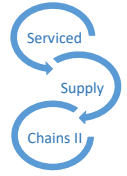
We thank the grower and farm staff for supplying fruit for trials.

6. References

Gamble, J., F. R. Harker, S. R. Jaeger, A. White, C. Bava, M. Beresford, B. Stubbings, M. Wohlers, P. J. Hofman and A. Woolf (2010). "The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase." *Postharvest Biology and Technology* **57**: 35-43.

Appendix 32

WA 'Hass' avocado storage trials report 2025



2025 WA Grower Report

John Archer, Minh Nguyen, Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

This report presents the findings from the 2025 Western Australia post-harvest storage trials. The study evaluates the impact of controlled atmosphere and temperature regimes on fruit quality.

Key Performance Indicators (KPIs):

- **Shelf Life (SL):** Days to senescence, defined as the time until fruit reached medium-ripe stage (durometer firmness of 39 or less).
- **Defect Severity (%):** The average percentage of flesh or surface area affected by defects.
- **Diffuse Discolouration (DD):** A specific indicator of chilling injury.
- **Total Severity Volume:** The cumulative volume of all recorded defects.

Treatments resulting in an Average Total Severity > 10% are flagged.

Shelf life and chilling injury responses in 2025 were generally similar to those observed in the 2024 season; however, overall defect levels were considerably higher in 2025. Controlled atmosphere storage significantly reduced chilling injury and improved storage performance at low temperature. Storage at 5°C was effective for extending storage duration, although fruit held under air storage showed an increased risk of chilling injury with prolonged storage. Higher storage temperatures (10–15°C) reduced chilling injury risk but accelerated senescence and rot development. Across all treatments, increasing storage duration was correlated with increased levels of defect. Comparison of the three trials did not indicate a consistent seasonal trend in shelf life or firmness. However, rot-related defects, particularly body rot and stem-end rot, were higher in the mid- and late-season trials than in the early-season trial.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters, helping them maximize product value, reduce claims, and expand trade volume.

This report focuses on the export simulation trial work conducted during the 2025 'Hass' avocado season on fruit grown in WA. The central objective of these trials was to assess the fruit quality and shelf-life response of 'Hass' avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, temperature and controlled atmosphere storage.

2. Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Hass' avocados were harvested in 2025 by a commercial picking crew from a farm located near Busselton, WA. Following harvest, fruit were transported to a nearby packing facility, where they were graded and packed before being air-freighted to Cairns for experimental assessment. After packing, total transport time was less than 24 hours. Harvest dates for Trials 1, 2, and 3 were 17 August 2025, 9 October 2025, and 16 November 2025, respectively.

Experimental Design

The results presented in this report are based on combined data from three independent trials conducted during the 2025 'Hass' avocado season. Each trial included three replicates per treatment, with each replicate consisting of 8 fruit. This design ensured sufficient statistical power to detect treatment effects while accounting for biological variability.

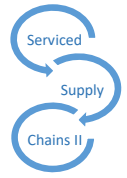
Dry Matter Content Measurement

Fruit dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values and then sorted by DM content. Fruit were assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A sub-set of 20 fruits were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

Fruit were stored under a range of temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. A subset of fruit was stored under controlled atmosphere conditions at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

**Table 1.** Trial storage temperature treatments

Storage Temperature (°C)	Controlled Atmosphere	Storage Duration (days)
5	Non-CA	5-6*, 9, 14, 21, 28, 35, 42
5	Controlled Atmosphere	21, 28, 35, 42, 65
7	Non-CA	5-6*, 9, 21, 28, 42
10	Non-CA	5-6*, 9, 14, 21
15	Non-CA	5-6*, 9, 14
20	Non-CA	0, 5-6*
* Storage durations of 5–6 days reflect minor variation (± 1 day) in removal timing due to scheduling around public holidays.		

At the conclusion of each storage treatment period, fruit were transferred to 20°C and 65% relative humidity for assessment of remaining shelf life. Harvest weather data were incorporated, and fruit temperature was monitored from the time of collection at the packing shed through to removal from cold storage. This enabled the calculation of time $\times$ temperature units (TTU), which were used in the development of avocado modelling.

Humidity Control

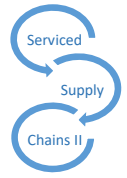
Relative humidity (RH) during cold storage was maintained at approximately 90% to simulate commercial cold chain conditions. Following removal from storage, fruit were held at 20°C and 65% RH to replicate retail shelf conditions.

Bareiss Firmness and Shelf Life Assessment

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit at the equator. When fruit neared medium ripe (durometer firmness of 39 or less), a final assessment was undertaken. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discoloration were expressed as the percentage of flesh volume affected.

3. Results

The mean dry matter content for each trial, estimated using near-infrared spectroscopy (NIR), was 25.82%, 28.69%, and 28.06% for Trials 1, 2, and 3, respectively. These values represent the average DM of all fruit included in each trial. The increase in DM observed in later trials reflects seasonal progression and increasing fruit maturity over the harvest period.



4. Firmness

Firmness generally declined with longer storage and higher temperatures. Fruit held at 5 °C in controlled atmosphere retained high firmness even after 65 days (≈ 80 Shore units), while fruit stored at 15 °C for 15 days dropped to <55 Shore units (**Figure 1**). Results from the three successive harvests (Trials 1–3) were broadly consistent; any differences fell well within the normal, expected variation among individual fruit (**Figure 1**).

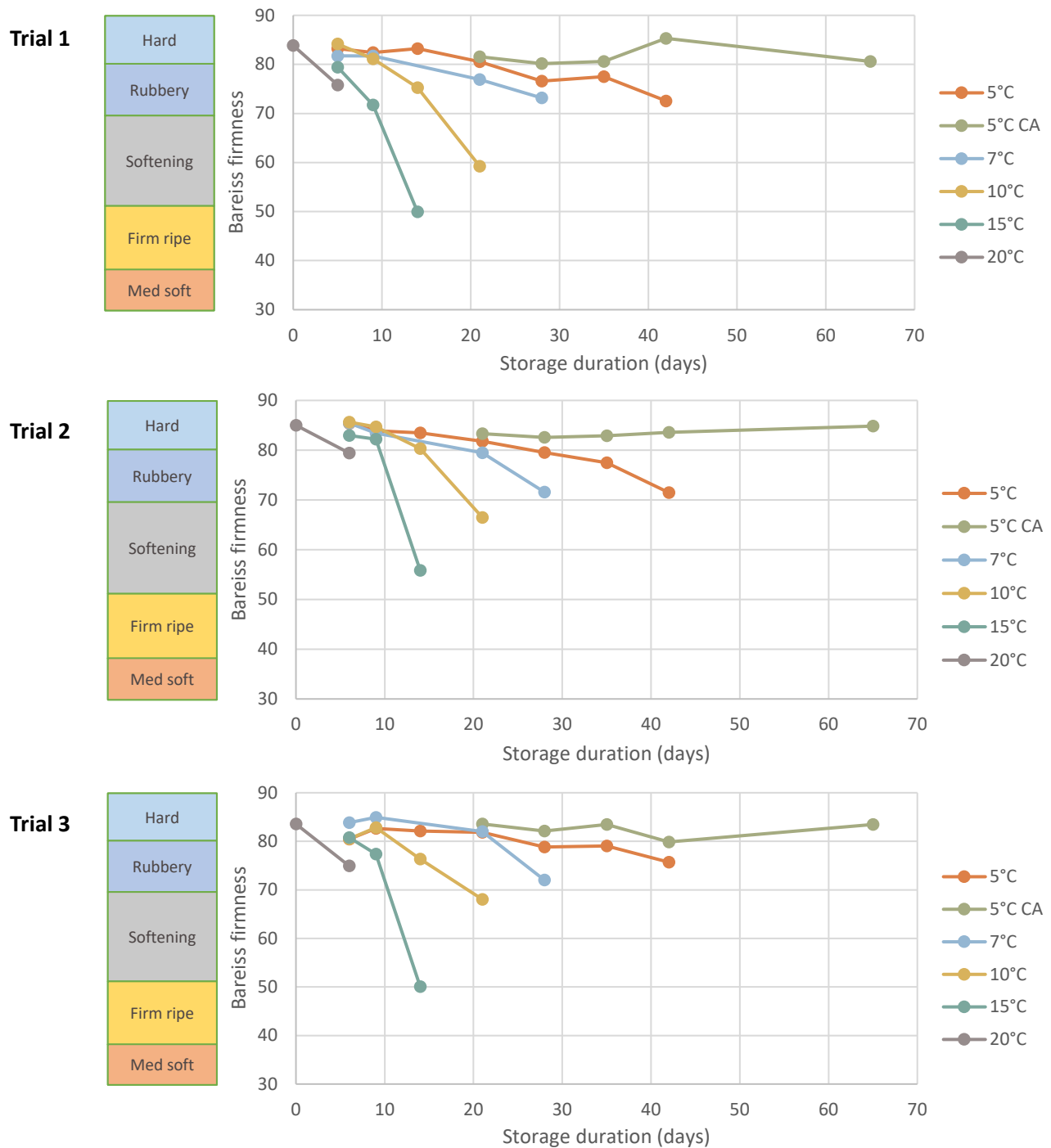


Figure 1. Firmness of 'Hass' avocados under storage conditions (5, 7, 10, 15 and 20 °C), CA refers to controlled atmosphere (2% O₂ and 5% CO₂). Three consecutive harvest trials (Trials 1–3). Side panels indicate the corresponding consumer firmness classes from "Hard" to "Medium-soft."

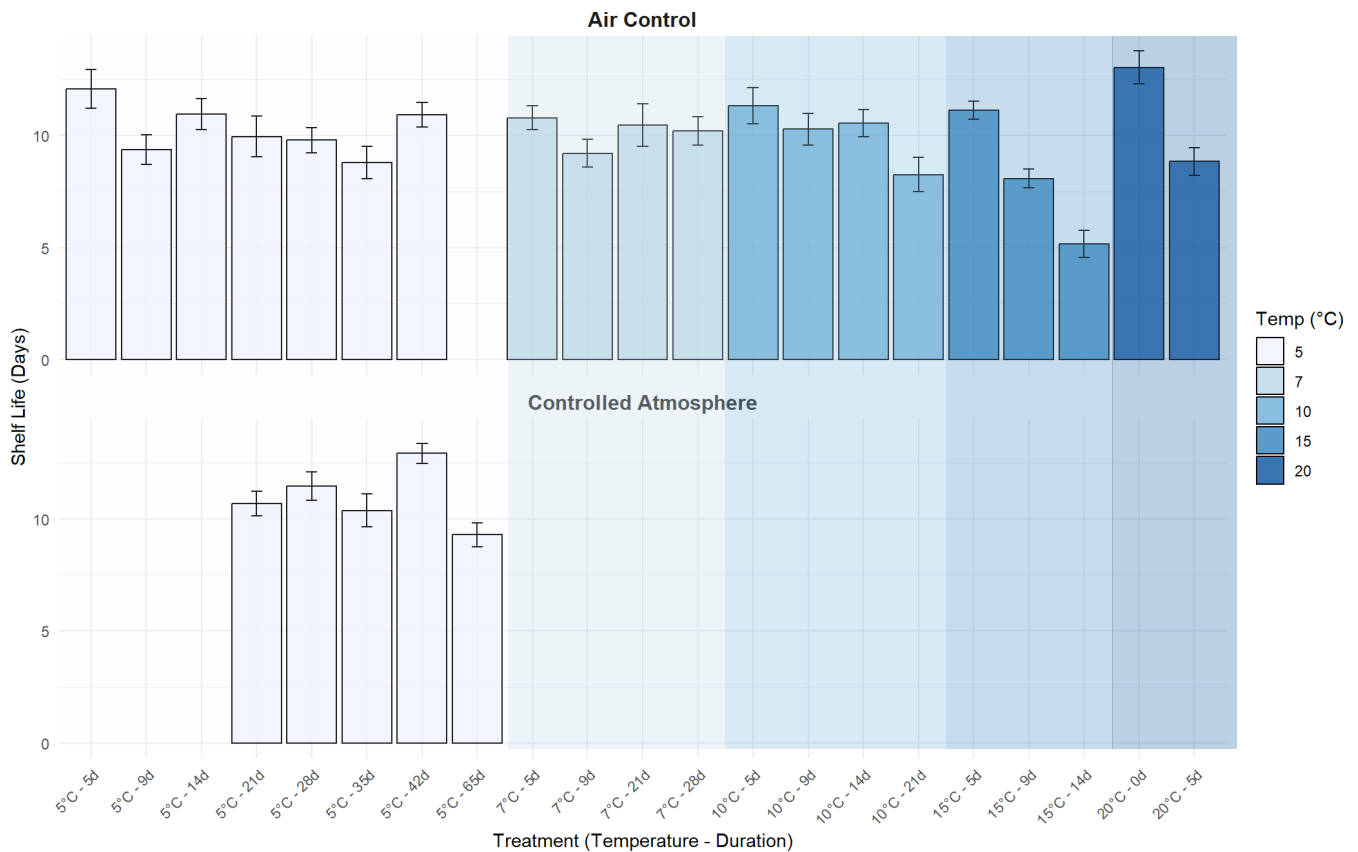


Figure 2. Impact of Storage on Average Shelf Life (Days). Error bars represent Standard Error (SE). Trial 1

5. Shelf Life Performance

The average marketable shelf life for each treatment is presented separately for Trial 1, Trial 2 and Trial 3 in Figure 2, Figure 3 and Figure 4, respectively. Across all three trials, shelf life generally declined with increasing storage duration, particularly at the higher storage temperatures of 10°C and 15°C. In contrast, fruit stored under controlled atmosphere at 5°C generally maintained a longer shelf life than fruit held under air storage, especially at extended storage durations. Although some variation was observed between trials, the overall trend was consistent, indicating that controlled atmosphere storage improved shelf life outcomes while higher temperatures accelerated senescence.

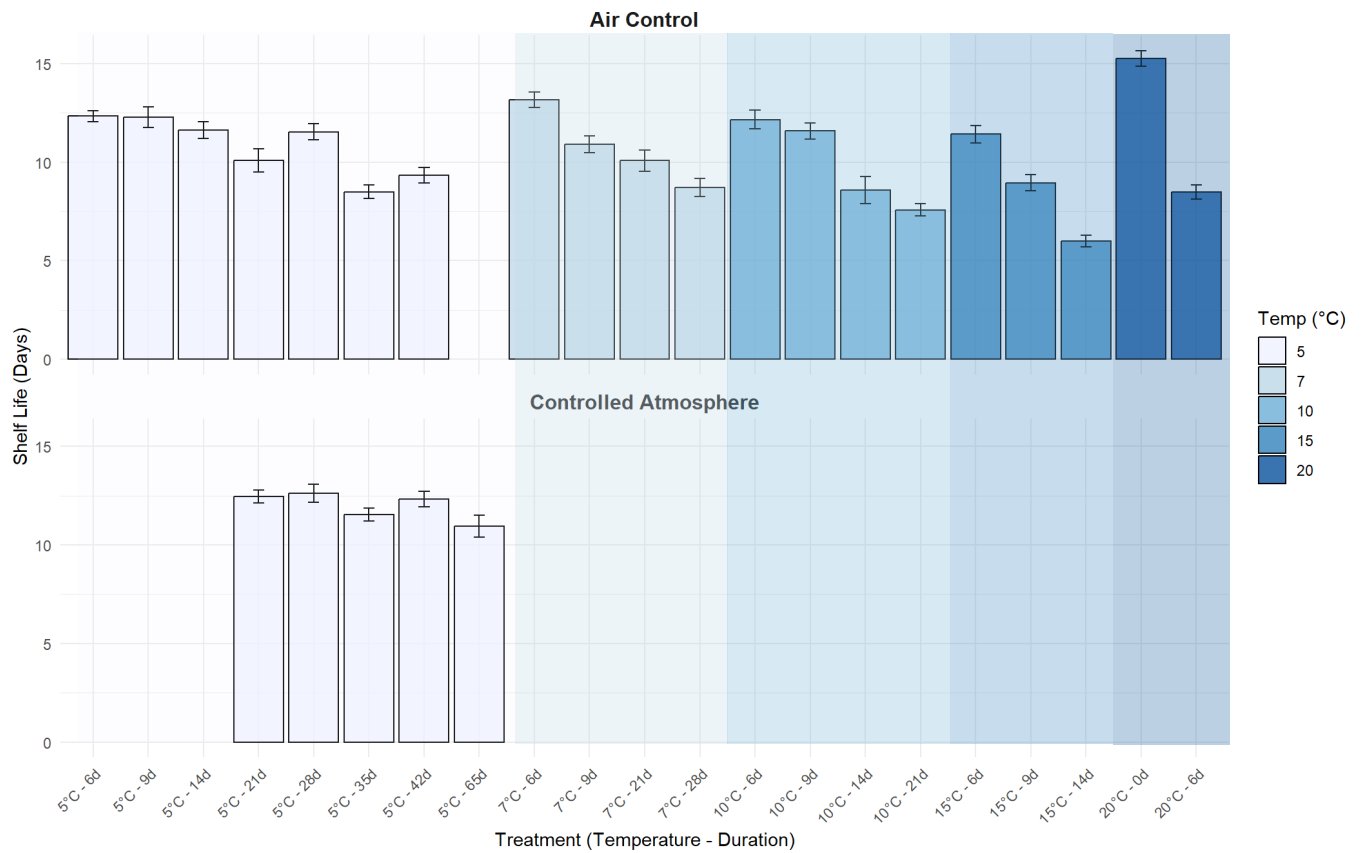
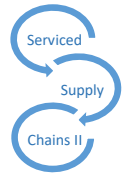


Figure 3. Impact of Storage on Average Shelf Life (Days). Error bars represent Standard Error (SE). Trial 2

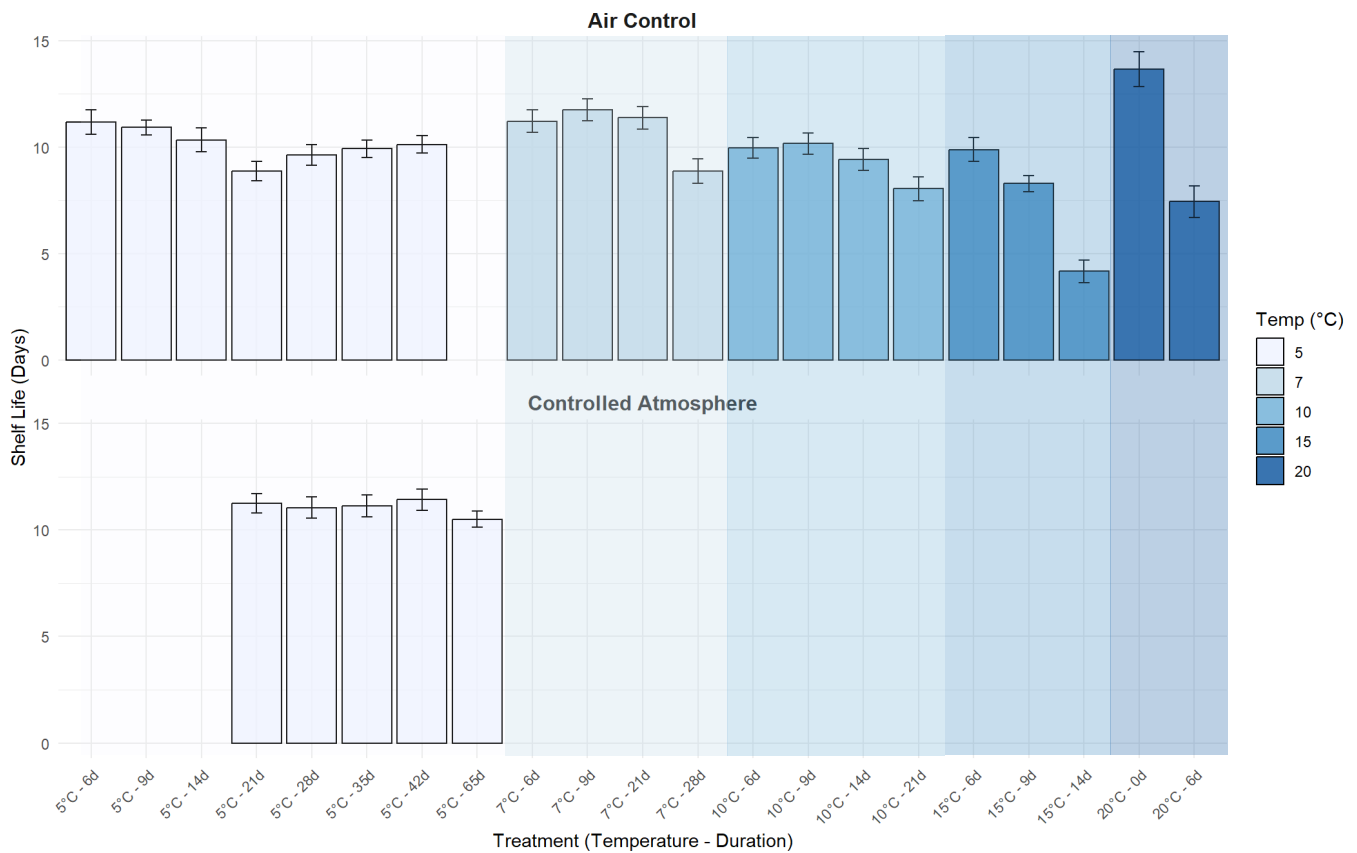
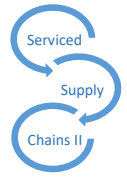


Figure 4. Impact of Storage on Average Shelf Life (Days). Error bars represent Standard Error (SE). Trial 3

6. Chilling Injury: Diffuse Discolouration (DD)

Diffuse discolouration (DD) is a specific manifestation of chilling injury. The severity of DD for each treatment is shown separately for Trial 1, Trial 2 and Trial 3 in Figure 5, Figure 6 and Figure 7, respectively. At temperatures above 5°C, DD was generally low and only appeared at minor levels after extended storage periods. At 5°C under air storage, DD increased markedly at longer storage durations, particularly at 42 days, confirming that chilling injury became more evident under prolonged low-temperature storage without controlled atmosphere. In contrast, fruit held under controlled atmosphere at 5°C showed consistently low DD across all three trials, including the 65-day treatment, demonstrating the protective effect of controlled atmosphere storage against chilling injury.

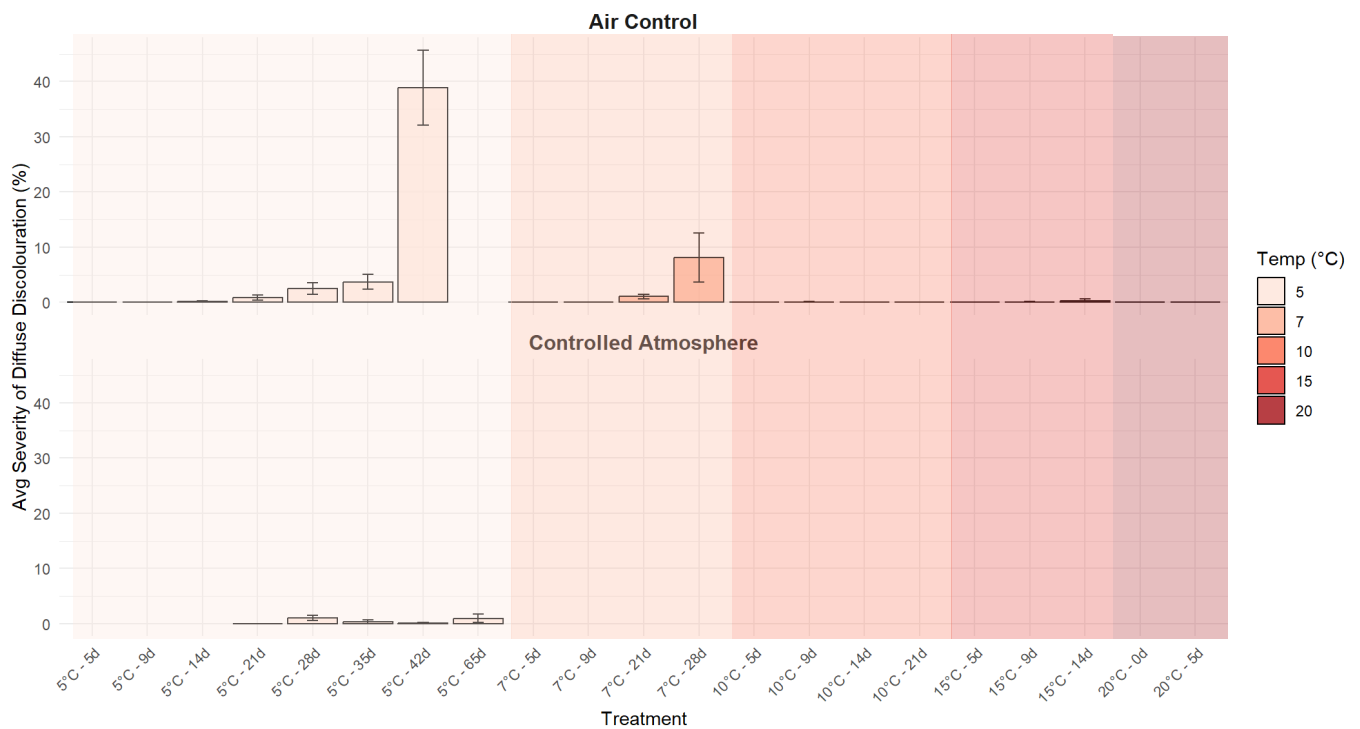


Figure 5. Average Severity of Diffuse Discolouration (Chilling Injury) by Treatment. Trial 1

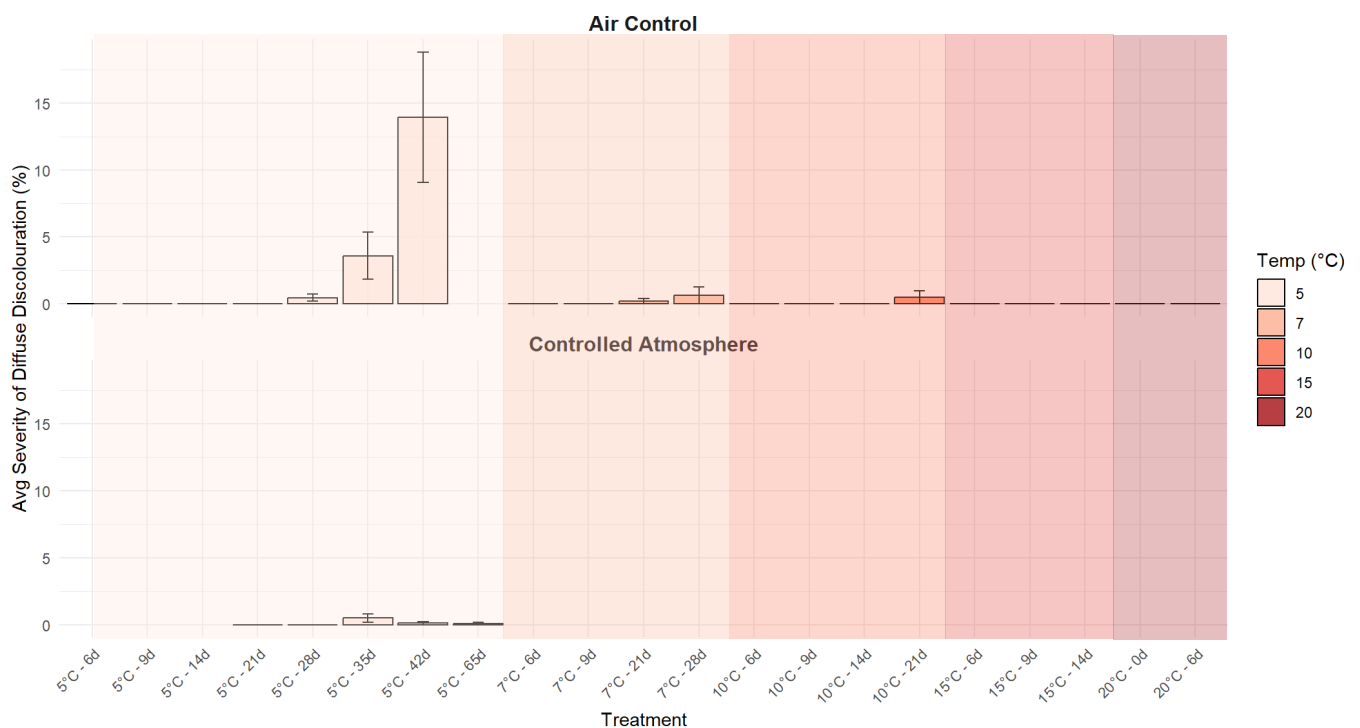


Figure 6. Average Severity of Diffuse Discolouration (Chilling Injury) by Treatment. Trial 2

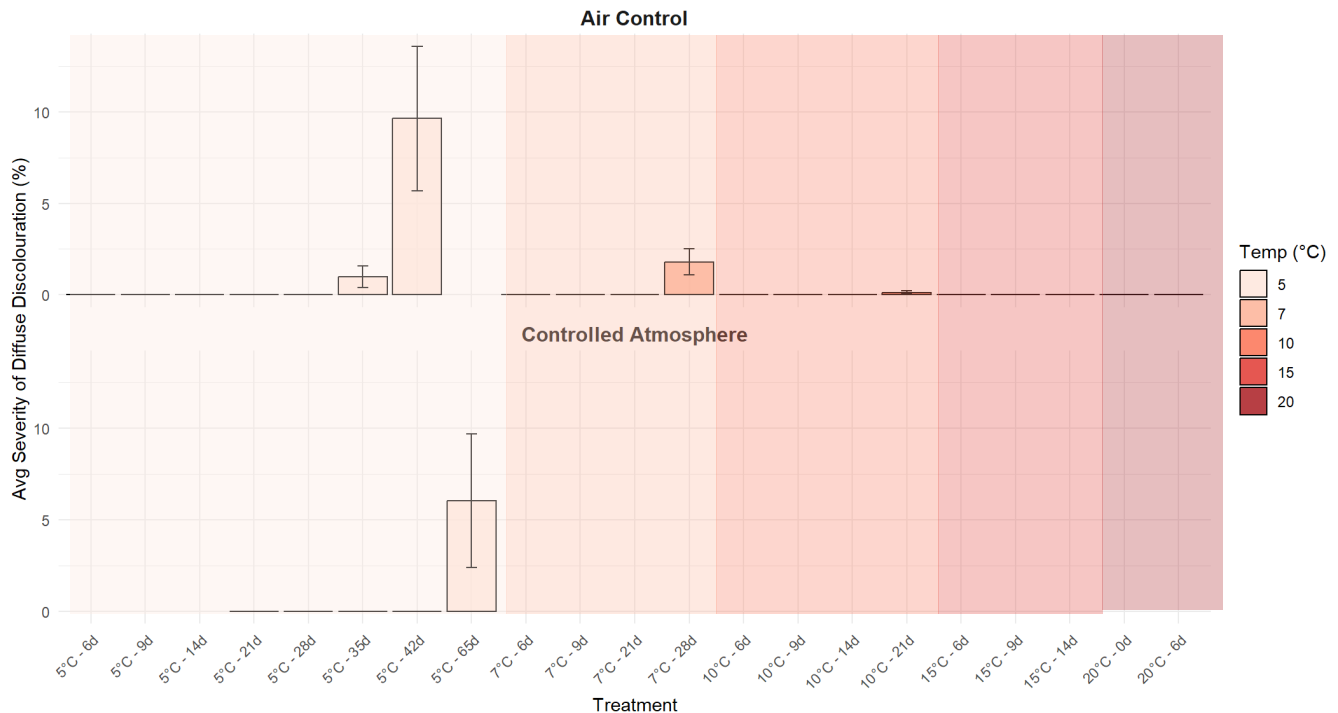


Figure 7. Average Severity of Diffuse Discolouration (Chilling Injury) by Treatment. Trial 3



Figure 8. Representative fruit showing the effect of storage conditions at 5°C. The three fruit on the left were stored under controlled atmosphere, while the three fruit on the right were stored under air conditions (no controlled atmosphere) for 42 days. Fruit stored without controlled atmosphere show increased diffuse discoloration and overall quality degradation compared with controlled atmosphere stored fruit.

7. Defect Severity Analysis (All Defects)

Defect severity reflects the impact of storage conditions and duration on fruit quality. The average defect severity for Trial 1, Trial 2 and Trial 3 is presented in Figure 9, Figure 10 and Figure 11, respectively. Across all trials, total defect severity generally increased with longer storage duration at each temperature. The defect severity figures include a 10% threshold line, which is used as a practical indicator of the point at which fruit quality is likely to become commercially unacceptable to consumers. Total severity comprises body rot, stem-end rot, vascular browning and chilling injury. In general, the storage duration required to exceed the 10% threshold depended strongly on temperature.

The 2025 season was affected by high rainfall, which likely contributed to higher background levels of rot and other defects than are typically observed. In addition, pre-trial handling, including transport of fruit from Western Australia to Cairns prior to storage, may have contributed to baseline defect pressure, even though total transport time was less than 24 hours by air freight.

A notable result was the high defect severity observed in fruit stored under air conditions at 5°C for 42 days in all trials (**Figure 9**, **Figure 10** and **Figure 11**), where substantial chilling injury was recorded in addition to rot-related defects. In contrast, the equivalent controlled atmosphere treatment maintained much lower chilling injury levels. This confirms that controlled atmosphere storage was effective in reducing chilling injury risk at low temperature. However, many long-duration controlled atmosphere treatments still exceeded the 10% threshold due to elevated rot levels, indicating that controlled atmosphere reduced chilling injury but did not fully prevent disease-related quality loss under the high defect-pressure conditions of the 2025 season.

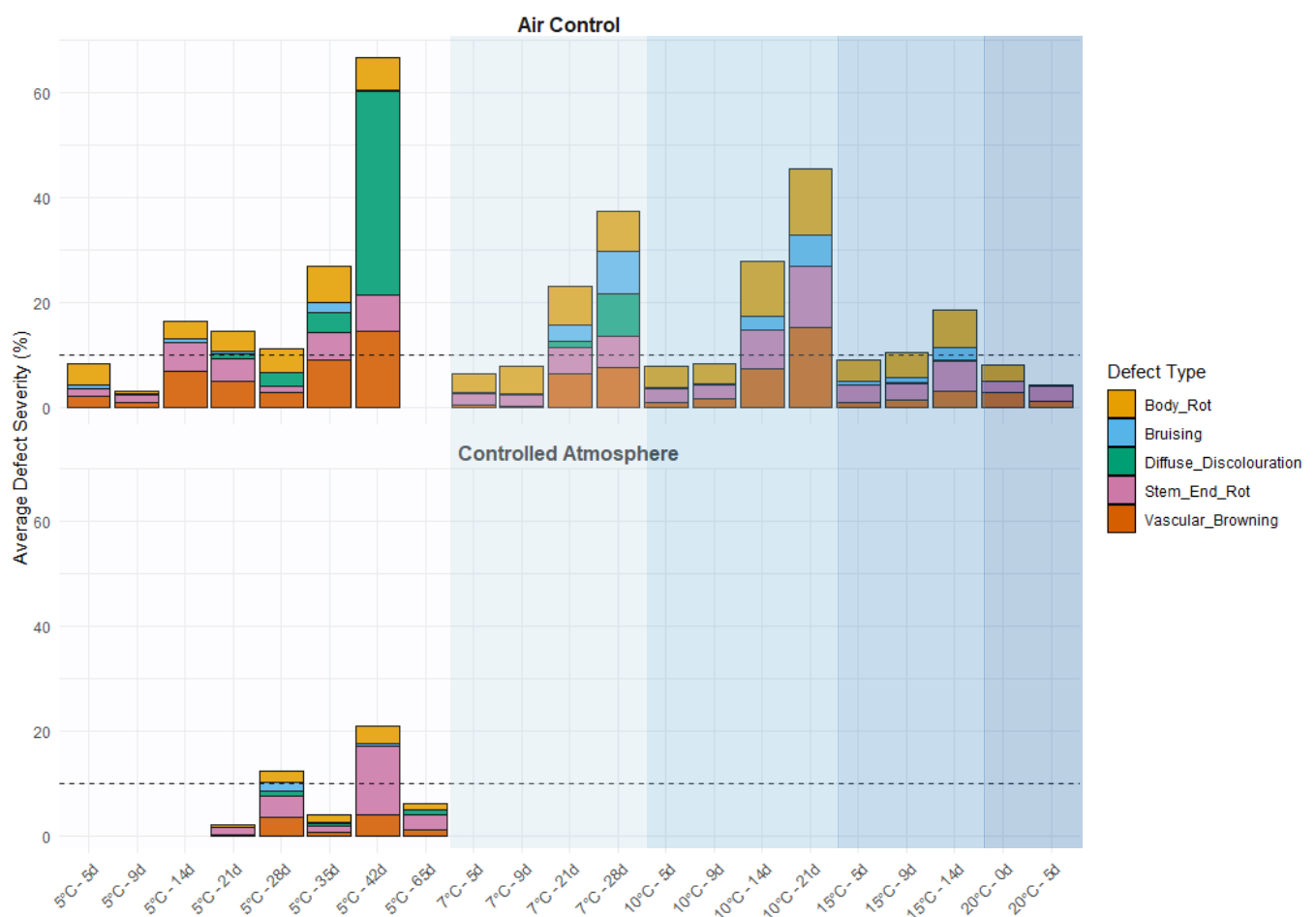


Figure 9. Average Defect Severity (% Flesh Affected). Stacked bars show the contribution of each defect. Trial 1

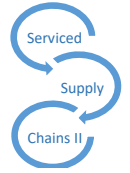


Figure 10. Average Defect Severity (% Flesh Affected). Stacked bars show the contribution of each defect. Trial 2

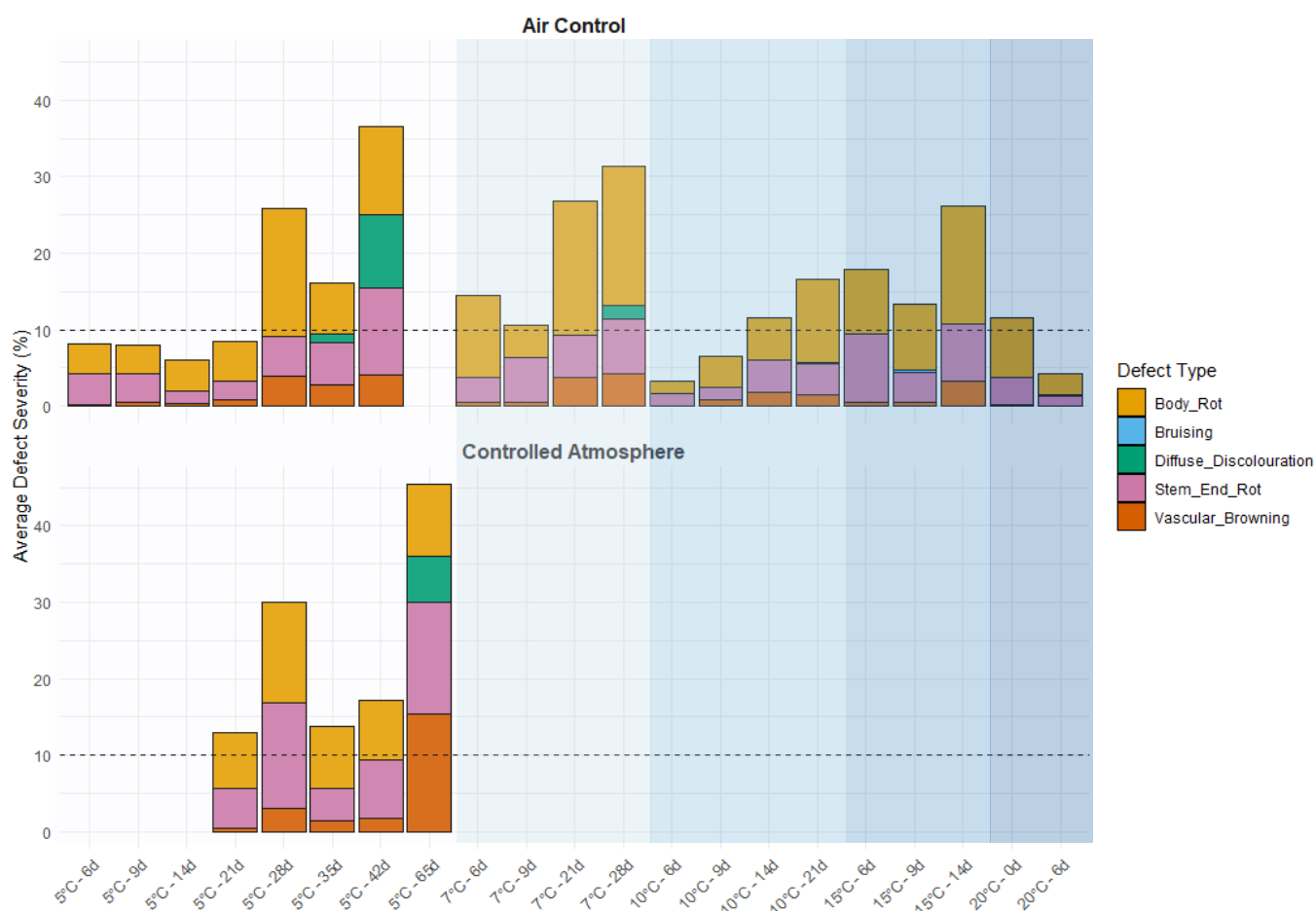


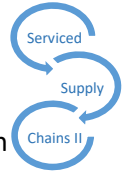
Figure 11. Average Defect Severity (% Flesh Affected). Stacked bars show the contribution of each defect. Trial 3

8. Skin Mineral Composition and Diffuse Discolouration

A sub-sample of fruit was analysed for skin mineral composition at the firm-ripe stage after storage at 5°C for 38–42 days. Fruit were separated into two symptom classes: fruit showing severe diffuse discolouration (DD) and fruit showing no diffuse discolouration symptoms. The purpose of this assessment was to determine whether mineral balance in the skin was associated with the expression of DD following extended low-temperature storage (**Table 2**).

Table 2 Mineral composition of dry skin tissue from ‘Hass’ avocado fruit at firm-ripe stage after storage at 5°C for 38–42 days.

Trial	Harvest	Symptom class	Ca (%)	N/Ca	(Mg+K)/Ca
Trial 1	Jul-25	Severe DD symptoms	0.060	23.7	63.0
Trial 1	Jul-25	No DD symptoms	0.085	10.8	26.4
Trial 2	Oct-25	Severe DD symptoms	0.066	18.4	43.8
Trial 2	Oct-25	No DD symptoms	0.062	13.2	30.6
Trial 3	Nov-25	Severe DD symptoms	0.071	20.4	45.2
Trial 3	Nov-25	No DD symptoms	0.067	11.9	34.6
LSD 5%			n.s.	7.5	18.6



Across all three trials, fruit with severe DD symptoms had higher N/Ca and (Mg+K)/Ca ratios than fruit with no DD symptoms. The average N/Ca ratio was 20.8 in fruit with severe DD compared with 12.0 in fruit with no symptoms. Similarly, the average (Mg+K)/Ca ratio was 50.7 in fruit with severe DD compared with 30.5 in symptom-free fruit. These differences indicate that fruit expressing severe DD tended to have a higher relative concentration of nitrogen, magnesium and potassium in relation to calcium.

Calcium concentration alone was not significantly different between symptom classes, with the LSD test indicating no significant difference for Ca (%). This suggests that DD expression was more closely associated with mineral balance, particularly the ratios involving calcium, rather than calcium concentration alone.

9. Conclusion

A series of export simulation trials were conducted using 'Hass' avocados to assess the impact of supply chain handling and storage conditions on fruit quality and shelf life. Increasing storage duration resulted in higher defect incidence, while storage at temperatures of 10°C and above led to reduced shelf life. Under the conditions of the 2025 season, chilling injury was not observed until approximately 28 days of storage, with fruit becoming commercially unacceptable by 42 days under air storage.

Key Findings

1. Controlled Atmosphere Benefits:
 - Significantly reduces chilling injury (DD)
 - Improves storage outcomes at low temperatures
2. Temperature Effects:
 - 5°C is effective for extending storage but carries CI risk without controlled atmosphere
 - 10–15°C reduces CI risk but accelerates senescence and rot
3. Storage Duration:
 - Increasing storage duration is the primary driver of defect accumulation
 - Risk increases substantially beyond 28–35 days
4. Seasonal Impact:
 - High rainfall in 2025 contributed to elevated baseline defect levels
 - Rot-related defects were prominent across all treatments

Practical Recommendations

- Use controlled atmosphere storage at 5°C for extended storage durations (>28 days)
- Avoid long-term storage (>35–42 days) under air conditions at 5°C
- Limit storage duration at 10–15°C to minimise rapid quality decline
- Consider seasonal conditions when setting storage strategies, particularly in high disease-pressure years



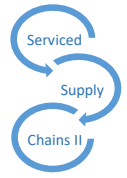
10. Appendix: Mean Data per Trial

The following tables present the raw mean severity and shelf life data, subset by experimental trial and sorted by treatment conditions.

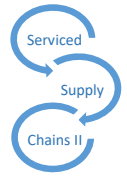
Trial 1 Summary

Table 3. Mean Summary Data: Trial 1

Storage	Treatment	Avg SL (Days)	Total Severity (%)	Body Rot (%)	Stem Rot (%)	Vascular Browning (%)	DD (CI) (%)
Air Control	5°C - 5d	12.1	8	4	2	2	0
Air Control	5°C - 9d	9.4	3	1	2	1	0
Air Control	5°C - 14d	11.0	17	3	5	7	0
Air Control	5°C - 21d	10.0	15	4	4	5	1
Controlled Atmosphere	5°C - 21d	10.7	2	1	1	0	0
Air Control	5°C - 28d	9.8	11	5	1	3	3
Controlled Atmosphere	5°C - 28d	11.5	12	2	4	3	1
Air Control	5°C - 35d	8.8	27	7	5	9	4
Controlled Atmosphere	5°C - 35d	10.4	4	2	1	1	0
Air Control	5°C - 42d	10.9	67	6	7	14	39
Controlled Atmosphere	5°C - 42d	12.9	21	3	13	4	0
Controlled Atmosphere	5°C - 65d	9.3	6	1	3	1	1
Air Control	7°C - 5d	10.8	7	4	2	1	0
Air Control	7°C - 9d	9.2	8	5	2	0	0
Air Control	7°C - 21d	10.5	23	7	5	7	1
Air Control	7°C - 28d	10.2	37	8	6	8	8
Air Control	10°C - 5d	11.3	8	4	3	1	0
Air Control	10°C - 9d	10.3	8	4	2	2	0
Air Control	10°C - 14d	10.5	28	11	7	7	0
Air Control	10°C - 21d	8.3	45	13	12	15	0
Air Control	15°C - 5d	11.1	9	4	3	1	0
Air Control	15°C - 9d	8.1	11	5	3	1	0
Air Control	15°C - 14d	5.2	18	7	6	3	0
Air Control	20°C - 0d	13.0	8	3	2	3	0
Air Control	20°C - 5d	8.8	5	0	3	1	0
Air Control	20°C - 6d	9.0	0	0	0	0	0

*Trial 2 Summary***Table 4.** Mean Summary Data: Trial 2

Storage	Treatment	Avg SL (Days)	Total Severity (%)	Body Rot (%)	Stem Rot (%)	Vascular Browning (%)	DD (CI) (%)
Air Control	5°C - 6d	12.3	10	4	6	1	0
Air Control	5°C - 9d	12.3	14	7	6	1	0
Air Control	5°C - 14d	11.6	18	9	9	1	0
Air Control	5°C - 21d	10.1	15	12	3	0	0
Controlled Atmosphere	5°C - 21d	12.5	17	12	4	1	0
Air Control	5°C - 28d	11.5	34	19	10	4	0
Controlled Atmosphere	5°C - 28d	12.6	29	17	11	2	0
Air Control	5°C - 35d	8.5	18	6	6	1	4
Controlled Atmosphere	5°C - 35d	11.5	31	17	11	2	1
Air Control	5°C - 42d	9.3	37	14	8	1	14
Controlled Atmosphere	5°C - 42d	12.3	35	20	13	3	0
Controlled Atmosphere	5°C - 65d	11.0	23	15	7	1	0
Air Control	7°C - 6d	13.2	15	8	7	1	0
Air Control	7°C - 9d	10.9	9	5	4	0	0
Air Control	7°C - 21d	10.1	20	10	6	3	0
Air Control	7°C - 28d	8.7	29	16	10	3	1
Air Control	10°C - 6d	12.2	16	5	10	1	0
Air Control	10°C - 9d	11.6	14	6	7	1	0
Air Control	10°C - 14d	8.6	26	18	6	2	0
Air Control	10°C - 21d	7.6	26	14	9	3	1
Air Control	15°C - 6d	11.4	15	5	10	0	0
Air Control	15°C - 9d	9.0	11	6	5	0	0
Air Control	15°C - 14d	6.0	28	14	12	2	0
Air Control	20°C - 0d	15.3	12	4	7	0	0
Air Control	20°C - 6d	8.5	10	4	5	1	0



Trial 3 Summary

Table 5. Mean Summary Data: Trial 3

Storage	Treatment	Avg SL (Days)	Total Severity (%)	Body Rot (%)	Stem Rot (%)	Vascular Browning (%)	DD (CI) (%)
Air Control	5°C - 6d	11.2	8	4	4	0	0
Air Control	5°C - 9d	10.9	8	4	4	1	0
Air Control	5°C - 14d	10.3	6	4	2	0	0
Air Control	5°C - 21d	8.9	9	5	3	1	0
Controlled Atmosphere	5°C - 21d	11.3	13	7	5	1	0
Air Control	5°C - 28d	9.6	26	17	5	4	0
Controlled Atmosphere	5°C - 28d	11.0	30	13	14	3	0
Air Control	5°C - 35d	9.9	16	7	6	3	1
Controlled Atmosphere	5°C - 35d	11.1	14	8	4	1	0
Air Control	5°C - 42d	10.1	37	12	11	4	10
Controlled Atmosphere	5°C - 42d	11.4	17	8	8	2	0
Controlled Atmosphere	5°C - 65d	10.5	45	9	15	15	6
Air Control	7°C - 6d	11.2	14	11	3	0	0
Air Control	7°C - 9d	11.8	11	4	6	0	0
Air Control	7°C - 21d	11.4	27	18	6	4	0
Air Control	7°C - 28d	8.9	31	18	7	4	2
Air Control	10°C - 6d	10.0	3	2	2	0	0
Air Control	10°C - 9d	10.2	7	4	2	1	0
Air Control	10°C - 14d	9.4	12	6	4	2	0
Air Control	10°C - 21d	8.0	17	11	4	2	0
Air Control	15°C - 6d	9.9	18	8	9	1	0
Air Control	15°C - 9d	8.3	13	9	4	1	0
Air Control	15°C - 14d	4.2	26	15	7	3	0
Air Control	20°C - 0d	13.7	12	8	4	0	0
Air Control	20°C - 6d	7.4	4	3	1	0	0

Appendix 33

NQ 'Shepard' avocado simulation trials report 2023



Predicting fruit quality and shelf life for 'Shepard' avocado

A 2023 season North Queensland grower report

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Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Shepard' avocados to quantify fruit quality and shelf-life response to a range of supply chain handling scenarios. Commercially mature fruit of sizes 30 were harvested from a farm near Mareeba, Queensland in 2023. The fruit were stored at 3, 5, 7, 10 and 15°C, and 90% relative humidity (RH) for up to 45 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. Also, the influence of controlled atmosphere (CA) storage on fruit quality was evaluated. Key observations included:

- Firmness change in 'Shepard' avocados was strongly affected by storage temperature, with minimal change in firmness occurring in fruit held at 5°C or lower.
- Storage temperature effects on shelf life were negligible following storage at 3-10°C for up to 9,10 days but became more apparent after longer storage periods.
- Skin darkening was a common defect in 'Shepard' avocados at medium soft, worsening with longer storage duration.
- Chilling injury emerged as an issue after 20 days at 3°C, and after approximately 30 days at 7°C or lower.
- Fruit harvested later in the season exhibited increased instances of skin darkening.
- Susceptibility to internal chilling injury varied substantially between blocks.

Data from this trial will be used to generate shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

- Develop predictive shelf-life models for a range of fresh horticultural produce.
- Apply the models to develop decision aid tools and updated handling guidelines.
- Establish an information portal that facilitates access to the decision aid tools.

The current report covers export simulation trial work completed during the 2023 'Shepard' avocado season on fruit grown in North Queensland. The main objective of the trials was to quantify the fruit quality and shelf-life response of 'Shepard' avocados to various supply chain conditions. The trials also investigated a wide range of factors affecting fruit quality and shelf life, including controlled atmosphere storage and fruit maturity (dry matter). Data generated from the trials will assist in developing fruit quality and shelf-life prediction models.

2. Materials and methods

Commercially mature 'Shepard' avocado fruit (targeting dry matter >21%) were sourced for trials during the 2023 season. Fruit were harvested on 6/2/23 and 5/3/23 from a farm located near Mareeba, Queensland. The fruit were transferred to a nearby packing house within 24 hours. They were treated with a fungicide, sorted by size and quality, and packed into cardboard trays. Count 30 fruit were used in the trials. Packed fruit were transported to the postharvest laboratory at the Cairns Research Facility in an air-conditioned car at 22-25°C within 3 hours and kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. All trial fruit were grouped by NIR predicted DM values. The fruit was sorted by DM and then assigned evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. All treatments were applied to a single tray of 20 fruit. A subset group at 5°C was stored with or without a controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Fruit within this trial were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C for ongoing assessment.

The air temperature adjacent to fruit was monitored from the time of collection at the pack shed to removal from the storage temperatures to calculate time x temperature units (TTU). Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.



Table 1. Time x temperature matrix used to simulate supply chain handling of 'Shepard' avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	2	5	10	20	30	45
Block A 6/2/23							
3			x	x	x	x	
5			x	x	x	x	x
5+CA					x	x	x
7		x	x	x	x	x	
10			x	x	x	x	
15			x	x			
20	x						
	0	2	5	9	20	29	44
Block B 5/3/23							
3			x	x	x	x	
5			x	x	x	x	x
5+CA					x	x	x
7		2	x	x	x	x	
10			x	x	x	x	
15			x	x			
20	0						

CA: Controlled atmosphere treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

At trial commencement, all fruit were weighed, and firmness was measured for 120 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with a 5mm spherical tip and 1 second readings. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf-life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm soft (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium soft (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury, and %SA of skin darkening. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discoloration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit had an average oven DM of 22.3% for the first harvest and 24.8% for late harvest.



Firmness changes in storage treatments

Changes in fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to medium soft stage within around 11 days. Storage at cooler temperatures progressively slowed ripening. Fruit maintained at 5°C were found to remain slightly firmer than those at 3°C. In these samples, the firmness change was minimal, with fruit remaining firm after 29 days. Slightly higher temperatures of 7 to 10°C did not substantially change firmness over short durations, but rapid softening occurred later in storage, particularly after 20 days.

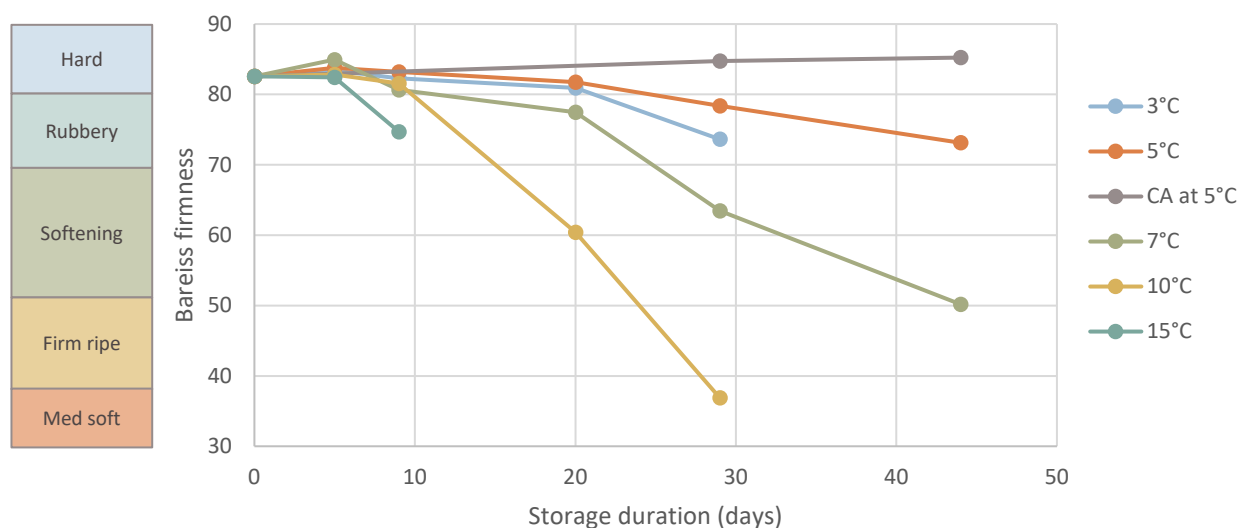


Figure 1. Changes in fruit firmness ‘Shepard’ avocados (Block B) during storage at various temperatures.

Firmness changes during shelf-life assessment

Fruit kept constantly at 20°C reached the firm soft stage after an average of 6.2 days (Figure 2 and Figure 3). After storage at 3°C, fruit took an average of 6-8 days at 20°C to reach firm soft, regardless of previous storage duration. At temperatures of 5°C and higher, longer duration storage and warmer storage temperatures tended to hasten subsequent softening to firm soft at 20°C. In Figure 3, it is observed that the fruit stored at 3°C for 29 days exhibited a shelf life exceeding 7 days when subsequently stored at 20°C. Conversely, fruits stored at 5°C, 7°C, and 10°C for the same duration demonstrated shelf lives of 4.7 days, 4.9 days, and 0.5 day, respectively, at 20°C. It was observed that prolonged storage periods adversely affect the shelf life of fruits. Specifically, when fruits were stored at 10°C for a duration of 5 days, the subsequent shelf life at 20°C was recorded at 6.3 days for Block A and 7.9 days for Block B. However, extending the storage period to 30 days resulted in a significant reduction in shelf life at 20°C, dropping to just 1.7 days for Block A and a mere 0.5 days for Block B. This represents a reduction in shelf life at 20°C of over 4 days for both storage blocks, highlighting the impact of extended storage at higher temperatures on fruit longevity. CA treatment effectively preserved fruit firmness throughout the storage period, with fruits stored for 44 days exhibiting a Bareiss firmness rating of 85. This preservation of firmness under CA conditions was also observed in the extension of shelf life, where CA treatment resulted in an average increase of 1.2 days in Block A and 1.7 days in Block B. These results underscore the efficacy of CA treatment in enhancing both the physical firmness and the shelf life of the stored fruit (Figure 1, Figure 2 and Figure 3).

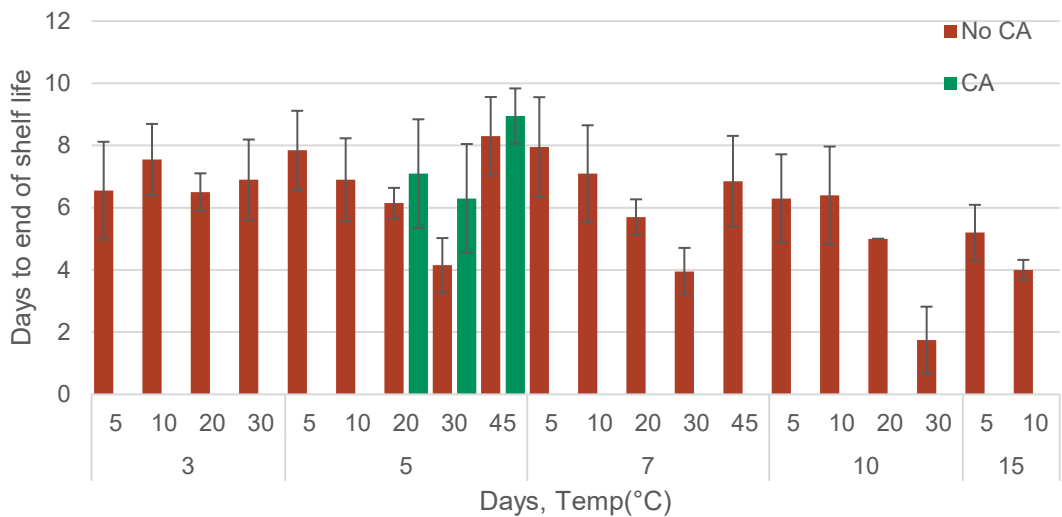


Figure 2. Days taken for ‘Shepard’ avocados (Block A) to reach firm soft stage after various storage treatments.

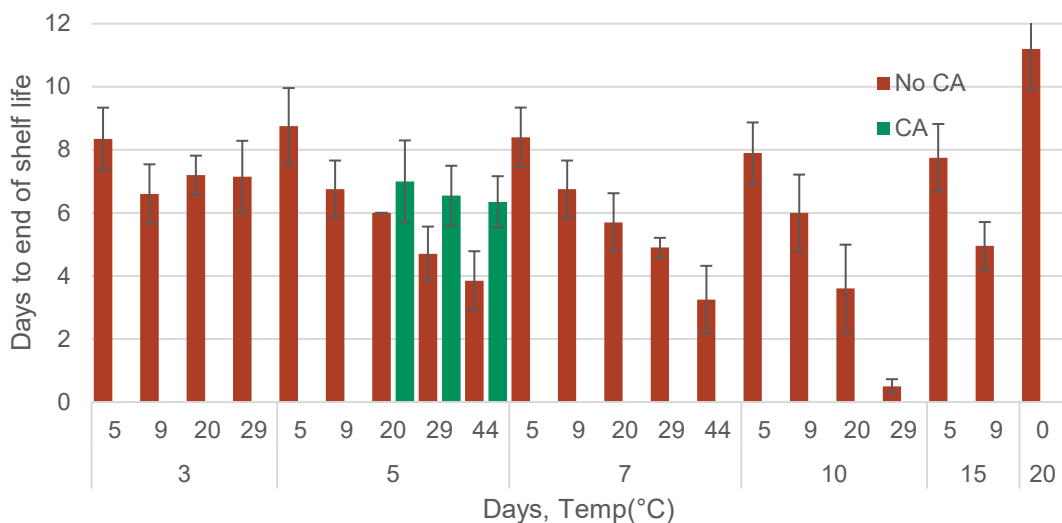


Figure 3. Days taken for ‘Shepard’ avocados (Block B) to reach firm soft stage after various storage treatments.

Skin darkening

The development of skin darkening was seen, with 3.5% of trial fruit showing symptoms exceeding 5% SA from Block A and 19% from Block B. Skin darkening was difficult to distinguish from skin chilling injury and was observed in fruit across all storage temperatures. Skin darkening was particularly prevalent after storage periods of 20 days or longer (Table 2). After storage for 45 days most fruit showed substantial skin darkening, affecting 35% of the fruit surface on average.



Figure 4. Skin darkening symptoms on ‘Shepard’ avocado.



Table 2. Incidence of skin darkening exceeding 5% SA in 'Shepard' avocados at medium soft stage, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage				
	5	10	20	30	45
Block A 6/2/23					
3	0	0	0	20%	
5	0	0	0	5%	7.5%
7	0	0	0	0	40%
10	0	0	0	0	
15	0	0			
20	0				
Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage				
	5	9	20	29	44
Block B 5/3/23					
3	0%	5%	15%	35%	
5	5%	10%	10%	28%	48%
7	15%	0%	35%	75%	65%
10	15%	10%	10%	5%	
15	5%	10%			
20	0%				



Skin chilling injury

Chilling injury on the fruit skin was characterised by mottled, sunken areas, with a notable prevalence around the lenticels. This condition was observed in trial fruit stored for 20 days or longer. Predominantly, skin chilling injury was evident in fruit subjected to extended storage periods (44 days Block B), at temperatures of 5°C and 7°C. It affected 27% of the fruit skin at 5°C and 14% of the fruit skin at 7°C. Block A experienced more severe skin chilling injuries compared to Block B (Table 3).

Table 3 Severity of Skin Chilling Injury after various storage conditions

Temp	Duration (days)	Skin chilling injury severity (% SA)	
		Block A	Block B
3°C	5	0%	0%
	10,9	0%	1%
	20	13%	3%
	30,29	31%	5%
5°C	5	0%	1%
	10,9	0%	1%
	20	6%	6%
	30,29	10%	5%
	45, 44	54%	27%
CA 5°C	20	1%	0%
	30	0%	2%
	45, 44	4%	1%
7°C	5	0%	1%
	10,9	0%	0%
	20	0%	0%
	30,29	3%	3%
	45, 44	17%	14%
10°C	5	0%	0%
	10,9	0%	0%
	20	0%	2%
	30,29	1%	1%
15°C	5	0%	0%
	10	0%	0%
20°C	0	0%	0%

Internal chilling injury

Possible symptoms of internal chilling damage were first observed in fruit stored for 20 days, particularly at 3°C. Light grey-brown vascular discolouration typically originating from the base of the seed was the thought to be the first sign of internal chill damage / long storage deterioration. More severe chill damage was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed.

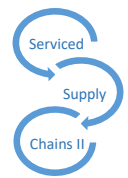


Figure 5. Symptoms observed in 'Shepard' avocados associated with chilling damage.

Chilling injury worsened with longer storage durations and lower temperatures. Significant internal chilling injury occurred after 20 days at 3°C, while slight chilling injury occurred at 5°C or 7°C. Storage for 30 days or longer at 7°C or lower resulted in significant internal damage (Table 4).

Table 4 Incidence and severity of internal chilling injury in medium soft 'Shepard' avocados after various storage conditions

Temp	Duration (days)	Internal chilling injury severity (% vol)		Internal chilling injury incidence > 0.05% (%)	
		Block A	Block B	Block A	Block B
3°C	5	0%	0%	0%	0%
	10,9	2%	0%	10%	0%
	20	11%	1%	35%	0%
	30,29	31%	17%	70%	45%
5°C	5	0%	0%	0%	0%
	10,9	0%	0%	0%	0%
	20	1%	0%	5%	0%
	30,29	0%	0%	0%	0%
	45,44	24%	2%	50%	5%
CA 5°C	20	0%	2%	0%	10%
	30	2%	1%	5%	5%
	45,44	26%	9%	45%	40%
7°C	2	0%	0%	0%	0%
	5	0%	0%	0%	0%
	10,9	0%	0%	0%	0%
	20	0%	3%	0%	5%
	30,29	7%	3%	25%	10%
10°C	5	0%	0%	0%	0%
	10,9	0%	0%	0%	0%
	20	0%	0%	0%	0%
	30,29	0%	0%	0%	0%
15°C	5	0%	0%	0%	0%
	10	0%	0%	0%	0%
20°C	0	0%	0%	0%	0%



Rots

Storage treatments extending 30 days or more resulted in a higher percentage of fruit exhibiting defects exceeding 10%. The levels of rot and stem end rot were low in assessed fruit. On average, fruit from Block A, harvested on 6 February 2023, displayed a greater incidence of fruit with defects surpassing the 10% threshold compared to Block B, harvested on 5 March 2023. This comparison underscores the variability in defect rates in fruit from different blocks.



Table 5 Incidence and Severity of Rots and Fruit with Greater than 10% Defects in Medium-Soft ‘Shepard’ Avocados Under Various Storage Conditions.

Temp	Duration (days)	Body rot severity (% vol)		Body rot incidence (%)		Stem end rot severity (% vol)		Stem end rot incidence (%)		Fruit with >10% defects (%)	
		Block A	Block B	Block A	Block B	Block A	Block B	Block A	Block B	Block A	Block B
3°C	5	0%	0%	20%	0%	1%	0%	25%	0%	0%	0%
	10,9	1%	0%	20%	15%	3%	0%	40%	15%	20%	0%
	20	0%	1%	0%	50%	0%	0%	5%	50%	25%	0%
	30,29	6%	1%	50%	45%	4%	1%	30%	45%	65%	50%
5°C	5	0%	1%	10%	30%	1%	2%	5%	30%	5%	5%
	10,9	0%	0%	10%	20%	0%	0%	0%	20%	0%	0%
	20	0%	1%	10%	35%	1%	1%	15%	35%	5%	0%
	30,29	0%	1%	10%	45%	1%	0%	10%	45%	5%	5%
	45,44	1%	2%	40%	15%	1%	1%	15%	15%	50%	15%
CA 5°C	20	0%	0%	0	15%	0%	0%	0.1	15%	0%	5%
	30	0%	0%	15%	15%	2%	0%	20%	15%	20%	0%
	45,44	2%	0%	35%	25%	4%	0%	60%	25%	55%	25%
7°C	2	0%	1%	0%	30%	1%	0%	5%	30%	5%	0%
	5	0%	1%	5%	25%	1%	0%	10%	25%	0%	0%
	10,9	0%	1%	5%	45%	1%	1%	25%	45%	0%	0%
	20	0%	0%	25%	65%	1%	2%	25%	65%	5%	0%
	30,29	6%	1%	75%	55%	3%	0%	50%	55%	55%	15%
10°C	5	1%	3%	15%	55%	1%	0%	30%	55%	0%	5%
	10,9	0%	0%	5%	35%	0%	2%	5%	35%	0%	10%
	20	1%	1%	20%	45%	0%	0%	5%	45%	5%	0%
	30,29	1%	1%	25%	40%	1%	2%	15%	40%	5%	10%
15°C	5	0%	1%	0%	50%	0%	1%	10%	50%	0%	10%
	10	1%	1%	15%	50%	1%	1%	20%	50%	0%	5%
20°C	0	2%	1%	0%	35%	0%	2%	20%	35%	2%	5%

Note: The parameter “Fruit with >10% defects (%)” encompasses the total flesh defects combined, which include rot, stem end rot, bruising, and chilling damage. This comprehensive measure provides an aggregate view of the quality impact factors, facilitating a holistic assessment of fruit condition post-storage.



Consumer tolerance

Fruit was considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010).

4. Summary and recommendations

- Dry matter content may have been factor in determining fruit quality, with harvested fruit showing average dry matter of 22.3% and 24.8% for early and late harvests, respectively.
- Fruit harvested from Block A exhibited greater internal and skin chilling injury at low temperatures compared to fruit from Block B
- Storage temperature significantly influenced the rate of firmness change in avocados, with cooler temperatures slowing the ripening process.
- Storage at 5-7°C would be recommended for the best overall quality and shelf life in 'Shepard' avocados.
- Storage for up to 20 days was possible with minimal loss of quality if fruit was stored at or below 7°C.
- Acceptable internal quality could be maintained for up to 30 days at 5°C for fruit, but skin darkening at medium soft and minor internal chilling injury were observed after this period.
- CA storage extended shelf life and effectively maintained fruit firmness during the storage period. However, in this trial, CA storage did not significantly reduce incidences of rot or mitigate chilling injuries.
- Quality issues such as susceptibility to rot or chilling can vary substantially with factors such as maturity, season and weather conditions. Further trials would be recommended to confirm these findings across a greater variety of conditions.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

6. Reference

Gamble, J., Harker, F.R., Sara, R.J., White, A., Bava, C., Beresford, C., Stubbings, B., Wohlers, M., Hofman, P.J., Marques, P., Woolf, A. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* 57, 35–43.

Appendix 34

CQ 'Shepard' avocado simulation trials report 2023a

Predicting fruit quality and shelf life for 'Shepard' avocado

A 2023 season Central Queensland grower report

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Department of Agriculture and Fisheries

Summary

A series of export simulation trials were completed with 'Shepard' avocados to quantify fruit quality and shelf life response to a range of supply chain handling scenarios. Commercially mature fruit of 2 different sizes were harvested from a farm near Childers, Queensland in 2023. The fruit were stored at 3, 5, 7, 10 and 15°C and 90% relative humidity (RH) for up to 45 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. The influence of controlled atmosphere (CA) storage on fruit quality was also evaluated. Key observations included:

- Firmness change in 'Shepard' avocados was strongly affected by storage temperature, with minimal change in firmness occurring in fruit held at 5°C or lower.
- Storage temperature effects on shelf life were negligible following storage at 3-10°C for up to 11 days, but became more apparent after longer storage periods.
- In this trial, large avocados took slightly longer to reach firm soft and had slightly longer shelf life than small avocados.
- Skin darkening was a common defect in 'Shepard' avocados at medium soft, worsening with longer storage duration.
- Chilling injury emerged as an issue after 20 days at 3°C, and after 32 days at 7°C or lower.
- Large avocados were more prone to skin darkening and chilling injury.
- For small fruit, acceptable internal quality was maintained for up to 11 days at 3°C, 20 days at 7°C and 32 days at 5°C.
- For large fruit internal quality remained acceptable after 20 days at 5°C.
- CA extended shelf life by around 1 day and tended to reduce skin darkening compared with air.
- However, CA increased the incidence of shrivel at medium soft.
- Simple linear regression models showed a moderate fit to the data, but more complex modelling will likely provide better predictions of shelf life.

Data from this trial will be used to generate shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2023 'Shepard' avocado season with fruit grown in Central Queensland. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Shepard' avocados to various supply chain conditions. The trials also investigated a wide range of factors affecting fruit quality and shelf life, including controlled atmosphere storage, fruit maturity (dry matter) and fruit size. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Shepard' avocado fruit (targeting dry matter >21%) were sourced for trials during the 2023 season. Fruit were harvested on 21 March 2023 from a farm near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the same day. On the following day, they were treated with a fungicide, sorted by size and quality, and packed into cardboard trays. Large (count 20) and small (count 28) fruit were used in the trial. Packed fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car at ca. 22-25°C within 3 hours and kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 large and 20 small fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. All treatments were applied to a single tray of 20 small (count 28) fruit. Selected treatments were also applied to a tray of 20 large (count 20) fruit. A subset group at 5°C was stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Fruit within this trial were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored from the time of collection at the pack shed to removal from the storage temperatures to calculate time x temperature units (TTU). Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Shepard’ avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage				
3		5	11	20	32
5		5	11	20 ^L	32 ^L 45 ^L
5+CA				20 ^L	32 ^L 45 ^L
7	2 ^L	5	11	20	32
10		5	11	20	32
15		5	11		
20	0 ^L	5 ^{L*}	11 ^{L*}		

^L Indicates treatments were applied to trays of small and large fruit, while other treatment were only applied to small fruit

*Indicates these treatments were the same fruit from the 0 day 20°C tray remeasured after 5 and 11 days at 20°C and 65% RH
CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

At trial commencement all fruit were weighed and firmness was measured in 120 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm soft (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium soft (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury, the incidence of severe shrivel, and % surface area (SA) of skin darkening. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit had an average oven DM of 23.2% for small fruit and 23.0% for large fruit. While these values were very similar, the distribution of the values differed. The small fruit values were skewed towards the lowest end of the range, with 25% fruit having DM <21%. In contrast the large fruit showed a normal distribution, with only 10% of large fruit having DM <21%. The relationships between NIR predicted DM and oven DM were poor in this trial, averaging $R^2=0.33$ (data not shown). Small and large fruit showed slightly different responses in some quality traits.

Weight loss

Fruit weight loss at cold removal tended to increase with storage time and temperature. For all treatments at 15°C or lower, weight loss remained less than 4% for up to 32 days (data not shown). Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Small fruit lost an average 6.7% of their weight after 5 days at 20°C and 13.3% at 11 days. After 45 days at 5°C air-stored small fruit had lost

5.4% of their initial weight. Large fruit weight loss tended to be slightly lower than in small fruit. This was likely due to higher SA : volume ratio in smaller fruit.

Firmness changes in storage treatments

Changes in small fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to medium soft stage within around 10 days. Storage at cooler temperatures progressively slowed ripening. At 3 to 5°C, firmness change was minimal, with fruit remaining hard after 32 days. Slightly higher temperatures of 7 to 10°C did not substantially change firmness over short durations, but rapid softening occurred later in storage, particularly after 20 days. Plots of firmness measured at removal in large fruit were very similar to small fruit (data not shown).

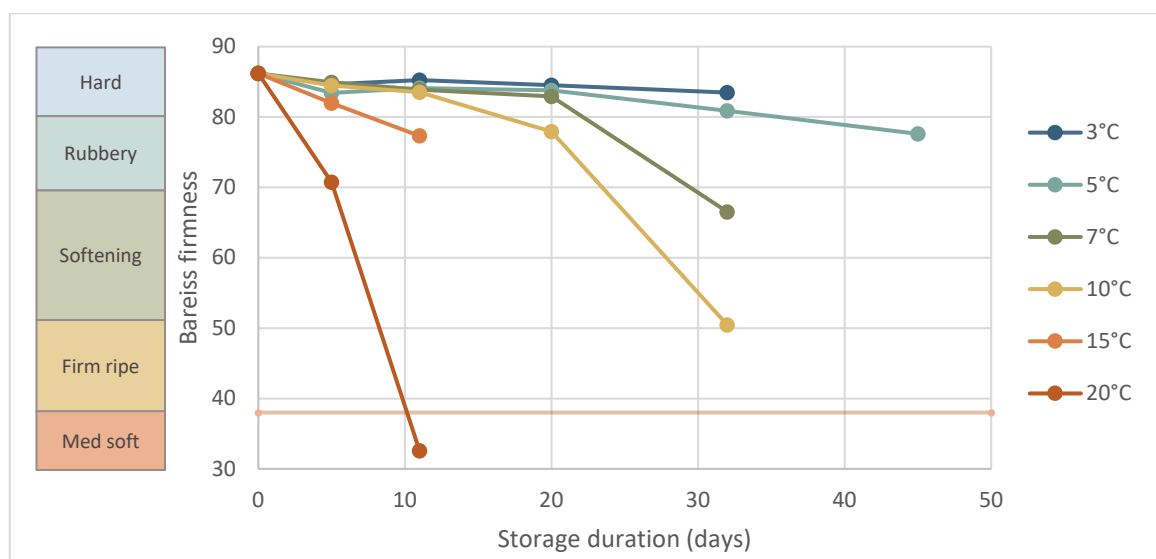


Figure 1. Changes in fruit firmness of small (count 28) 'Shepard' avocados during storage at various temperatures

Firmness changes during shelf life assessment

Small fruit kept constantly at 20°C reached firm soft stage after an average 8.5 days (Table 2). After storage at 3°C, fruit took an average of 5-6 days at 20°C to reach firm soft, regardless of previous storage duration. At temperatures of 5°C and higher, longer duration storage and warmer storage temperatures tended to hasten subsequent softening to firm soft at 20°C.

Table 2. Days taken for small 'Shepard' avocados to reach firm soft stage after various storage treatments

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
	0	2	5	11	20	32
3			6.2	5.1	5.2	6.4
5			6.5	5.3	4.7	3.7
7		8.0	6.7	5.2	3.9	2.5
10			6.5	4.9	3.6	0.6
15			5.7	3.0		
20	8.5		3.5			

Large 'Shepard' avocados took slightly longer to reach firm soft than small sized fruit (Table 3). Analysis of paired small and large treatments by two factor ANOVA showed a significant fruit size effect.

Table 3. Comparing large and small ‘Shepard’ avocados for days taken to reach firm soft stage after various storage treatments

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	2	20	32	45
5	Small			4.7	3.7	4.1
5	Large			4.7	4.8	5.4
7	Small		8.0			
7	Large		9.0			
20	Small	8.5				
20	Large	8.8				

Fruit took an average of 1.6 days to ripen from firm soft to medium soft. At 20°C, observed rates of firmness change suggest that one day after reaching medium soft the fruit would tend to be oversoft and unmarketable.

Shelf life

Quality traits measured at medium soft stage were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots exceeded 10% flesh volume. Over-softening was the key reason for fruit reaching ESL, with less than 1% of fruit in the current trial reaching ESL due to rots.

The shelf life of fruit kept constantly at 20°C averaged 11.2 days for small fruit (Table 4). Shelf life tended to progressively decline with increasing duration of storage, and to be lost more rapidly at higher storage temperatures (Figure 2). After short storage periods, shelf life did not differ substantially across temperatures ranging from 3 to 10°C. Storage temperature impacts on shelf life became more apparent after longer storage durations.

Fruit stored at 3°C showed a slight upward trend in shelf life after 20 to 32 days. This was associated with inhibition of normal ripening due to chilling injury. These fruit had significant internal chilling damage, but were assessed as reaching ESL later as they remained firm.

Table 4. Remaining shelf life (days at 20°C) of small ‘Shepard’ avocados after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	2	5	11	20	32	45
3			8.0	7.7	8.1*	9.4*	
5			8.8	7.6	7.3	6.9*	6.6*
7		10.7	9.4	7.6	6.4	5.1*	
10			9.2	7.2	6.4	3.7	
15			8.4	6.0			
20	11.2		6.2	0.2			

* Indicates treatments with internal chilling damage incidence >10%

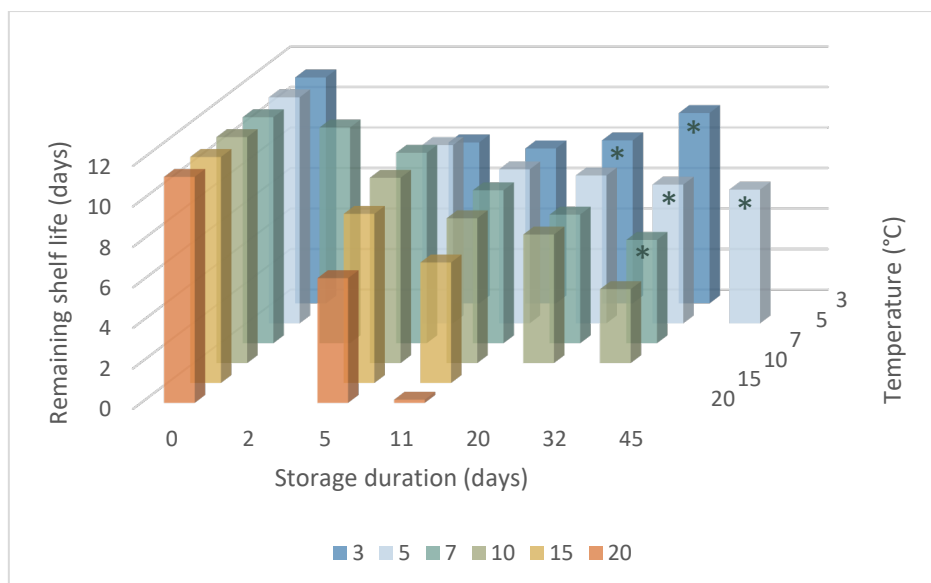


Figure 2. Remaining shelf life at 20°C of small 'Shepard' avocados after storage at various temperatures (* Indicates treatments with internal chilling damage incidence >10%)

Large fruit tended to have slightly longer shelf life than small fruit, averaging 0.9 days longer (Table 5). The shelf life of large fruit remained stable at around 8 days following 5°C storage, regardless of the duration of storage, from 20 to 45 days. However, significant quality issues emerged as fruit ripened to medium soft following prolonged storage duration.

Table 5. Comparing remaining shelf life (days at 20°C) of small and large 'Shepard' avocados after various storage conditions

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	2	20	32	45
5	Small			7.3	6.9	6.6
5	Large			7.8	8.0	8.0
7	Small		10.7			
7	Large		11.5			
20	Small	11.2				
20	Large	11.9				

Shrivel

Shrivel was observed in around 25% of all trial fruit and was most common in the 20°C stored fruit. The relatively low RH of 65% in 20°C storage accelerated moisture loss and the risk of shrivel. Shrivel was more often observed in fruit when weight loss exceeded 11% and tended to be slightly more common in small fruit than in large (data not shown).

Skin darkening

The development of skin darkening was relatively common, with 26% of trial fruit showing symptoms exceeding 5% SA. Skin darkening was difficult to distinguish from skin chilling injury, and was observed in fruit across all storage temperatures. Skin darkening was particularly prevalent after storage periods of 32 days or longer (Table 6). After storage for 45 days most fruit showed substantial skin darkening, affecting 35% of the fruit surface on average.



Fig 3. Skin darkening symptoms on 'Shepard' avocado

Table 6. Incidence of skin darkening exceeding 5% SA in small 'Shepard' avocados at medium soft stage, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	2	5	11	20	32	45
3			10	15	26	80	
5			10	0	10	40	70
7		20	10	15	10	55	
10			10	5	35	40	
15			20	10			
20	0						

Skin darkening tended to be more of an issue in large than in small fruit (Table 7). Around half of all large fruit showed skin darkening exceeding 5% SA, while in corresponding treatments 28% of small fruit were affected.

Table 7. Comparing incidence of skin darkening exceeding 5% SA in small and large 'Shepard' avocados at medium soft stage after various storage conditions

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	2	20	32	45
5	Small			10	40	70
5	Large			15	75	90
7	Small		20			
7	Large		40			
20	Small	0				
20	Large	35				

Skin chilling injury

Chilling injury on the skin was characterised by mottled sunken areas, particularly around the lenticels, and was observed in some trial fruit stored for 20 days or longer (Data not shown). Storage at 3°C for 20 days resulted in 20% of fruit with skin chilling injury exceeding 5% SA. Storage at 5°C resulted in some very minor chilling on the skin of small fruit after 20 days, but no damage exceeding 5% SA.

Large fruit appeared to be slightly more prone to skin chilling damage than small fruit. After 20 days at 5°C, 15% of large fruit showing chilling injury greater than 5% SA, while none was observed in small fruit. For

storage periods greater than 20 days, the observation of chilling damage declined, probably being masked by skin darkening issues.

Internal chilling injury

Possible symptoms of internal chilling damage were first observed in fruit stored for 20 days, particularly at 3°C. Light grey-brown vascular discolouration typically originating from the base of the seed was thought to be the first sign of internal chill damage / long storage deterioration. More severe chill damage was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed.



Figure 4. Symptoms observed in 'Shepard' avocados associated with chilling damage

Chilling injury worsened with longer storage durations and lower temperatures. In small fruit significant internal chilling injury occurred after 20 days at 3°C, while slight chilling injury occurred at 5°C or 7°C (Table 8). Storage for 32 days or longer at 7°C or lower resulted in significant internal damage. Greater incidence of internal chilling damage occurred in large fruit than in small fruit.

Table 8. Incidence and severity of internal chilling injury in medium soft ‘Shepard’ avocados after various storage conditions

Temp	Duration (days)	Internal chilling injury severity (% vol)		Internal chilling injury incidence (%)	
		Large	Small	Large	Small
3°C	5		0		0
	11		0		0
	20		9.8		65
	32		51.6		90
5°C	5		0		0
	11		0		0
	20	1.5	1.6	40	10
	32	12.9	2.7	100	30
	45	24.3	20.6	95	75
7°C	2	0	0	0	0
	5		0		0
	11		0		0
	20		0.4		10
	32		3.2		20
10°C	5		0		0
	11		0		0
	20		0		0
	32		1.3		5
15°C	5		0		0
	11		0		0
20°C	0	0	0	0	0

Rots

In storage treatments of 20 days or less, the incidence of body rot and stem end rot was very low, averaging less than 3%. Storage for 32 days at 3 or 10°C slightly increased rot development (Table 9). In contrast, little rot development was observed following 5°C storage for 32 days. Storage for 45 days resulted in high levels of stem end and body rots developing in large fruit. Half of all large fruit developed body rots after being stored for 45 days at 5°C, while 25% had stem end rots. Rots were not so prevalent in small fruit stored for the same period, with both types of rots occurring at 10% incidence.

Table 9. Incidence and severity of rots in medium soft ‘Shepard’ avocados after various storage conditions

Temp	Duration (days)	Body rot severity (% vol)		Body rot incidence (%)		Stem end rot severity (% vol)		Stem end rot incidence (%)		Total % fruit with any rot	
		Large	Small	Large	Small	Large	Small	Large	Small	Large	Small
3°C	5		0.15		10		0.00		0		10
	11		0.00		0		0.00		0		0
	20		0.00		0		0.03		5		5
	32		0.55		15		0.50		5		20
5°C	5		0.00		0		0.03		5		5
	11		0.00		0		0.00		0		0
	20	0.00	0.10	0	5	0.15	0.00	5	0	5	5
	32	0.10	0.00	5	0	0.00	0.00	0	0	5	0
	45	1.83	0.50	50	10	0.63	0.13	25	10	60	20
7°C	2	0.43	0.05	10	5	0.00	0.18	0	15	10	15
	5		0.25		5		0.45		10		15
	11		0.10		5		0.00		0		5
	20		0.15		5		0.00		0		5
	32		0.15		10		0.03		5		15
10°C	5		0.00		0		2.50		5		5
	11		0.00		0		0.00		0		0
	20		0.15		5		0.05		5		10
	32		0.30		20		0.15		5		20
15°C	5		0.03		5		0.00		0		5
	11		0.00		0		0.03		5		5
20°C	0	0.00	0.53	0	5	0.00	0.00	0	0	0	5

Consumer tolerance

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010). Treatments of up to 11 days did not affect the percentage of unacceptable fruit, regardless of storage temperature (Table 10). After 20 days, fruit at 3°C started to show a decline in quality, which worsened after 32 days. Fruit stored at 5°C for 45 days also rated very poorly in consumer tolerance.

Table 10. Percentage of small ‘Shepard’ avocados with unacceptable internal defects at medium soft stage, after various storage conditions.

Orange shading indicates that the treatment did not meet industry guidelines for consumer tolerance.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	2	5	11	20	32	45
3			0	0	25	85	
5			0	0	10	10	55
7		0	5	0	0	20	
10			5	0	0	5	
15			0	0			
20	5						

Large fruit were more prone to developing unacceptable internal defects with prolonged storage than small fruit (Table 11). After 32 days at 5°C, 10% of small fruit were unacceptable when they reached medium soft. In contrast, 65% of large fruit exceeded the consumer tolerance threshold.

Table 11. Percentage of small and large ‘Shepard’ avocados with unacceptable internal defects after various storage conditions.

Orange shading indicates that the treatment did not meet industry guidelines for consumer tolerance.

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	2	20	32	45
5	Small			10	10	55
5	Large			5	65	90
7	Small		0			
7	Large		5			
20	Small	5				
20	Large	0				

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage, with all treatments held at 5°C for periods of 20, 32 and 45 days. CA slightly reduced weight loss compared with air (Table 12). This effect was consistent across all paired treatments. Fruit firmness after storage was fairly similar across all treatments, with fruit remaining very firm after storage for up to 45 days. Slight softening was shown in small fruit held for long periods at 5°C in air. The CA treatment appeared to lessen this softening.

Table 12. Weight loss and firmness of ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Weight loss after storage (%)		Firmness after storage	
		Air	CA	Air	CA
Small	20	2.6	2.2	83.8	84.2
Small	32	3.9	3.4	80.9	82.4
Small	45	5.4	3.7	77.6	82.4
Large	20	2.0	1.6	84.8	84.4
Large	32	3.6	2.4	83.1	83.9
Large	45	4.3	2.8	81.2	83.4

Treatment with CA slowed ripening, with CA treated fruit taking an average 1.4 days longer to reach firm soft (Table 13). The CA treated fruit subsequently ripened from firm soft to medium soft slightly more rapidly (taking an average of 1.5 days, compared with 1.9 days in air stored fruit). The total shelf life was slightly longer in CA treated fruit, averaging 1 day longer.

Table 13. Ripening and shelf life of ‘Shepard’ avocados following storage under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Days to reach firm soft (after storage treatment)		Days from firm soft to medium soft		Shelf life (after storage treatment)	
		Air	CA	Air	CA	Air	CA
Small	20	4.7	5.8	1.7	1.5	7.3	8.3
Small	32	3.7	5.8	2.2	1.4	6.9	8.1
Small	45	4.1	5.5	1.6	1.2	6.6	7.7
Large	20	4.7	6.3	2.2	1.9	7.8	9.2
Large	32	4.8	6.1	2.2	1.5	8.0	8.6
Large	45	5.4	6.4	1.6	1.5	8.0	8.9

Skin chilling injury occurred only at low levels in this trial and may have been masked by skin darkening in some cases. There was no observed difference in skin chilling injury between CA and air treatments (Table 14). In fruit stored for long durations, CA substantially reduced skin darkening compared with air storage. However, severe shrivel at medium soft stage was observed more frequently in fruit stored under CA. This was often associated with slightly greater weight loss at medium soft stage. Taking longer to ripen resulted in CA stored fruit being stored for longer before reaching medium soft, leading to the potential for greater weight loss.

Table 14. Skin defects and weight loss in ‘Shepard’ avocados at medium soft stage, after storage under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Skin chilling injury incidence (% fruit with CI >5% SA)		Skin darkening severity (average % SA)		Skin darkening incidence (% fruit with >5% SA)		Severe shrivel incidence (% fruit)		Weight loss at medium soft (%)	
		Air	CA	Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0	10	2.3	4.1	10	20	30	60	9.4	10.7
Small	32	0	0	9.9	5.4	40	15	25	75	10.4	11.9
Small	45	5	0	26.7	1.9	70	15	10	25	11.7	11.6
Large	20	15	5	6.4	8.5	15	45	5	25	8.7	9.1
Large	32	0	0	24.8	3.0	75	15	10	10	11.7	10.6
Large	45	5	0	43.0	13.1	90	55	5	20	11.2	11.6

Internal defects at medium soft tended to be similar under CA and air storage (Table 15 and **Table 16**). Overall, the total volume of internal defects, and percentage of unacceptable fruit did not seem to be strongly or consistently affected by CA storage.

Table 15. Rot severity and incidence in ‘Shepard’ avocados after ripening to medium soft following storage in air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Body rot severity (% vol)		Body rot incidence (%)		Stem end rot severity (% vol)		Stem end rot incidence (%)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0.1	0	5	0	0	0	0	0
Small	32	0	0	0	0	0	0	0	0
Small	45	0.5	0.1	10	5	0.13	0.38	10	15
Large	20	0	0	0	0	0.15	0	5	0
Large	32	0.1	0	5	0	0	0	0	0
Large	45	1.8	0.75	50	20	0.63	0.05	25	5

Table 16. Internal defects in ‘Shepard’ avocados after ripening to medium soft following storage in air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Vascular browning severity (% vol)		Internal chilling injury severity (% vol)		Total internal defect severity (% vol)		Unacceptable internal defects (% fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0.0	1.3	1.6	1.6	1.7	2.8	10	10
Small	32	0.3	2.5	2.7	6.2	3.0	8.7	10	30
Small	45	6.5	8.8	20.6	14.3	27.7	23.5	55	60
Large	20	0.0	0.0	1.5	5.3	1.7	5.3	5	25
Large	32	11.9	8.5	12.9	18.7	24.9	27.2	65	50
Large	45	20.1	46.6	24.3	10.5	46.8	57.9	90	85

Shelf life models

A preliminary linear regression of shelf life against time temperature units (TTUs) for small fruit is shown in Figure 5. Chill affected treatments were excluded from this plot (internal chilling in more than 10% of fruit). The linear regression of tray average values plotted across all temperatures shows a moderate fit ($R^2=0.68$)¹. However, the plot is suggestive of different responses to TTUs in fruit stored at 10°C versus 20°C, particularly at TTU ranges greater than 5000. It should be noted that the plotted points for 20°C treatments are not true replicates, but represent the same tray measured at different time intervals. The values are an accurate reflection of corresponding TTUs and shelf life for this tray, but give an unrealistically linear illustration of the relationship. In future trials, multiple trays will be used for these measurements.

A simple TTU linear model may give some indication of ‘Shepard’ avocado shelf life, but it is likely that more complex modelling approaches will be advantageous.

¹ The R^2 value is a statistical measure of 0 to 1 that represents the proportion of the variance for a dependent variable (shelf life) that is explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

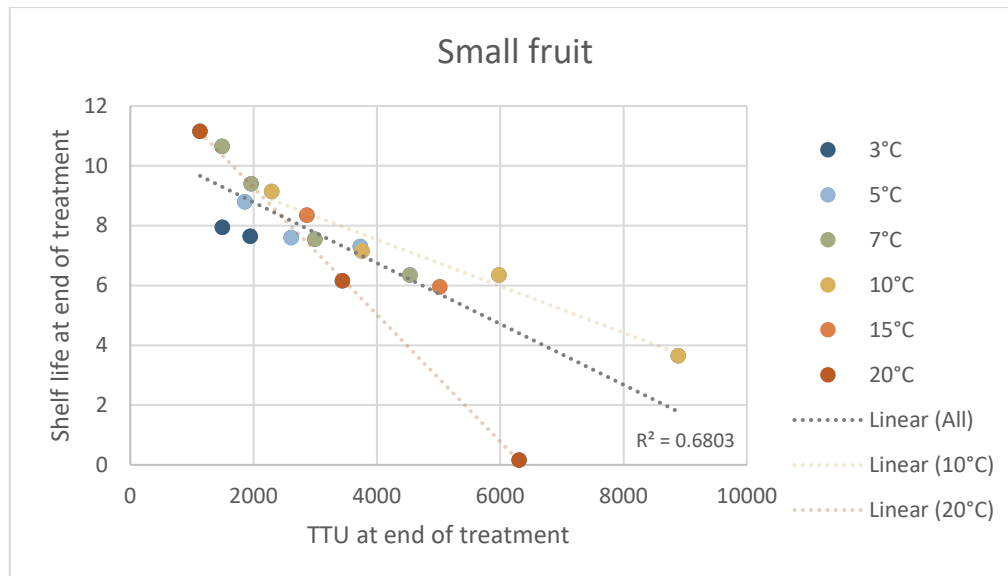


Figure 5 Preliminary linear regression of shelf life and TTUs for small CQ ‘Shepard’ avocados 2023 (tray average values)

4. Summary and recommendations

- Storage at 5-7°C would be recommended for the best overall quality and shelf life in ‘Shepard’ avocados.
- Storage for up to 20 days was possible with minimal loss of quality.
- Acceptable internal quality could be maintained for up to 32 days at 5°C for small fruit, but skin darkening at medium soft and minor internal chilling injury were observed after this period.
- Large fruit showed greater quality loss after long storage periods, with greater susceptibility to skin darkening and chilling injury.
- For long storage periods such as sea freight, small fruit size would be recommended based on the results of this trial.
- CA slightly extended shelf life, but overall did not provide strong benefits in the current trial.
- The benefits of CA in maintaining quality may be greater in higher DM batches.
- Quality issues such as susceptibility to rot or chilling can vary substantially with factors such as maturity, season and weather conditions. Further trials would be recommended to confirm these findings across a greater variety of conditions.
- Suggested improvements to future trials include the use of true replicates rather than pseudo-replicates at 20°C and greater focus within the 20 to 30 day range commonly encountered in sea freight.
- While simple linear regression using TTUs showed some predictive ability, more complex modelling is suggested to better predict shelf life of ‘Shepard’ avocados.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 35

CQ 'Shepard' avocado simulation trials report 2023b

Predicting fruit quality and shelf life for 'Shepard' avocado

A 2023 season Central Queensland grower report

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Department of Agriculture and Fisheries

Summary

An export simulation trial was completed with 'Shepard' avocados to quantify fruit quality and shelf life response to a range of supply chain handling scenarios. Commercially mature fruit of 2 different sizes were harvested from a farm near Childers, Queensland in 2023. The fruit were stored at 3, 5, 7, 10 and 15°C and 90% relative humidity (RH) for up to 45 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. The influence of controlled atmosphere (CA) storage on fruit quality was also evaluated. Key observations included:

- Firmness change in 'Shepard' avocados was strongly affected by storage temperature, with minimal change in firmness occurring in fruit held at 5°C or lower.
- As would be expected, shelf life tended to progressively decline with increasing duration of storage, and to be lost more rapidly at higher storage temperatures.
- Small fruit averaged 13.6 days shelf life when kept at 20°C, while large fruit averaged 14.5 days.
- Following 32 days at 5°C, shelf life at 20°C averaged around 7 days.
- The difference in shelf life between large and small fruit varied across storage treatments.
- Small fruit tended to be better suited to long storage, while large fruit showed greater loss of internal quality following storage.
- Small fruit were more susceptible to shrivel, while large fruit were more prone to skin darkening.
- Storage for 32 days at 3°C caused chilling damage, while minimal chilling was seen at 5°C.
- Over-softening was the main reason for shelf life ending, with low incidence of rots.
- Overall fruit quality was high, with most fruit showing acceptable internal quality at medium soft, even following treatments of up to 45 days.
- CA slowed ripening and extended shelf life.
- Following long duration storage of 32 to 45 days, CA treatment increased shelf life by around 3 days.
- CA did not give any obvious benefits in reducing defects at medium soft.
- Simple linear regression models using TTUs showed a good fit to the data, but more complex modelling will likely provide better predictions of shelf life.

Data from this trial will be used to generate shelf life and fruit quality prediction models. Future work will focus on relationships between fruit dry matter content and shelf life, the potential to extend low temperature shipping durations, and quantifying fruit quality variation between batches and blocks.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2023 'Shepard' avocado season on fruit grown in Central Queensland. The main objective of the trial was to quantify the fruit quality and shelf life response of 'Shepard' avocados to various supply chain conditions. The trial also investigated a wide range of factors affecting fruit quality and shelf life, including controlled atmosphere storage, fruit maturity (dry matter) and fruit size. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Shepard' avocado fruit (targeting dry matter >21%) were sourced for trials during the 2023 season. Fruit were harvested on 8 March 2023 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to the nearby packing shed on the same day. On the following day, they were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Large (count 20) and small (count 28) fruit were used in the trial. Packed fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned car at ca. 22-25°C within 3 hours and kept overnight at 22°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. The NIR measurement was performed on two sides (ventral and dorsal) of each fruit, near the centre. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 large and 20 small fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. All treatments were applied to a single tray of 20 small (count 28) fruit. Selected treatments were also applied to a tray of 20 large (count 20) fruit. A subset group at 5°C was stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Fruit within this trial were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored during storage to calculate time x temperature units (TTU). Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Shepard’ avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage				
3		5	10	20	32
5		5	10	20 ^L	32 ^L 45 ^L
5+CA				20 ^L	32 ^L 45 ^L
7	1 ^L	5	10	20	32
10		5	10	20	32
15		5	10		
20	0 ^L	5 ^{L*}	10 ^{L*}		

^L Indicates treatments were applied to trays of small and large fruit, while other treatment were only applied to small fruit

*Indicates these treatments were the same fruit from the 0 day 20°C tray remeasured after 5 and 10 days at 20°C and 65% RH
CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

At trial commencement all fruit were weighed and firmness was measured in 120 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm soft (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium soft (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury, the incidence of severe shrivel, and %SA of skin darkening. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit had an average oven DM of 22.9% for small fruit and 24.3% for large fruit (with values significantly different by t-test). Small fruit showed greater variability in DM, with a standard deviation of 3.8, as compared to 2.2 in large fruit. This was largely due to a few small fruit with unusually high DM. The relationships between NIR predicted DM and oven DM were moderately strong, averaging $R^2=0.67$ (data not shown).

Weight loss

Fruit weight loss at cold removal tended to increase with storage time and temperature. For all treatments at 15°C or lower, weight loss remained less than 6% (data not shown). Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Small fruit lost an average 3.9% of their weight after 5 days at 20°C and 8.3% at 10 days. After 45 days at 5°C air-stored small fruit had lost 4.5% of their initial weight.

Firmness changes in storage treatments

Changes in small fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to firm ripe stage within around 11-12 days. Storage at cooler temperatures progressively slowed ripening. At 3 to 5°C, firmness change was minimal, with fruit remaining firm after 32 days. Slightly higher temperatures of 7 and 10°C slowed and delayed softening over short durations, but rapid softening occurred after 20 days. Changes in firmness at removal in large fruit were generally similar to small fruit, although large fruit were softer than small fruit after 45 days at 5°C (data not shown).

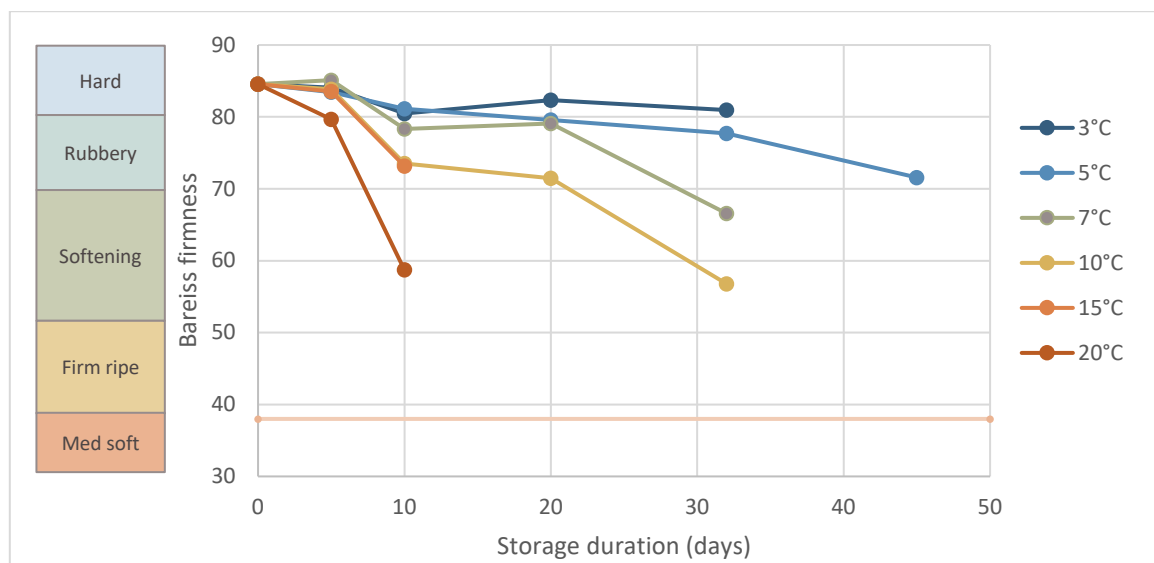


Figure 1. Changes in fruit firmness of small (count 28) 'Shepard' avocados during storage at various temperatures

Firmness changes during shelf life assessment

Small fruit kept constantly at 20°C reached firm soft stage after an average 11 days (Table 2). Longer durations of storage and warmer storage temperatures tended to hasten subsequent softening to firm soft after fruit were transferred to 20°C.

Table 2. Days taken for small 'Shepard' avocados to reach firm soft stage following various storage treatments

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
	0	1	5	10	20	32
3			10.4	6.3	5.2	5.3
5			10.2	7.6	6.6	3.9
7		11.3	9.2	7.5	5.2	3.0
10			8.4	6.0	4.3	1.9
15			7.8	5.4		
20	11.0		6.0	1.0		

In fruit kept constantly at 20°C, large 'Shepard' avocados took around 1 day longer to reach firm soft than small sized fruit (Table 3, with these values significantly different by t-test). However, following long storage at 5°C, large fruit tended to soften to firm ripe stage more rapidly than small fruit.

Table 3. Comparing large and small ‘Shepard’ avocados for days taken to reach firm soft stage after various storage treatments

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	1	20	32	45
5	Small			6.6	3.9	2.8
5	Large			5.1	3.4	2.6
7	Small		11.3			
7	Large		11.2			
20	Small	11.0				
20	Large	12.0				

Fruit took an average of 1.8 days to ripen from firm soft to medium soft. At 20°C, observed rates of firmness change suggest that 1-2 days after reaching medium soft the fruit would tend to be oversoft.

Shelf life

Quality traits measured at medium soft stage were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots exceeded 10% flesh volume. Over-softening was the key reason for fruit reaching ESL, with less than 1% of fruit in the current trial reaching ESL due to rots.

The shelf life of fruit kept constantly at 20°C averaged 13.6 days for small fruit (Table 4). Shelf life tended to progressively decline with increasing duration of storage, and to be lost more rapidly at higher storage temperatures (Figure 2). Little difference was observed between fruit stored at 10 and 15°C, which was unexpected. These two treatments also showed very similar changes in firmness over 10 days. Fruit stored at 3°C showed similar shelf life following storage for periods of 10 to 32 days, with a sharp decline in shelf life between 5 and 10 day treatments.

Table 4. Remaining shelf life (days at 20°C) of small ‘Shepard’ avocados after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	1	5	10	20	32	45
3			13.0	8.9	8.6	8.5*	
5			12.6	10.2	10.6	7.4	5.8
7		13.8	11.6	10.3	8.2	6.4	
10			10.8	8.4	6.7	4.1	
15			10.3	8.3			
20	13.6		8.6	3.6			

* Indicates treatment with internal chilling damage incidence >10%

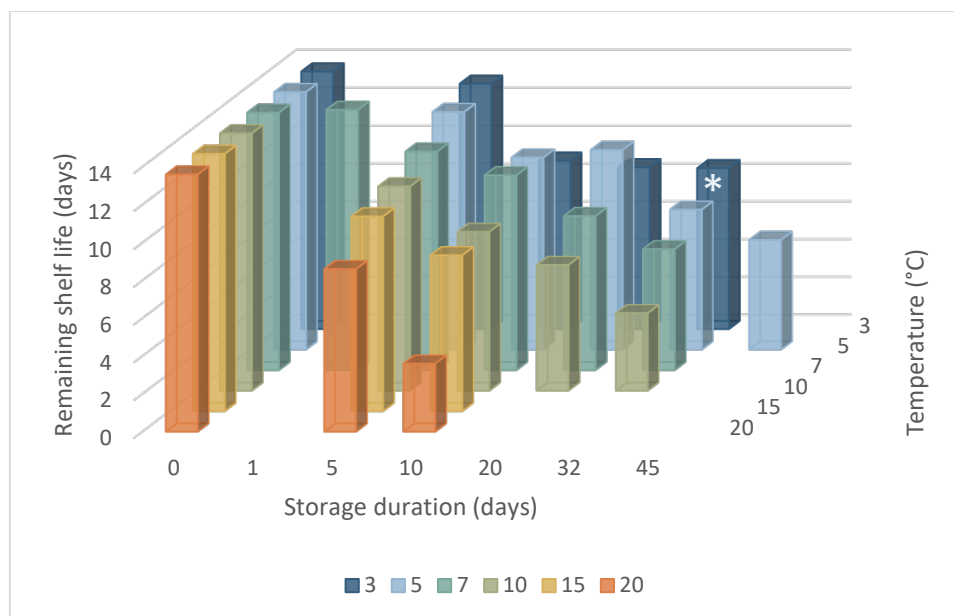


Figure 2. Remaining shelf life at 20°C of small ‘Shepard’ avocados after storage at various temperatures (* Indicates treatment with internal chilling damage incidence >10%)

Differences in shelf life between large and small fruit were inconsistent across different storage regimes (Table 5). Large fruit tended to have slightly longer shelf life than small fruit when stored at 20°C, while the reverse was observed following 20 days at 5°C.

Table 5. Comparing remaining shelf life (days at 20°C) of small and large ‘Shepard’ avocados after various storage conditions

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	1	20	32	45
5	Small			10.6	7.4	5.8
5	Large			8.6	6.9	5.8
7	Small		13.8			
7	Large		14.0			
20	Small	13.6				
20	Large	14.5				

Shrivel

Shrivel at medium soft was observed in 58% of all trial fruit and was more common in small fruit. In matching treatments, 71% of small fruit showed shrivel at medium soft, while 41% of large fruit had shrivel recorded. The relatively low RH of 65% in 20°C storage accelerated moisture loss and the risk of shrivel. Shrivel was more often observed in fruit when weight loss exceeded 10%.

Skin darkening

Some skin darkening was observed after long storage treatments, particularly at 3°C (Table 6). Skin darkening was difficult to distinguish from skin chilling injury. While it was rarely seen at 15 or 20°C in the current trial, this disorder has been observed at non-chilling temperatures in other Shepard trials. Skin darkening tended to be more of an issue in large than in small fruit (Table 7). After storage at 5°C for 45 days, 55% of large fruit showed skin darkening exceeding 5% SA, while 15% of small fruit were affected.



Fig 3. Skin darkening symptoms on 'Shepard' avocado

Table 6. Incidence of skin darkening exceeding 5% SA in small 'Shepard' avocados at medium soft stage, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	1	5	10	20	32	45
3			0	0	10	25	
5			0	0	0	5	15
7		0	0	5	0	10	
10			0	0	5	10	
15			0	0			
20	0						

Table 7. Comparing incidence of skin darkening exceeding 5% SA in small and large 'Shepard' avocados at medium soft stage after various storage conditions

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	2	20	32	45
5	Small			0	5	15
5	Large			0	15	55
7	Small		0			
7	Large		0			
20	Small	0				
20	Large	5				

Skin chilling injury

Chilling injury on the skin was characterised by mottled sunken areas, particularly around the lenticels, and was observed in some trial fruit stored for 32 days or longer (data not shown). Storage at 3°C for 32 days resulted in 35% of small fruit showing signs of skin chilling injury, averaging around 7% SA. Less damage was shown at 5°C, with very minor skin chilling on 15% of small fruit, averaging less than 1% SA.

Internal chilling injury

Possible symptoms of internal chilling damage were observed in fruit stored for 32 days or longer. Light grey-brown vascular discolouration typically originating from the base of the seed was the thought to be the first sign of internal chill damage / long storage deterioration. More severe chill damage was

characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Very little diffuse discolouration was observed in air stored fruit.



Figure 4. Symptoms observed in 'Shepard' avocados associated with chilling damage

Small fruit stored at 3°C for 32 days showed 25% incidence of any internal chilling, averaging 6% volume. Much less was shown at 5°C, with 10% of fruit affected after 32 days, and damage averaging less than 1% volume. Following 45 days storage at 5°C, no internal chilling was observed in small fruit.

In large fruit stored for 32 days at 5°C, 15% of fruit were affected by internal chilling, with damage averaging less than 2% volume. No internal chilling was observed in large fruit following storage for 45 days in air.

Rots

Overall, the incidence of body rot and stem end rot was fairly low (Table 8). Across all air-stored fruit 7% showed signs of body rots at medium soft assessment. Most of these body rots were small in size and occurred in fruit nearing oversoft. Stem end rot affected 10% of trial fruit, but very rarely exceeded 10% volume. The highest levels of rots were shown in large fruit stored constantly at 20°C. Higher levels of rot following other storage regimes likely reflected the high inherent variability of the values, rather than any treatment effects.

Table 8. Incidence and severity of rots in medium soft ‘Shepard’ avocados after various storage conditions

Temp	Duration (days)	Body rot severity (% vol)		Body rot incidence (%)		Stem end rot severity (% vol)		Stem end rot incidence (%)	
		Large	Small	Large	Small	Large	Small	Large	Small
3°C	5		1.20		15		1.20		30
	10		0		0		0.40		5
	20		0.35		10		0.15		10
	32		0.10		5		0.08		10
5°C	5		0		0		0.03		5
	10		0		0		0.40		5
	20	0	0.05	0	5	0.55	0.70	10	35
	32	0	0	0	0	0	0.18	0	15
	45	0	0.05	0	5	0	0.05	0	5
7°C	1	0.15	0.03	15	5	0	0.10	0	10
	5		0		0		0.35		10
	10		0		0		0.05		5
	20		0.15		5		0.25		15
	32		0		0		0.35		15
10°C	5		0.20		10		0.08		10
	10		0		0		0.10		5
	20		0		0		0.05		5
	32		0		0		0.48		25
15°C	5		0.05		5		0.53		15
	10		0		0		2.83		20
20°C	0	0.99	0	40	0	0.03	1.30	45	10

Consumer tolerance

Overall, a high level of internal quality was observed following storage. Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010). The percentage of unacceptable fruit remained at 10% or lower in all air stored small fruit (Table 9). Large fruit showed a decline in quality after storage at 45 days at 5°C, with 20% of fruit developing unacceptable internal defects (Table 10).

Table 9. Percentage of small ‘Shepard’ avocados with unacceptable internal defects at medium soft stage, after various storage conditions.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	1	5	10	20	32	45
3			10	0	0	5	
5			0	0	0	0	0
7		0	0	0	0	0	
10			0	0	0	0	
15			0	10			
20	5		5	5			

Table 10. Percentage of small and large ‘Shepard’ avocados with unacceptable internal defects after various storage conditions.

Orange shading indicates that the treatment did not meet industry guidelines for consumer tolerance.

Storage temperature (°C)	Fruit Size	Storage duration (days) prior to ongoing 20°C storage				
		0	1	20	32	45
5	Small			0	0	0
5	Large			5	0	20
7	Small		0			
7	Large		0			
20	Small	5				
20	Large	0				

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage, with all treatments held at 5°C for periods of 20, 32 and 45 days. CA slightly reduced weight loss compared with air (Table 11). This effect was consistent across all paired treatments. CA also maintained fruit firmness, with fruit remaining hard when stored under CA for up to 45 days. In contrast, fruit firmness gradually declined in fruit held at 5°C in air.

Table 11. Weight loss and firmness of ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Weight loss after storage (%)		Firmness after storage	
		Air	CA	Air	CA
Small	20	2.5	1.5	79.6	80.7
Small	32	3.9	1.9	77.7	82.9
Small	45	4.5	3.9	71.6	80.7
Large	20	2.4	1.8	80.6	80.6
Large	32	3.0	1.9	79.9	83.2
Large	45	5.1	3.3	62.4	81.3

The use of CA slowed fruit ripening compared with air storage. On average, CA treated fruit took 3 days longer to reach firm soft after being shifted to 20°C (Table 12). This effect was strongest in the longer 32 and 45 day treatments. CA treated fruit subsequently tended to ripen from firm soft to medium soft slightly more rapidly (taking an average of 1.8 days, compared with 2.5 days in air stored fruit).

Shelf life was increased by the use of CA. Following 20 day storage, the total shelf life under CA was slightly increased compared with air. After 32 and 45 day storage periods, shelf life was markedly longer in CA treated fruit, averaging 3 days longer than for fruit stored in air.

Table 12. Ripening and shelf life of 'Shepard' avocados following storage under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Days to reach firm soft (after storage treatment)		Days from firm soft to medium soft		Shelf life (after storage treatment)	
		Air	CA	Air	CA	Air	CA
Small	20	6.6	8.1	3.0	2.0	10.6	11.1
Small	32	3.9	8.3	2.5	1.6	7.4	10.8
Small	45	2.8	6.9	2.0	1.9	5.8	9.8
Large	20	5.1	6.6	2.6	1.9	8.6	9.4
Large	32	3.4	6.9	2.5	2.0	6.9	9.8
Large	45	2.6	6.3	2.2	1.4	5.8	8.7

No consistent differences in skin defects were observed between CA and air treatments (Table 13), with tray averages showing a large degree of inherent variability.

Table 13. Skin defects in 'Shepard' avocados at medium soft stage, after storage under air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Skin chilling injury severity (average % SA)		Skin chilling injury incidence (% fruit with CI >5% SA)		Skin darkening severity (average % SA)		Skin darkening incidence (% fruit with >5% SA)		Shrivel incidence (% of fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0	0	0	0	0.8	0.3	0	0	80	85
Small	32	0.6	0.6	5	5	0.8	1.3	5	5	80	90
Small	45	1.0	0	5	0	2.8	3.2	15	10	55	90
Large	20	0	0	0	0	0.6	1.6	0	5	50	15
Large	32	0.7	5.7	0	30	4.0	9.6	15	40	45	75
Large	45	4.8	0	25	0	15.3	6.9	55	20	35	70

Similarly, a large degree of inherent variability occurred in rot severity and incidence, with no consistent CA effects observed (Table 14). While the incidence of stem end rot appears high at medium soft stage, the volume of these rots tended to be very small.

Table 14. Rot severity and incidence in ‘Shepard’ avocados after ripening to medium soft following storage in air or CA at 5°C for various durations

Fruit size	Storage duration (days)	Body rot severity (% vol)		Body rot incidence (%)		Stem end rot severity (% vol)		Stem end rot incidence (%)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0.1	0	5	0	0.7	0.4	35	15
Small	32	0	0	0	0	0.2	0.3	15	15
Small	45	0.1	0	5	0	0.1	0.6	5	35
Large	20	0	0.1	0	5	0.6	0.1	10	5
Large	32	0	0.2	0	10	0	0.3	0	5
Large	45	0	0.2	0	5	0	0.1	0	5

CA did not show any benefits in reducing internal defects compared with air storage (Table 15). Internal chilling damage and total defects in large fruit after 32 and 45 days seemed slightly higher under CA compared with air. Large fruit stored for 45 days did not meet industry guidelines for internal quality. After 32 days, large fruit stored in air were acceptable, while those stored in CA exceeded consumer tolerance thresholds. Overall, small fruit tended to handle long storage better than large fruit, with less deterioration of internal quality.

Table 15. Internal defects in ‘Shepard’ avocados after ripening to medium soft following storage in air or CA at 5°C for various durations

Orange shading indicates that the treatment did not meet industry guidelines for consumer tolerance.

Fruit size	Storage duration (days)	Vascular browning severity (% vol)		Internal chilling injury severity (% vol)		Total internal defect severity (% vol)		Unacceptable internal defects (% fruit)	
		Air	CA	Air	CA	Air	CA	Air	CA
Small	20	0.3	0	0	0	1.0	0.4	0	0
Small	32	0	0	0.3	0	0.4	0.3	0	0
Small	45	0	0	0	0.1	0.1	0.7	0	0
Large	20	0.8	0	0	0	1.3	0.2	5	0
Large	32	0	0.4	1.8	3.5	2.0	4.3	0	20
Large	45	4.0	3.9	0	6.2	4.0	10.3	20	25

Shelf life models

A preliminary linear regression of shelf life against time temperature units (TTUs) for small fruit is shown in Figure 5. Chill affected treatments were excluded from this plot (internal chilling in more than 10% of fruit). The linear regression of tray average values plotted across all temperatures shows a good fit ($R^2=0.81$)¹. The regression lines from 5 to 15°C were consistent and similar to the overall regression (individual plot lines not shown). However, the relationship between TTUs and shelf life seemed to differ in fruit stored at 3°C and 20°C. It should be noted that the plotted points for 20°C treatments are not true replicates, but represent the same tray measured at different time intervals. The values are an accurate reflection of corresponding TTUs and shelf life for this tray, but give an unrealistically linear illustration of the relationship. In future trials, multiple trays will be used for these measurements.

¹ The R^2 value is a statistical measure of 0 to 1 that represents the proportion of the variance for a dependent variable (shelf life) that is explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

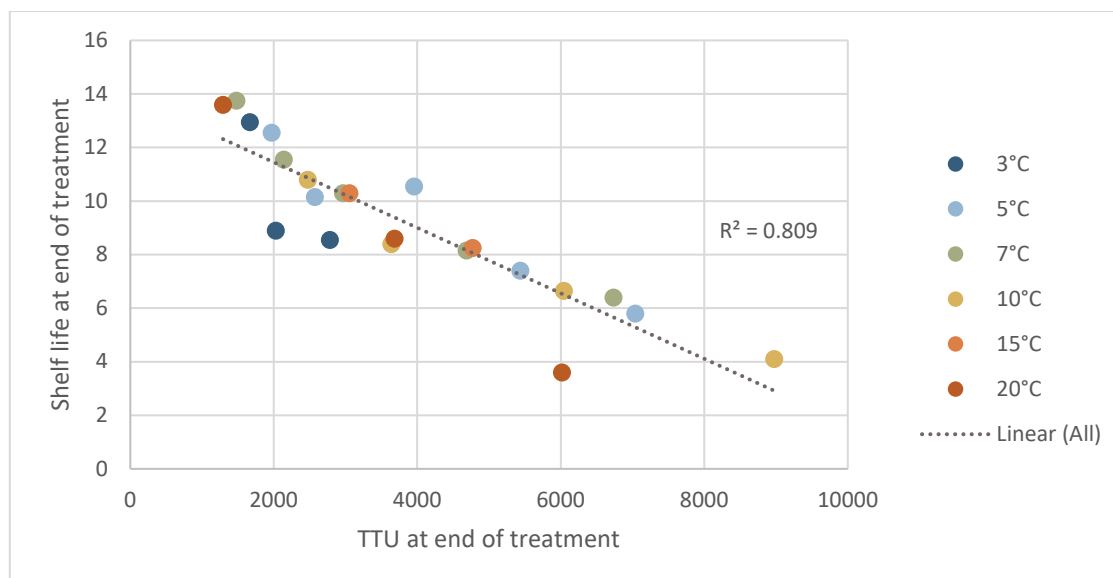


Figure 5. Preliminary linear regression of shelf life and TTUs for small CQ 'Shepard' avocados 2023 (tray average values)

A simple TTU linear model may give some indication of 'Shepard' avocado shelf life, but it is likely that more complex modelling approaches will give better predictive power.

4. Summary and recommendations

- Storage at 5-7°C would be recommended for the best overall quality and shelf life in 'Shepard' avocados.
- Some minor chilling damage started to develop after storage periods of 32 days, with 3°C storage causing more damage than 5°C.
- Small fruit were able to retain an acceptable level of internal quality following storage at 5°C for up to 45 days, but subsequent shelf life was very short.
- Large fruit showed greater quality loss after long storage periods, with greater susceptibility to skin darkening and internal defects.
- For long storage periods such as sea freight, small fruit size would be recommended based on the results of this trial.
- CA slowed ripening and extended shelf life, particularly over long storage periods of 32 days or greater.
- Further trials would be recommended to confirm these findings across a greater variety of conditions. Quality issues such as susceptibility to rot or chilling can vary substantially with factors such as maturity, season and weather conditions.
- Suggested improvements to future trials include the use of true replicates rather than pseudo-replicates at 20°C, elimination of the 45 day storage duration, and greater focus within the 20 to 30 day range commonly encountered in sea freight.
- While simple linear regression using TTUs showed good predictive ability, more complex modelling is suggested to better predict shelf life of 'Shepard' avocados.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 36

NQ 'Shepard' avocado simulation trials report 2024



Predicting fruit quality and shelf life for ‘Shepard’ avocado

John Archer, Minh Nguyen, Md Ashraful Islam, Lawrence Smith, Pip Bryant and Andrew Macnish

Department of Agriculture and Fisheries

Summary

A series of export simulation trials were conducted with ‘Shepard’ avocados to assess the impact of different supply chain handling and storage conditions on fruit quality and shelf life. The trials involved commercially mature fruit grown in North Queensland (NQ) in 2024.

- Trial 1 used fruit of size 28 from Block ‘A’
- Trial 2 used fruit sizes 30 and 20 Block ‘B’

The avocados were stored at 3, 5, 7, 10 and 15°C, with 90% relative humidity (RH) for 10 to 41 days to replicate conditions observed in monitored air and seafreight supply chains. Sub-samples of fruit were periodically removed from storage and held at 20°C and 65% RH to assess their remaining shelf life. Additionally, the influence of controlled atmosphere (CA) storage at 5°C on fruit quality was evaluated.

Key observations from the trials included:

- Firmness Change: Firmness in ‘Shepard’ avocados was significantly influenced by storage temperature, with minimal change observed during storage of fruit at or below 5°C.
- Chilling Injury: Chilling injury became noticeable after 20 days of storage at 3 and 5°C.

The data gathered from these trials will be used to develop and update best practice handling guidelines and decision aid tools based on predictive models for avocado shelf life and fruit quality. Future work will focus on exploring the relationship between fruit dry matter content and shelf life, extending the potential for low-temperature shipping durations, and examining the variation in fruit quality across different batches and blocks.

Introduction

The Serviced Supply Chains II (AM21000) project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters to help them maximize product value, reduce claims, and expand trade volume. The primary objectives of the project are:

- Develop predictive shelf-life models for a wide range of fresh horticultural produce.
- Apply these models to create decision aid tools and update handling guidelines for improved quality and consistency.
- Establish an information portal to facilitate access to these decision aid tools, making them readily available to stakeholders.

This report focuses on the export simulation trial work conducted during the 2024 NQ ‘Shepard’ avocado season. The central objective of these trials was to assess the fruit quality and shelf-life response of ‘Shepard’ avocados under various supply chain conditions. In addition, the trials explored a range of factors influencing fruit quality and shelf life, such as CA storage and fruit maturity (dry matter content). The data generated from these trials will contribute to the development of predictive models for avocado quality and shelf life, enhancing decision-making for exporters and stakeholders.



Materials and Methods

Fruit Selection and Harvesting

Commercially mature 'Shepard' avocado fruit, with a target dry matter (DM) content of >21%, were selected for the trials during the 2024 season. The fruit were harvested by a commercial picking crew on 11th March 2024 and 14th April 2024 from a farm located in the Tablelands region, NQ. The harvested fruit were transferred to a nearby packing house within 24 hours.

Post-Harvest Treatment and Packing

Upon arrival at the packing house, the avocados were treated with a fungicide, sorted by size and quality, and then packed into cardboard trays. The packed fruit of count 28 (Trial 1) and count 20 and 30 (Trial 2) were transported in an air-conditioned vehicle to the Cairns Research Facility within 3 hours, maintaining a temperature of 22-25°C. The fruit were kept overnight at 20°C to stabilize before further processing.

Dry Matter Content Measurement

At the laboratory, the dry matter (DM) content of each fruit was estimated using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general avocado dry matter model. The NIR measurement was taken on two sides of each fruit (ventral and dorsal), near the centre.

All trial fruit were grouped according to their NIR-predicted DM values, and then sorted by DM content. Fruit were assigned to treatment trays such that each tray contained a normal distribution of DM values from the entire sample group. A subset of 20 fruits per size category were also assessed for DM using the traditional oven-drying method. NIR values were corrected based on the correlation between NIR-predicted DM and oven-dried DM measurements.

Storage Conditions

The fruit were assigned to different storage temperature treatments designed to simulate potential air and sea freight conditions, as detailed in Table 1. Each treatment was applied to a single tray of 20 fruit. A subset of fruit stored at 5°C was kept in CA storage at 2% O₂ and 5% CO₂. No ethylene treatments were applied to the fruit.

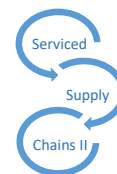
At the conclusion of each treatment storage period, the fruit were moved to 20°C for further assessment of their remaining shelf life. The air temperature adjacent to the fruit was monitored from the time of collection at the packing shed through to removal from the cold storage treatments. This allowed for the calculation of time × temperature units (TTU), which helped quantify the effects of storage duration and temperature.

Humidity Control

Relative humidity (RH) inside the cold storage rooms was maintained at approximately 90% to simulate typical cold storage conditions. Once removed from storage, the fruit were placed in a controlled environment at 20°C, with the RH held at 65% to replicate retail conditions.

Bareiss Firmness Measurement

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit. A firmness value of 54 was defined as the threshold for firm soft (FS), while the end of shelf life (ESL) was determined when firmness reached 39. These benchmarks provided consistent criteria for assessing ripeness and the remaining usability of the fruit during the trials.



Results

Dry matter

Trial 1: Moderate variability was observed in overall DM content, with an average of 29.32% and a standard error of 0.61%.

Trial 2: Small avocados had a higher mean DM content (34.36%) compared to large avocados (31.99%), but with slightly greater variability.

Table 1 Dry Matter Content Analysis

Trial	Fruit Size	Average DM (%)	Maximum DM (%)	Minimum DM (%)	Standard Error (%)
1	Small	29.32	35.6	21.2	0.61
2	Small	34.36	43.9	24.4	0.70
2	Large	31.99	42.0	25.2	0.58

Changes in Fruit Firmness During Storage

Figure 1 (Trial 1) and Figure 2 (Trial 2) present the changes in fruit firmness during storage at different temperatures. As expected, the rates of firmness change were strongly influenced by the storage temperature. Storage at cooler temperatures progressively slowed the ripening process, with fruit stored at 5°C (and 5°C CA in Trial 1) maintaining greater firmness compared to those stored at higher temperatures. In these treatments, the firmness change was minimal, with the fruit remaining hard even after 30 days of storage.

However, fruit in Trial 2 (Figure 2) did not maintain firmness as effectively as in Trial 1. This suggests potential variations between the two trials, possibly reflecting different orchard blocks, fruit maturity and/or seasonal/management factors.

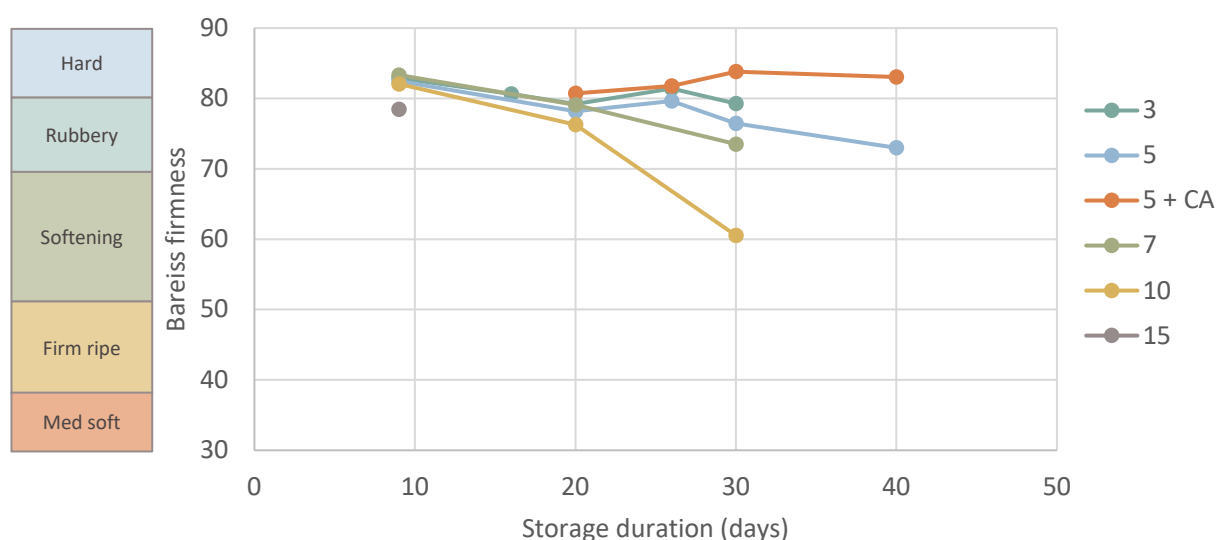


Figure 1 Changes in fruit firmness 'Shepard' avocados during storage at various temperatures (3, 5, 7, 10, 15°C) at removal Trial 1 11th March 2024. CA refers to controlled atmosphere

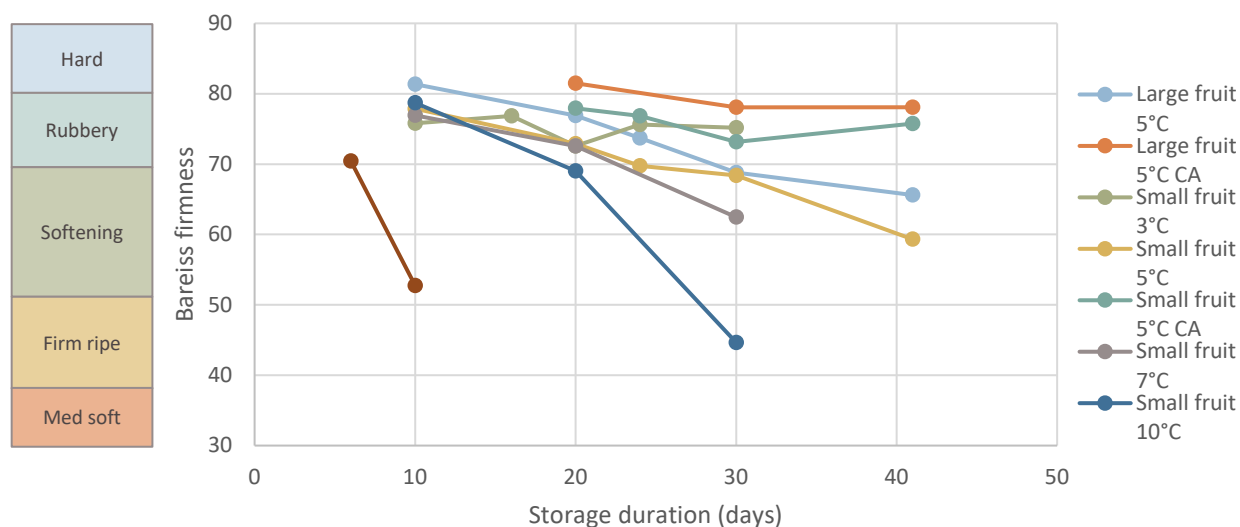
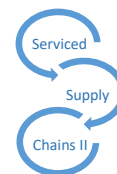


Figure 2 Changes in fruit firmness 'Shepard' avocados during storage at various temperatures at removal Trial 2 14th April 2024

Figure 3 shows the firmness of fruit at removal for Trial 1, comparing fruit stored under Non-CA and CA conditions. As depicted, the fruit stored under CA treatment consistently remained firmer at every removal stage compared to those stored under non-CA conditions. This trend was observed across all storage durations (20, 26, 30, and 40 days), suggesting that CA treatment was effective in maintaining fruit firmness throughout the storage period.

In contrast, fruit stored under non-CA conditions showed a gradual decrease in firmness, indicating that CA storage helped slow the ripening process and preserved fruit quality more effectively.

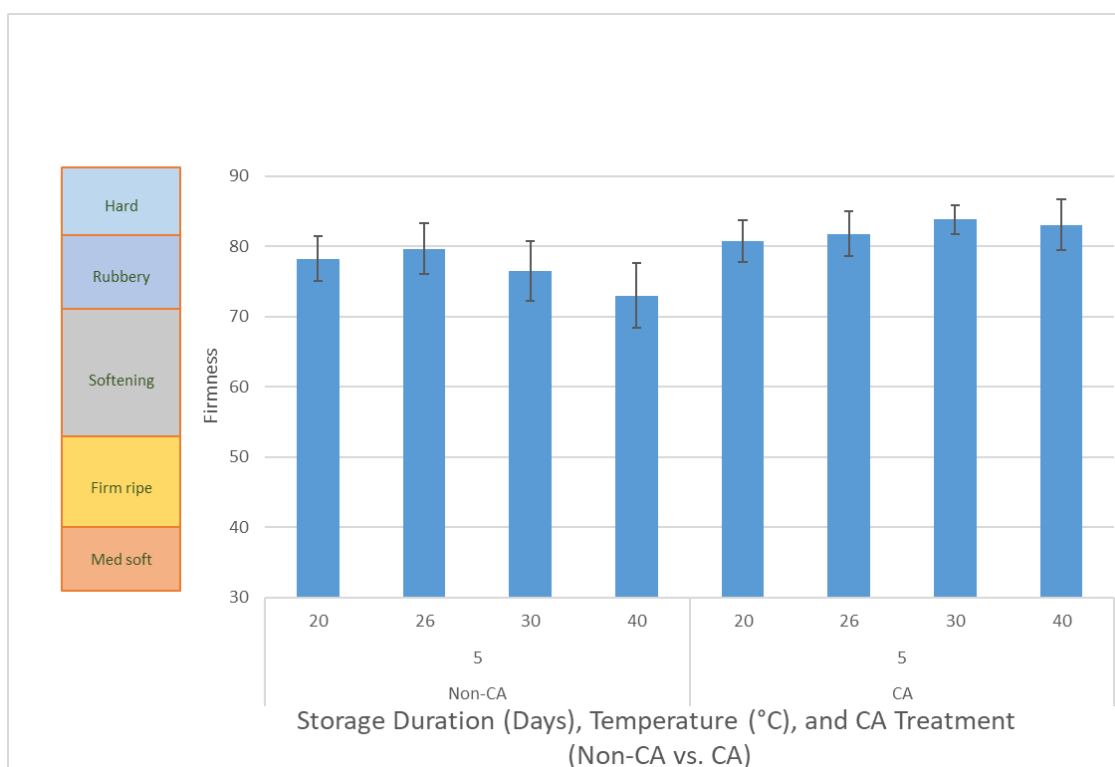


Figure 3 Firmness of 'Shepard' Avocados after Different Storage Durations and CA Treatment at removal Trial 1 11th March 2024



Impact of Storage Duration on Fruit Defects

Longer storage treatments resulted in a higher percentage of fruit exhibiting defects once ripe. On average, fruit from Trial 1 (Figure 4) showed higher levels of fruit defects compared to fruit from Trial 2 (Figure 5). This comparison underscores the variability in fruit quality, highlighting the significant impact of storage duration on the development of defects. Additionally, the different blocks from which the fruit were harvested played a role in influencing the observed defects, further emphasizing the variability in fruit quality across different growing conditions.

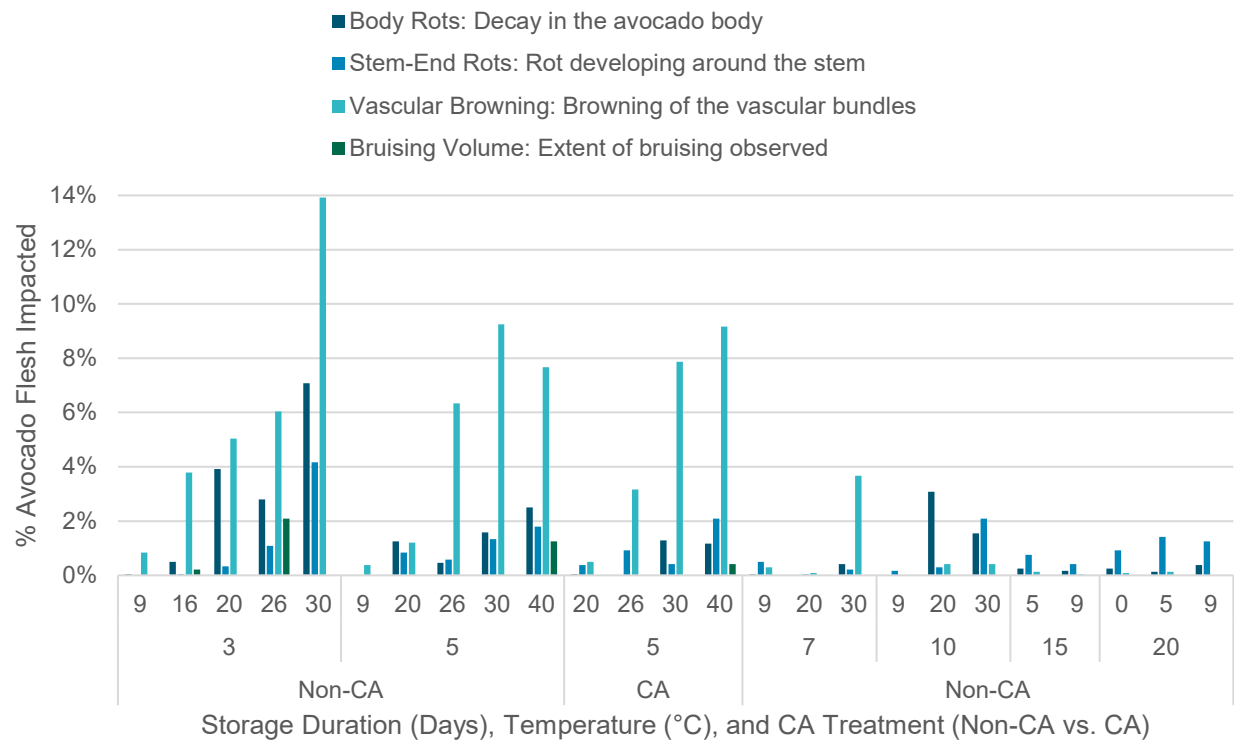


Figure 4 Impact of Storage Duration, Temperature, and CA Treatment on Avocado Flesh Quality (Body Rot, Stem-End Rot, Vascular Browning, and Bruising) Trial 1 11th March 2024

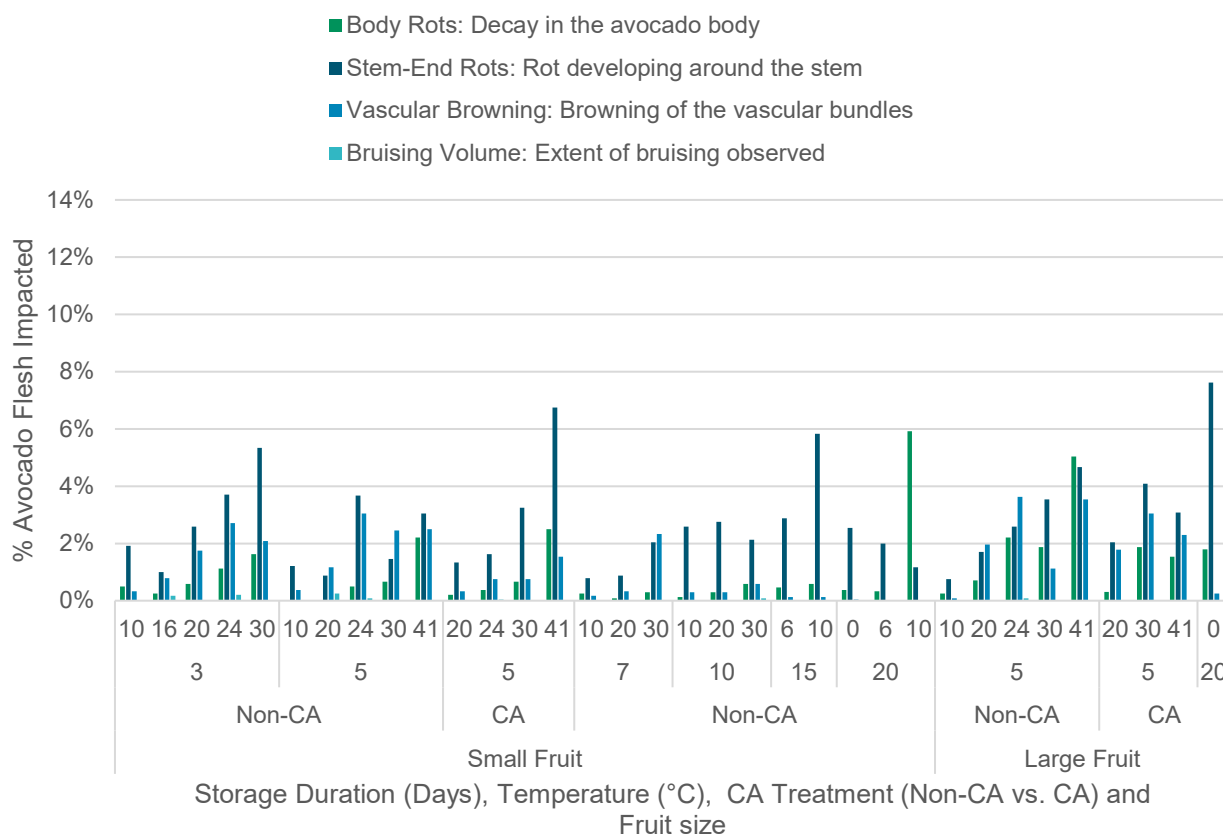


Figure 5 Impact of Storage Duration, Temperature, and CA Treatment on Avocado Flesh Quality (Body Rot, Stem-End Rot, Vascular Browning, and Bruising) Trial 2 14th April 2024

Internal Chilling Injury

Internal chilling damage was first observed in fruit stored for 20 days, particularly at 3°C. The initial signs of internal chill damage were light grey-brown vascular discoloration, typically originating from the base of the seed, which is thought to be the first indicator of internal chilling or long storage deterioration. As the storage period extended, more severe chill damage developed, characterized by dark brown-grey diffuse discoloration of the flesh surrounding the seed, as shown in Figure 6.

The severity of chilling injury worsened with longer storage durations and lower temperatures. Significant internal chilling injury occurred after 20 days at 3°C and 5°C, while slight chilling injury was observed at 7°C. Interestingly, Trial 1 (Figure 7) fruit were slightly more chilling-tolerant than Trial 2 (Figure 8) fruit, suggesting potential differences in maturity or growing conditions.



Figure 6 Symptoms observed in 'Shepard' avocados associated with chilling damage

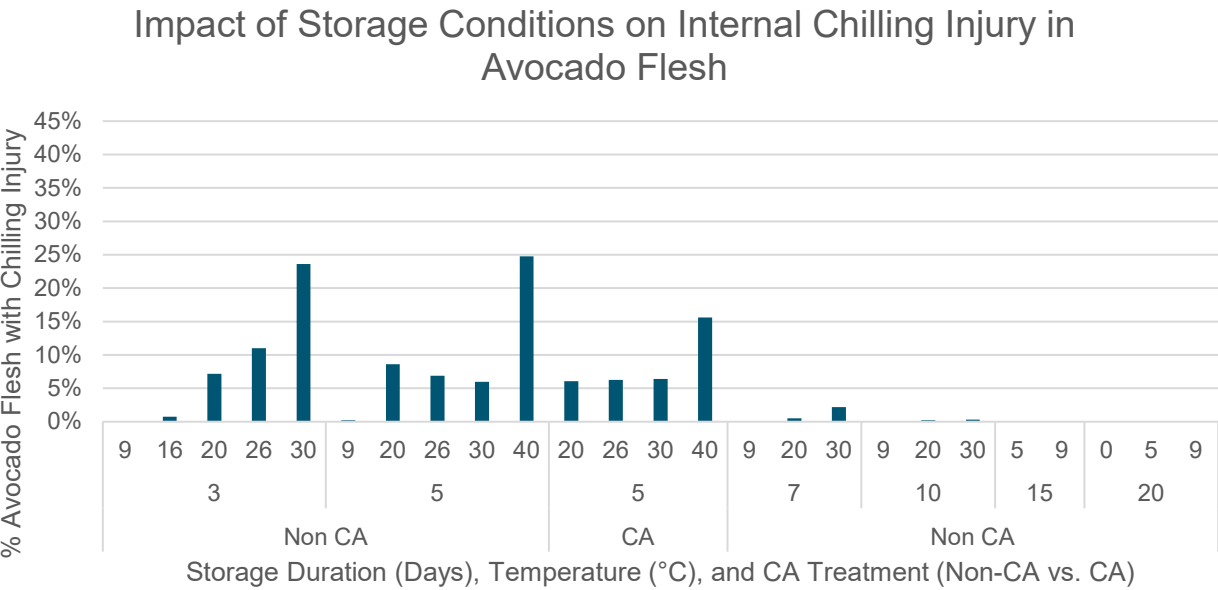


Figure 7 Impact of Storage Conditions on Internal Chilling Injury in Avocado Flesh Trial 1 11th March 2024

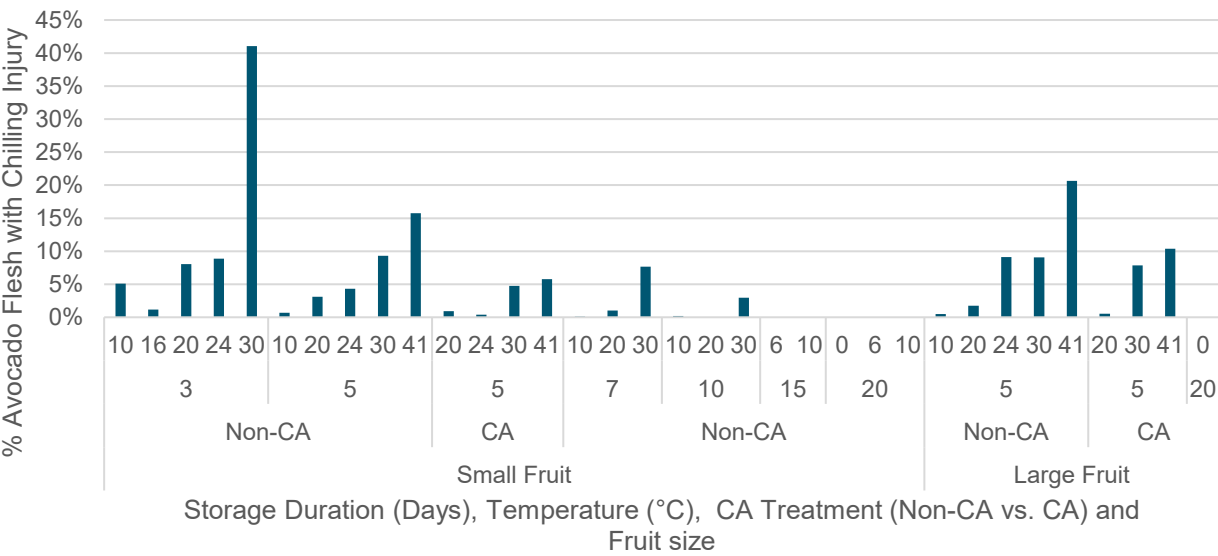


Figure 8 Impact of Storage Conditions on Internal Chilling Injury in Avocado Flesh Trial 2 14th April 2024

Trial 1: Estimated Shelf Life and Firmness

Figure 9 presents the ESL of ‘Shepard’ avocados stored at different temperatures (3°C, 5°C, 7°C, and 10°C) with and without CA treatment. The ESL is represented in days on the y-axis, while the x-axis shows storage durations (in days). The data reveal that avocados stored at cooler temperatures (3°C and 5°C) had longer shelf lives compared to those stored at higher temperatures (7°C and 10°C). In particular, CA-treated fruit showed a longer shelf life across all temperature treatments compared to non-CA fruit, which highlights the beneficial effect of CA storage.

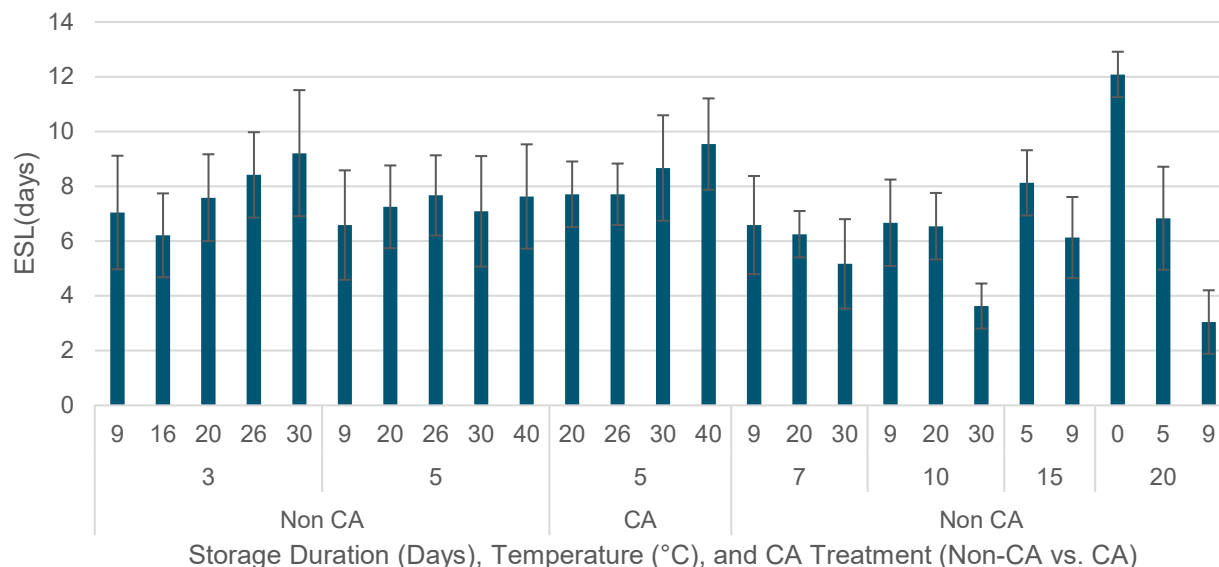


Figure 9 Effect of Storage Conditions on the Estimated Shelf Life (ESL) of Avocado Fruit Trial 1 11th March 2024 following removal from cold storage.

Trial 2: Shelf Life and Firmness by Fruit Size

Figure 10 provides a comparison of Days to ESL (39) and FS (54) for both small and large fruit stored at various temperatures (3°C, 5°C, 7°C, and 10°C) with or without CA treatment. This figure shows how storage conditions and fruit size impact the estimated shelf life and the time it takes for the fruit to reach firm-soft stage.

- Large fruit tended to have a shorter shelf life compared to small fruit, especially in the non-CA treatments.
- CA-treated fruit exhibited a higher ESL, regardless of fruit size, further confirming the advantages of CA storage in extending shelf life.
- The days to firm-soft measurements were generally lower for larger fruit, suggesting that they ripened more quickly, while smaller fruit took longer to soften under similar storage conditions (Figure 10). The data also indicate that cooler storage temperatures (3°C and 5°C) contributed to longer shelf life and slower ripening. However, chilling injury was observed at 3°C after 10 days and at 5°C after 20 days (Figure 7 and Figure 8).

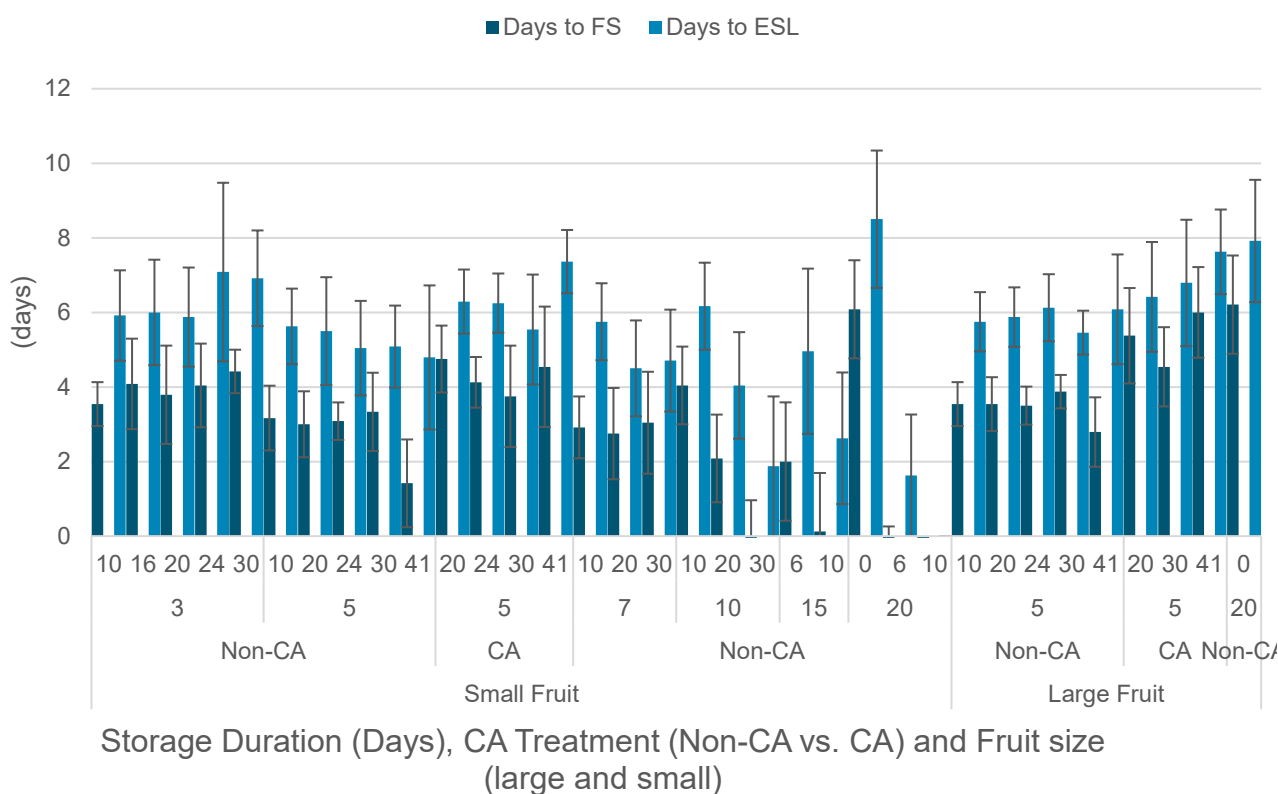


Figure 10 Comparison of Estimated Shelf Life (ESL) and Days to Firm Soft (FS) for Small and Large Avocados Under Different Storage Conditions Trial 2 14th April 2024

Summary

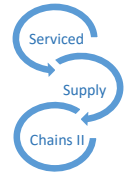
The export simulation trials with 'Shepard' avocados demonstrated how storage conditions significantly influence fruit quality and shelf life. Key findings include:

- **Firmness Retention:** Storage at 5°C, particularly with CA treatment, effectively slowed ripening and maintained firmness for up to 30 days.
- **Chilling Injury:** Internal chilling injury was observed after 20 days at 3°C and 5°C, with severity increasing at lower temperatures and longer durations.
- **Fruit Defects:** Longer storage durations resulted in higher defect levels, with Trial 1 fruit showing greater susceptibility compared to Trial 2, highlighting variability due to block-specific factors.
- **Shelf Life:** CA-treated fruit consistently exhibited a longer ESL than non-CA fruit, with small fruit demonstrating slightly better shelf-life performance than large fruit.

Recommendations

Storage at 5°C under CA conditions showed the best balance between firmness retention and chilling injury risk for storage periods up to 30 days. Treatments at 7°C and above also reduced the risk of chilling injury.

Avoid long-term storage at or below 3°C to reduce the risk of chilling injury.



- Implement block-specific monitoring of fruit maturity and quality to address variability in storage outcomes.

Use CA storage systems for seafreight shipments to extend avocado shelf life and reduce losses due to early ripening or defects.

- Limit storage durations for non-CA fruit to less than 20 days to avoid chilling injury.

Appendix 37

CQ 'Shepard' avocado simulation trials report 2024a

Predicting fruit quality and shelf life of 'Shepard' avocados

2024 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith, Andrew Mead and Andrew Macnish

Department of Primary Industries

Summary

'Shepard' avocados were exposed to a wide range of supply chain handling scenarios to quantify shelf life and quality responses. Commercially mature fruit were harvested from a farm near Childers, Queensland in 2024. The fruit were stored at 3, 5, 7, 10 and 15°C and approximately 90% relative humidity (RH) for up to 39 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and approximately 65% RH to evaluate fruit quality and remaining shelf life. The influence of controlled atmosphere (CA) storage and Akorn™ coating on fruit quality were also evaluated. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from the simulation trials included:

- Firmness changes in 'Shepard' avocados were strongly affected by storage temperature, with minimal change in firmness occurring in fruit held at 5°C or lower.
- Storage temperature effects on ripening and shelf life were negligible following storage at 3-10°C for up to 10 days, but became more apparent after longer storage periods.
- Skin darkening was a common defect in 'Shepard' avocados at medium ripe, worsening with longer storage duration.
- Internal chilling injury was a limiting factor from 20 days at 3°C and 31 days at 5°C.
- Acceptable internal quality at medium ripe was maintained following 17 days at 3°C, 20 days at 7°C and 25 days at 5°C.
- Across all storage treatments of 31 days or longer, internal defects at medium ripe exceeded consumer tolerance thresholds.
- CA extended shelf life by an average of 0.7 days and tended to reduce skin darkening compared with air.
- While CA reduced the development of body rots in long duration storage treatments, internal chilling damage severity was slightly increased in some treatments. As a result, air and CA treatments showed similar levels of unacceptable internal defects.
- Akorn™ coating reduced weight loss and increased shelf life, particularly at 20°C. Under 7°C storage, the coating treatment reduced shrivel, but increased body rots.
- Overall, the patterns shown in 2024 were very similar to those observed the previous season.
- Simple linear regression models showed a good fit to the data, particularly from 3 to 15°C, while complex modelling will likely provide more accurate predictions of shelf life.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2024 'Shepard' avocado season. The main objective of the trial was to quantify fruit quality and shelf life responses of 'Shepard' avocados to various supply chain conditions. The trial investigated the impacts of time and temperature effects, CA storage, fruit coatings and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Shepard' avocado fruit (targeting dry matter >21%) were sourced for the trial during the 2024 season. Fruit were harvested on 10th April 2024 from a farm near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the same day. On the following day they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 28 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. Fruit responses to a potential market access cold treatment were explored through treatment at 3°C for 17 days. At 5°C fruit were stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Two storage regimes were tested with and without the application of Akorn™ fruit coating at the trial start. All treatments were applied to 3 replicate trays of 10 fruit. Fruit within this trial were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored throughout the trials, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Shepard’ avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
3	0*	10	17	20	25	31
5		10		20	25	31
5+CA				20	25	31
7		10		20*		31
10		10		20		31
15		6	10			
20		6	10			

CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

Treatments marked with an asterisk were tested with and without application of Akorn™ coating

At trial commencement all fruit were weighed and firmness was measured in 30 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury and % surface area (SA) of skin darkening. Skin gloss was rated and the incidence of any shrivel was recorded. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven dry matter averaged 24%. While 30% of fruit had low DM (less than 21%), most of these were only slightly below 21%. The relationships between NIR predicted DM and oven DM were moderately strong in this trial, averaging $R^2=0.73$ (data not shown).

Weight loss

Fruit weight loss at cold removal generally tended to increase with storage time and temperature. The relative humidity (RH) of individual cool rooms also affected weight loss. After 31 days in storage at 10°C or lower, fruit lost an average of 5% of their initial weight. Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Fruit kept at 20°C lost an average 7.2% of their weight after 6 days and 11.6% after 10 days.

Firmness changes in storage treatments

Changes in fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to medium ripe stage within around 9 days. Storage at cooler temperatures progressively slowed ripening. At 3 to 5°C, firmness change was minimal, with fruit remaining hard or rubbery after 32 days. Slightly higher temperatures of 7 to 10°C delayed fruit softening, with fruit remaining in the hard to rubbery stage for around 15 days at 10°C and 25 days at 7°C.

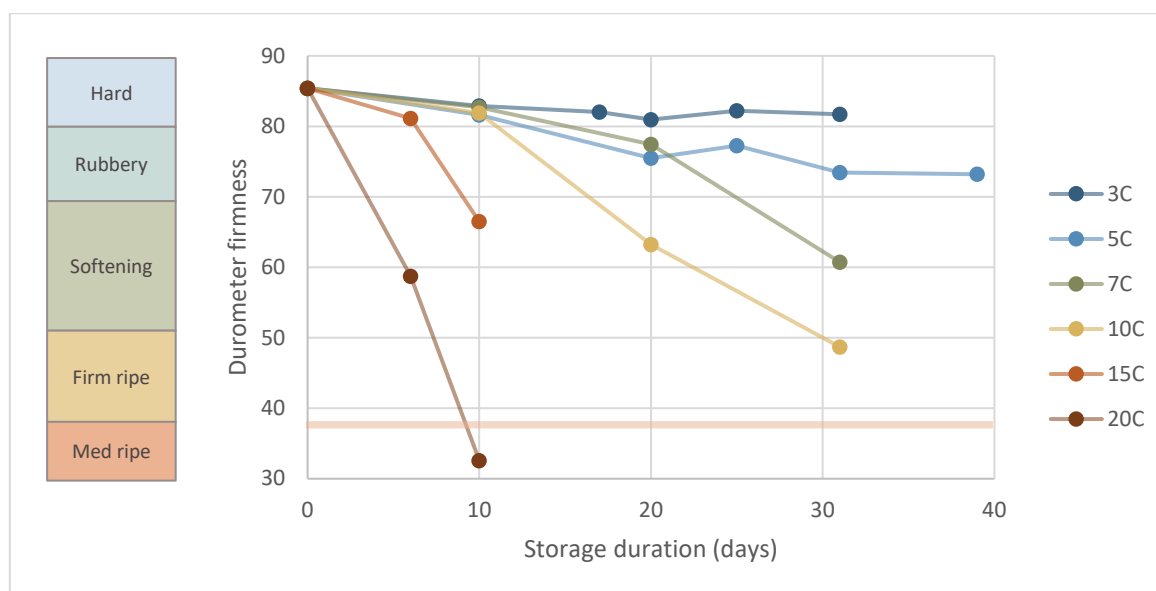


Figure 1. Changes in fruit firmness of 'Shepard' avocados during storage at various temperatures

Firmness changes during shelf life assessment at 20°C

'Shepard' avocados kept constantly at 20°C reached firm ripe stage after an average 7.7 days (Table 2). After storage at 3°C, fruit took an average of 4-5 days at 20°C to reach firm ripe, regardless of previous storage duration. At temperatures of 5°C and higher, longer duration storage and warmer storage temperatures tended to hasten subsequent softening to firm ripe at 20°C.

Table 2. Days at 20°C taken for 'Shepard' avocados to reach firm ripe after various storage treatments

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			4.6	4.2	4.7	5.1	5.2	
5			4.2		3.4	2.9	3.3	3.0
7			4.4		2.8		2.2	
10			4.4		2.0		1.5	
15		4.6	1.9					
20	7.7	1.5	-1.5					

Fruit took an average of 2.5 days to ripen from firm ripe to medium ripe. Longer stored fruit took slightly longer to soften from firm ripe to medium ripe. Fruit previously stored for 0-6 days took an average 2 days, 10-20 day treatments averaged 2.4 days, and 25 day+ treated fruit took 2.9 days.

At 20°C, observed rates of firmness change suggest that one day after reaching medium ripe the fruit would tend to be oversoft (durometer firmness 29 or lower).

Shelf life

Quality traits measured at medium ripe stage were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots exceeded 10% flesh volume. Over-softening was the key reason for fruit reaching ESL. Around 7% of fruit in the current trial were predicted to reach ESL due to rot development prior to over-softening.

The shelf life of fruit kept constantly at 20°C averaged 10.7 days (Table 3). Shelf life tended to progressively decline with increasing duration of storage, and to be lost more rapidly at higher storage temperatures (Figure 2). After 10 days of storage, remaining shelf life did not differ substantially across temperatures ranging from 3 to 10°C. Storage temperature impacts on shelf life became more apparent as storage duration increased. These patterns were very similar to trends observed in the previous season.

Residual shelf life was 6.7 days or higher in all 3 and 5°C treatments, even after prolonged storage. However, for these long storage treatments, internal chilling issues were evident at medium ripe.

Table 3. Remaining shelf life (days at 20°C) of ‘Shepard’ avocados after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			8.0	7.8	8.0*	9.0*	8.3*	
5			7.6		7.1	6.7	6.9*	6.7*
7			7.6		6.5		5.3	
10			7.5		5.3		3.4	
15		7.4	5.4					
20	10.7	4.6	0.9					

* Indicates treatments with substantial internal chilling damage (diffuse discolouration of >5% volume in >10% of treated fruit)

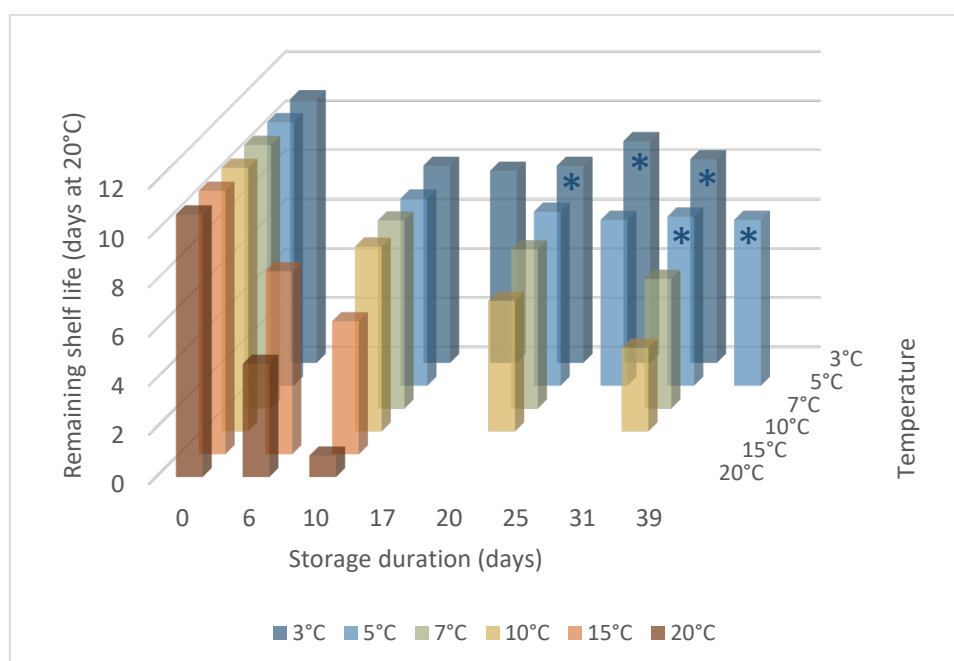


Figure 2. Remaining shelf life at 20°C of ‘Shepard’ avocados after storage at various temperatures

* Indicates treatments with substantial internal chilling damage (diffuse discolouration of >5% volume in >10% of treated fruit)

Shrivel

Shrivel was observed in many fruit at medium ripe, particularly where moisture loss exceeded 10%. This occurred both in long cool stored fruit and in fruit stored at 20°C. The relatively low RH of 65% in 20°C storage accelerated moisture loss and the risk of shrivel. Weight loss at medium ripe stage was lowest in treatments stored at 7 to 15°C, and shrivel incidence was also lowest in these treatments.

Skin chilling injury

Chilling injury on the skin was characterised by dark mottled sunken areas, particularly around the lenticels. At 3°C, very minor skin chilling was observed in fruit stored for 17 to 25 days. Following 31 days storage at 3°C, around one third of fruit showed mild to moderate skin chilling damage. Storage at 5°C resulted in some mild symptoms after 31 days, affecting less than 10% of fruit.

Skin darkening

The development of skin darkening was common, with 42% of trial fruit showing symptoms exceeding 5% SA at medium ripe (Table 4). The symptoms of skin darkening and skin chilling injury were difficult to differentiate, particularly as fruit ripened. Each fruit was assessed for signs of skin chilling injury following removal from storage. At medium ripe stage, the surface area of any skin darkening was recorded. Skin darkening was particularly prevalent when fruit ripened after long duration storage. Following storage for 31 days or longer, most fruit developed substantial skin darkening, averaging around a third of the fruit surface.



Fig 3. Skin darkening symptoms on 'Shepard' avocado

Table 4. Incidence of skin darkening exceeding 5% SA in 'Shepard' avocado fruit at medium ripe, following various storage conditions (% of fruit)

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			20	57	53	73	93	
5			27		50	63	83	90
7			20		43		57	
10			17		33		67	
15		13	30					
20	13	13	20					

Table 5. Severity of skin darkening (average % surface area across all fruit) on ‘Shepard’ avocados at medium ripe, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			6	17	17	25	42	
5			5		18	17	35	39
7			6		13		31	
10			2		10		27	
15		3	10					
20	2	4	5					

Internal chilling injury

Severe internal chilling injury was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed was also considered an early sign of internal chill damage / long storage deterioration. Significant symptoms associated with internal chilling damage started to develop after 17 days storage at 3°C, and progressively worsened with longer storage (Table 6). After 25 days most fruit stored at 3°C were affected, and damage was severe (Table 7). At 5°C, internal chilling was first observed after 20 days, similarly worsening with longer storage.

Storage treatments of 20 days+ at 3°C, or 31 days+ at 5°C caused substantial internal chilling damage (diffuse discolouration exceeding 5% volume in greater than 10% of fruit). The incidence and severity of internal chilling damage followed similar patterns to those observed in the previous season.

Table 6. Incidence of any diffuse discolouration of the flesh in ‘Shepard’ avocado fruit at medium ripe, following various storage conditions (% of fruit)

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			3	20	40	87	100	
5			0		13	40	77	83
7			0		0		23	
10			0		0		0	
15		0	0					
20	0	0	0					

Table 7. Severity of diffuse discolouration (average % flesh volume across all fruit) in ‘Shepard’ avocados at medium ripe, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			0.7	0.9	6.9	26.2	44.1	
5			0		0.9	2.1	10.3	23.2
7			0		0		2.4	
10			0		0		0	
15		0	0					
20	0	0	0					

In some previous 'Hass' trials, a correlation was found between fruit firmness at removal and diffuse discolouration severity, but this effect was not observed in the current 'Shepard' trial.

Rots

The development of rots at medium ripe stage occurred to some extent across most treatments (Table 8). Rot development tended to become progressively worse with longer storage duration. The incidence and severity of rots tended to be exacerbated at 3°C compared with other storage temperatures.

Table 8. Incidence and severity of rots in medium ripe 'Shepard' avocados after various storage conditions

Temperature	Duration (days)	Body rot incidence (%)	Body rot severity (% vol)	Stem end rot incidence (%)	Stem end rot severity (% vol)
3°C	10	10	0.3	0	0.0
	17	27	0.8	7	0.1
	20	27	1.4	33	0.6
	25	67	2.9	20	0.5
	31	87	13.0	37	3.2
5°C	10	3	0.0	10	0.2
	20	13	0.7	0	0.0
	25	20	0.5	13	0.3
	31	63	4.8	30	1.4
	39	70	7.7	20	0.4
7°C	10	7	0.1	17	0.4
	20	14	0.2	14	0.1
	31	50	7.8	33	1.9
10°C	10	0	0.0	7	0.1
	20	20	0.3	17	0.2
	31	62	3.2	41	2.4
15°C	6	17	0.8	13	0.7
	10	30	0.7	13	0.3
20°C	0	3	0.0	10	0.1
	6	17	0.6	13	0.3
	10	20	1.1	17	0.3

Consumer tolerance

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010¹). Long storage treatments caused an increase in the levels of unacceptable internal defects in medium ripe fruit (Table 9). After 20 days, fruit at 3°C started to show a decline in quality, which worsened after 25 days. Fruit quality was acceptable following storage at 5°C for 25 days. However, after 31 days fruit quality was unacceptable across all storage temperatures. The results reflect similar trends to 'Shepard' trials carried out in 2023. However, rot levels were substantially lower in 2023, and acceptable fruit quality was retained after 32 days at 5°C.

¹ Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43

Table 9. Percentage of ‘Shepard’ avocados with unacceptable internal defects at medium ripe stage, after various storage conditions.

Orange shading indicates that the treatment did not meet industry guidelines for consumer tolerance.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	6	10	17	20	25	31	39
3			3	3	33	80	100	
5			0		10	10	53	73
7			0		0		37	
10			0		3		17	
15		10	0					
20	0	3	7					

Potential for 3°C market access treatment

A storage regime of 3°C for 17 days was included in the trial design to explore the impacts of a potential market access treatment on ‘Shepard’ avocado fruit quality. The tested treatment was 1 day longer than the proposed market access regime. An increase in skin darkening issues occurred after 17 days at 3°C, with an average of 17% of the skin affected at medium ripe. Similar levels of damage were observed at 20 days across all temperatures tested. Some internal chilling injury also emerged after the market access treatment regime, with 20% of fruit showing mild signs of diffuse discolouration. In all affected fruit, 7% or less of the flesh volume was discoloured. The market access treatment resulted in only 3% of fruit having unacceptable internal defects. Overall, the ‘Shepard’ avocados used in this trial were able to tolerate 17 days at 3°C. However, this test was very preliminary in nature. Chilling susceptibility can vary widely due to pre-harvest conditions, so further rigorous testing of this regime would be essential prior to adoption.

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage. Paired treatments with and without CA were held at 5°C for periods of 20 to 39 days. CA tended to slightly reduce weight loss compared with air (Table 10). This effect has been observed in many previous trials, including ‘Shepard’ storage trials on fruit from the same farm the previous season.

Table 10. Weight loss in ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Storage duration (days)	Air		CA	
20	5.3	b	4.5	a
25	6.4	c	6.4	c
31	7.0	d	5.9	c
39	7.4	d	7.1	d

Different letters indicate a significant difference between treatments at p<0.05

Fruit firmness after storage was fairly similar across all treatments, with fruit remaining very firm after storage for up to 39 days (Table 11). CA treatment prevented the slight softening that occurred in fruit stored for long durations in air.

Table 11. Firmness in ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Storage duration (days)	Durometer firmness after storage			
	Air		CA	
20	75.5	bc	76.6	cd
25	77.2	cde	78.3	de
31	73.5	ab	78.9	e
39	73.2	a	78.9	e

Different letters indicate a significant difference between treatments at $p < 0.05$

Treatment with CA slowed ripening, particularly in the longer duration treatments (Table 12). However, CA treated fruit ripened from firm ripe to medium ripe slightly more rapidly (taking an average of 2.6 days, compared with 2.9 days in air stored fruit). Total shelf life was slightly longer in CA treated fruit, averaging 0.7 days longer than air stored fruit.

Table 12. Ripening and shelf life of ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Storage duration (days)	Days to reach firm ripe (after storage treatment)				Shelf life (days at 20°C) after storage			
	Air		CA		Air		CA	
20	3.4	ab	3.8	bc	7.1	ab	7.3	ab
25	2.9	a	3.4	ab	6.7	a	7.5	b
31	3.3	ab	4.3	cd	6.9	a	7.6	b
39	3.0	a	4.5	d	6.7	a	7.6	b

Different letters indicate a significant difference between treatments at $p < 0.05$ within each pair of columns

CA reduced the severity and incidence of skin darkening compared with air storage (Table 13). In air stored fruit, skin darkening worsened with longer duration storage. The use of CA significantly reduced the incidence of skin darkening from 25 days onwards, and reduced darkening severity at 31 and 39 days. Skin chilling injury occurred at very low levels in this trial, with no differences between CA and air treatments (data not shown).

Table 13. Skin darkening of ‘Shepard’ avocados at medium ripe stage, after storage under air or CA at 5°C for various durations

Storage duration (days)	Skin darkening severity (average % SA)				Skin darkening incidence (% fruit with >5% SA)			
	Air		CA		Air		CA	
20	17.9	b	9.1	ab	50	bc	33	ab
25	17.4	ab	10.0	ab	63	cd	33	ab
31	34.8	c	6.8	a	83	de	23	a
39	38.9	c	13.2	ab	90	e	50	bc

Different letters indicate a significant difference between treatments at $p < 0.05$ within each pair of columns

CA significantly reduced body rot volume and incidence following storage periods of 31 days and longer (Table 14). Body rot severity and incidence tended to increase with storage duration when fruit were stored in air, particularly after 31 days.

Table 14. Body rot severity and incidence in ‘Shepard’ avocados at medium ripe stage, after storage under air or CA at 5°C for various durations

Storage duration (days)	Body rot severity (average % SA)				Body rot incidence (% fruit)			
	Air		CA		Air		CA	
20	0.7	a	0.2	a	13	a	7	a
25	0.5	a	0.5	a	20	ab	23	ab
31	4.8	b	0.9	a	63	c	13	a
39	7.7	c	5.0	b	70	c	40	b

Different letters indicate a significant difference between treatments at $p < 0.05$ within each pair of columns

The incidence of diffuse discolouration was similar under CA and air (Table 15). Diffuse discoloration severity was slightly higher in CA treated fruit at day 25 and 31, compared with air. Vascular browning occurred at very low levels and was reduced by CA compared with air. In contrast, stem end rot incidence and severity remained similar under CA and air (data not shown).

Table 15. Severity of flesh defects (average % flesh volume across all fruit) in ‘Shepard’ avocados at medium ripe stage, after storage under air or CA at 5°C for various durations

Storage duration (days)	Diffuse discolouration severity (average % flesh volume across all fruit)		Diffuse discolouration incidence (% of fruit)		Vascular browning severity (average % flesh volume across all fruit)	
	Air	CA	Air	CA	Air	CA
20	0.9 a	0.0 a	13 a	0 a	0.83 b	0 a
25	2.1 ab	11.8 c	40 b	40 b	0.03 a	0 a
31	10.3 bc	24.2 d	77 cd	73 c	0.77 b	0 a
39	23.2 d	26.2 d	83 cd	93 d	0.23 ab	0 a

Different letters indicate a significant difference between treatments at $p < 0.05$ within each pair of columns

Total internal defect volume at medium ripe increased with storage time but was not significantly different between air and CA storage (data not shown). Similarly, the percentage of unacceptable fruit increased with duration, but was generally similar under air and CA (Table 16). The difference shown between air and CA stored fruit at 25 days was caused by the slight increase in diffuse discolouration volume shown in CA treated fruit.

Table 16. Percentage of ‘Shepard’ avocados with unacceptable internal defects at medium ripe stage, after storage under air or CA at 5°C for various durations.

Storage duration (days)	Unacceptable internal defects (% fruit)	
	Air	CA
20	10 c	0 c
25	10 c	40 b
31	53 ab	57 ab
39	73 a	73 a

Different letters indicate a significant difference between treatments at $p < 0.05$

Akorn™ fruit coating

Akorn™ coating treatment was applied to 2 different treatment regimes to test effects on fruit quality and shelf life. Fruit coatings were tested at constant 20°C storage and at 7°C for 20 days prior to shelf life assessment at 20°C.

The coating reduced weight loss significantly (Table 17). At 20°C, Akorn™ reduced daily rates of weight loss by a third from 1.2% to 0.8%. Rates of loss at 7°C were also reduced, from 0.13% to 0.11%.

Table 17. Weight loss in ‘Shepard’ avocados with and without Akorn™ coating.

Storage regime	Weight loss at 20 days (%)			Weight loss at medium ripe (%)		
	No coating	Coating	p-value	No coating	Coating	p-value
20°C ongoing	-	-	-	11.4	9.3	<0.001
7°C for 20d	2.6	2.3	0.001	9.2	8.2	0.001

Akorn™ coating significantly slowed ripening and extended shelf life in Shepard avocados kept constantly at 20°C (Table 18). Under this regime, shelf life was 2.7 days longer using the coating treatment. The effect was not as strong in fruit stored at 7°C for 20 days, with shelf life increasing by only 0.6 days.

Table 18. Ripening and shelf life in ‘Shepard’ avocados with and without Akorn™ coating.

Storage regime	Days to firm soft (at 20°C)			Shelf life (days at 20°C)		
	No coating	Coating	p-value	No coating	Coating	p-value
20°C ongoing	7.7	9.8	<0.001	10.7	13.3	<0.001
7°C for 20d	2.8	3.3	nsd	6.5	7.1	0.015

Nsd indicates no significant difference between coating and non-coating treatments at $p < 0.05$

Body rot volume was significantly increased by Akorn™ coating under the 7°C regime, but was unaffected at 20°C (Table 19). In fruit kept at 7°C, the incidence of body rots increased from 14 to 53% with coating. In contrast, shrivel incidence was reduced by coating in fruit kept at 7°C. Other defects such as skin darkening, gloss and stem end rots were not affected by the coating treatment (data not shown).

Table 19. Defects in ‘Shepard’ avocados with and without Akorn™ coating.

Storage regime	Body rot volume (average % of flesh affected)			Shrivel (% of fruit affected at medium ripe)		
	No coating	Coating	p-value	No coating	Coating	p-value
20°C ongoing	0.03	0.43	nsd	73	50	nsd
7°C for 20d	0.21	2.03	0.024	63	27	0.004

Nsd indicates no significant difference between coating and non-coating treatments at $p < 0.05$

Shelf life models

A preliminary linear regression of shelf life against time temperature units (TTUs) is shown in Figure 4. Chill affected treatments were excluded from this plot (diffuse discolouration of >5% volume in >10% of treated fruit). The linear regression of tray average values plotted across all temperatures shows a moderate fit ($R^2 = 0.66$)². The 20°C treatments show a more rapid loss of shelf life against TTUs than cooler storage

² The R^2 value is a statistical measure of 0 to 1 that represents the proportion of the variance for a dependent variable (shelf life) that is explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

temperatures. This response was also shown in data from the previous season. Lower RH at 20°C may have contributed to the more rapid loss of shelf life per TTU. From 3 to 15°C, a linear TTU model fits extremely well ($R^2=0.95$) (Figure 5). A simple TTU linear model may give some indication of 'Shepard' avocado shelf life. Complex modelling approaches undertaken on multi-season data sets will provide a more sound basis for accurate predictions.

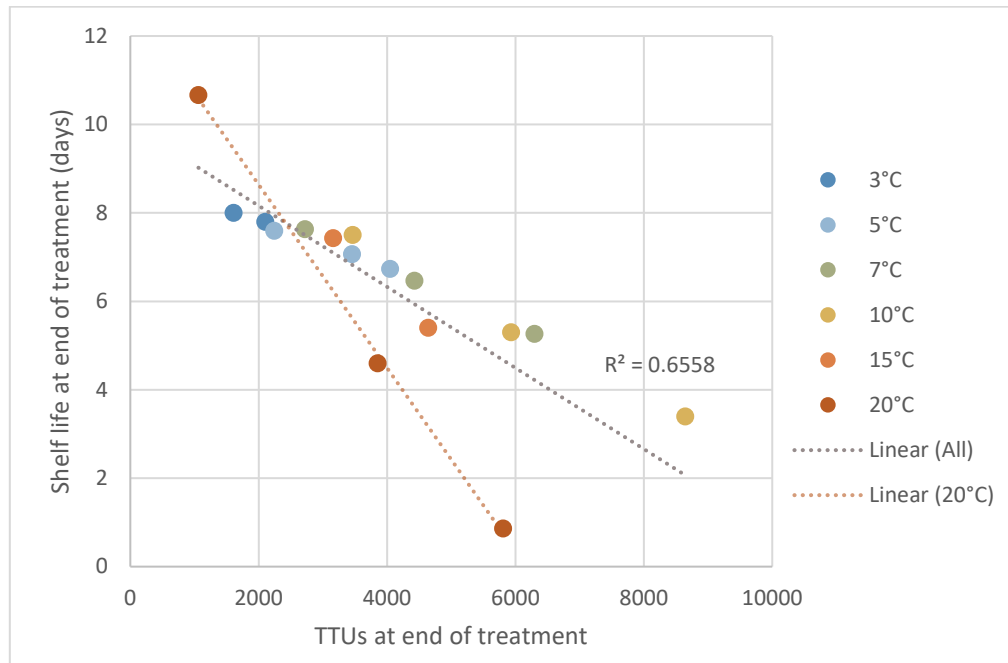


Figure 4 Preliminary linear regression of shelf life and TTUs across all storage temperatures for CQ 'Shepard' avocados (tray average values)

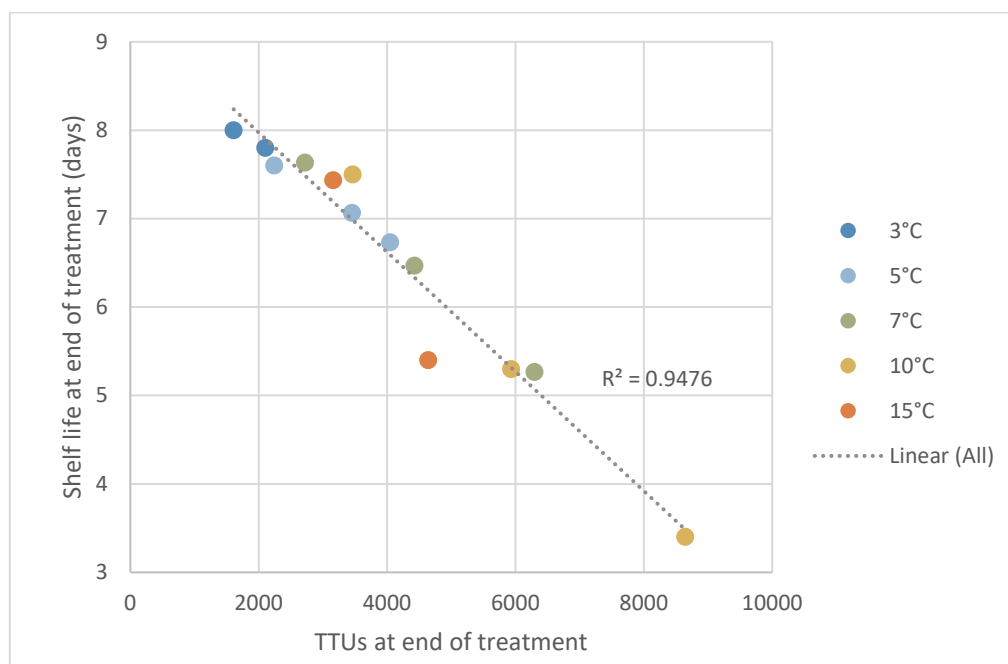


Figure 5 Preliminary linear regression of shelf life and TTUs from 3 to 15°C for CQ 'Shepard' avocados (tray average values)



4. Summary and recommendations

- Storage at 5°C is recommended for the best overall quality and shelf life in 'Shepard' avocados.
- In this trial, storage for up to 25 days at 5°C maintained acceptable fruit quality.
- Preliminary testing of a potential market access treatment (16 days at 3°C) was tolerated by 'Shepard' avocados.
- Internal chilling injury was a limiting factor to long storage from 20 days at 3°C and 31 days at 5°C.
- CA slightly extended shelf life, reduced skin darkening and helped to control body rots in long storage treatments.
- However, CA treated fruit showed a slight increase in internal chilling in some treatments, resulting in overall internal quality being similar between air and CA.
- Simple linear regression using TTUs showed excellent potential to predict shelf life in fruit stored at 3 to 15°C.
- Consistent outcomes across 2 seasons of 'Shepard' trials will provide a solid foundation for complex multi-season models.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 38

CQ 'Shepard' avocado simulation trials report 2024b

Predicting fruit quality and shelf life of 'Shepard' avocados

2024 season Central Queensland grower report

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Summary

'Shepard' avocados were exposed to a wide range of supply chain handling scenarios to quantify shelf life and quality responses. Commercially mature fruit were harvested from a farm near Childers, Queensland in 2024. The fruit were stored at 3, 5, 7, 10 and 15°C and approx. 90% relative humidity (RH) for up to 40 days. Sub-samples of fruit were regularly removed from storage and held at 20°C and approx. 65% RH to evaluate fruit quality and remaining shelf life. The influence of controlled atmosphere (CA) storage and Akorn™ coating on fruit quality were also evaluated. Data from this trial will be used to improve shelf life and fruit quality prediction models.

Key observations from the simulation trials included:

- Firmness changes in 'Shepard' avocados were strongly affected by storage temperature, with minimal change in firmness occurring in fruit held at 7°C or lower.
- Shelf life tended to decrease with increasing storage temperature and duration, following similar patterns to those shown the previous season.
- Skin darkening was a common defect in 'Shepard' avocados at medium ripe, worsening with longer storage duration. A noticeable increase in skin darkening occurred when storage duration was 20 days or longer.
- Large fruit were much more susceptible to skin darkening and internal chilling than small fruit.
- Internal chilling injury was a limiting factor in small fruit from 26 days at 3°C and 40 days at 5°C.
- For large fruit, internal chilling was limiting after 20 days storage at 5°C.
- Internal quality at medium ripe tended to worsen with longer storage duration. More internal quality issues occurred in large fruit than in small.
- Rots were a significant issue in this trial, particularly in large fruit.
- CA slightly extended shelf life in small fruit and tended to reduce skin darkening in large fruit compared with air.
- In this 'Shepard' trial, CA provided some benefits during long duration storage, but these were not as strong as usually seen in 'Hass'.
- A potential market access treatment of 3°C for 16 days did not cause any quality issues in this batch of fruit.
- Akorn™ coating reduced weight loss and increased shelf life by 1-2 days but resulted in duller skin appearance.
- Under 7°C storage, Akorn™ reduced body rots, skin darkening and shrivel.
- Overall, the patterns shown in 2024 were very similar to those observed the previous season.
- Simple linear regression models showed a good fit to the data, particularly from 3 to 15°C, while more complex modelling will provide more accurate predictions of shelf life.



1. Introduction

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2024 Central Queensland 'Shepard' avocado season. The main objective of the trial was to quantify fruit quality and shelf life responses of 'Shepard' avocados to various supply chain conditions. The trial investigated the impacts of time and temperature effects, CA storage, fruit coatings and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

2. Materials and methods

Commercially mature 'Shepard' avocado fruit (targeting dry matter >21%) were sourced for the trial during the 2024 season. Fruit were harvested on 14th April (main trial) and 15th April (coating trial) from a farm near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the same day. On the 15th April they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 28 and 23 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to different storage temperatures designed to reflect potential air and sea freight conditions as shown in Table 1. Fruit responses to a potential market access cold treatment were explored through treatment at 3°C for 16 days. At 5°C fruit were stored with or without controlled atmosphere (CA) at 2% O₂ and 5% CO₂. Two storage regimes were tested with and without the application of Akorn™ fruit coating at the trial start. All treatments were applied to 3 replicate trays of 10 small (count 28) fruit. A subset of treatments was also applied to large (count 23) fruit. Fruit within this trial were not treated with ethylene. At the end of each treatment storage duration, fruit were shifted to 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored throughout the trial, commencing at the pack shed. The total time x temperature units (TTU) accrued by each tray was calculated from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Shepard’ avocado fruit.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage					
3	0 ^{L*}	9	16 ^L	20	26	30
5		9 ^L		20 ^L	26 ^L	30 ^L
5+CA				20 ^L	26 ^L	30 ^L
7		9		20*		30
10		9		20		30
15		5	9			
20		5	9			

CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

Treatments marked with L were tested on trays of large (count 23) and small (count 28) fruit

Treatments marked with an asterisk were tested with and without application of Akorn™ coating

At trial commencement all fruit were weighed and firmness was measured in 30 large and 30 small fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were transferred to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% volume. Skin defects were recorded, including chilling injury and % surface area (SA) of skin darkening. Skin gloss was rated and the incidence of any shrivel was recorded. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

3. Results

Dry matter

Fruit oven dry matter averaged 25.9% in small fruit and 24.2% in large fruit. The relationships between NIR predicted DM and oven DM were moderately strong in this trial, averaging $R^2=0.7$ (data not shown).

Weight loss

Fruit weight loss at cold removal generally tended to increase with storage time and temperature. The relative humidity (RH) of individual cool rooms also affected weight loss. Across all treatments at 15°C or lower, weight loss remained at 5% or lower. Weight loss occurred rapidly at 20°C, due to the higher temperature and lower RH. Small fruit kept at 20°C lost an average 5.5% of their weight after 5 days and 9.6% after 9 days.

Firmness changes in storage treatments

Changes in small fruit firmness during storage at different temperatures are presented in Figure 1. As would be expected, rates of firmness change were strongly affected by storage temperature. At 20°C, fruit ripened rapidly, softening to medium ripe stage within around 8 days. Storage at cooler temperatures progressively slowed ripening. In this trial, a substantial difference was shown between 20 and 15°C, while in the previous season, the temperature effect on firmness change was more gradual. At 3 to 7°C, firmness change was minimal, with fruit remaining hard or rubbery after 30-40 days. Across the storage regimes tested, firmness changes in large fruit were similar to those shown in small fruit (data not shown).

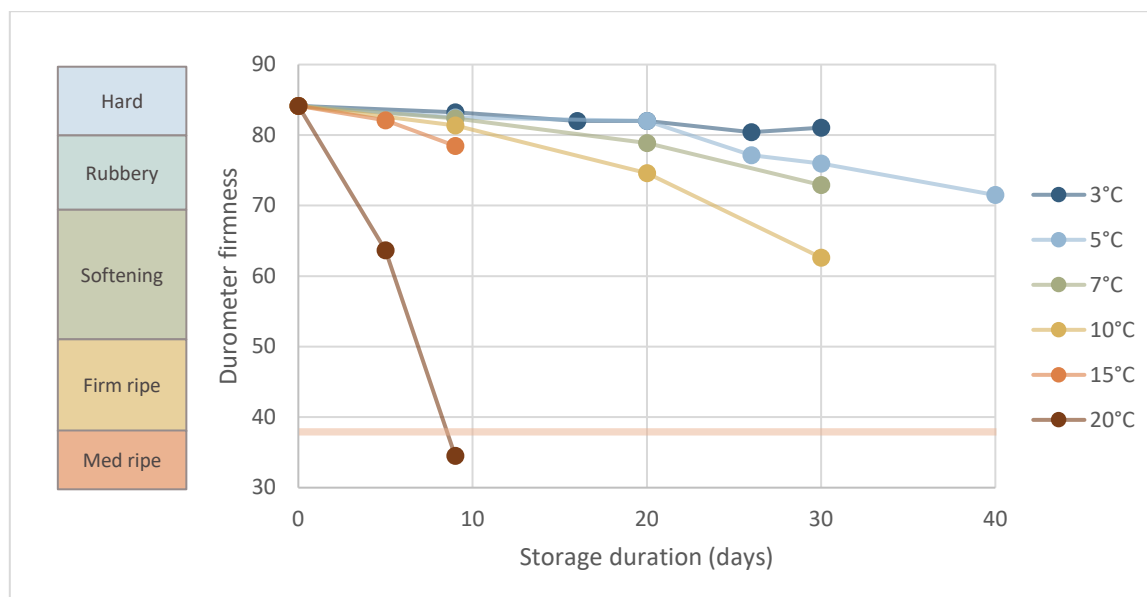


Figure 1. Changes in small fruit firmness of 'Shepard' avocados during storage at various temperatures

Firmness changes during shelf life assessment at 20°C

Small 'Shepard' avocados kept constantly at 20°C reached firm ripe stage after an average 7.8 days (Table 2). After storage at 3°C, fruit took an average of around 4 days at 20°C to reach firm ripe, regardless of previous storage duration. At temperatures of 5°C and higher, longer duration storage and warmer storage temperatures tended to hasten subsequent softening to firm ripe at 20°C.

Table 2. Days at 20°C taken for small 'Shepard' avocados to reach firm ripe after various storage treatments

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	5	9	16	20	26	30
3			4.6	3.8	4.5	4.0	4.1
5			4.7		3.6	3.5	2.6
7			5.2		3.1		2.3
10			6.1		2.9		1.4
15		5.1	3.6				
20	7.8	2.2	-2.3				

Small fruit took an average of 2.2 days to ripen from firm ripe to medium ripe. At 20°C, observed rates of firmness change suggest that one day after reaching medium ripe the fruit would tend to be oversoft (durometer firmness 29 or lower).

Large fruit took an average of 0.5 days longer to reach firm ripe than small fruit, with fruit kept at 20°C taking 8.1 days. Large fruit also took slightly longer to soften from firm ripe to medium ripe compared with small fruit, averaging 0.5 days longer across the treatment regimes tested.

Shelf life

Quality traits measured at medium ripe stage were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots exceeded 10% flesh volume. Over-softening was the key reason for fruit reaching ESL. Around 12% of small fruit in the current trial were predicted to reach ESL due to rot development, prior to over-softening. Body rots were prevalent as a cause of ESL in large fruit, particularly following long storage treatments. Body rots were the primary cause of ESL in around a third of large fruit stored for 26 days or longer at 5°C (data not shown).

The shelf life of small fruit kept constantly at 20°C averaged 10.2 days (Table 3). Shelf life tended to progressively decline with increasing duration of storage, and to be lost more rapidly at higher storage temperatures (Figure 2). The patterns shown were very similar to the previous season. One exception was the unusually long shelf life remaining after 9 days of storage for 10°C stored fruit. Interestingly, this cool room had particularly high RH, running at an average 97.6%, while other cool rooms averaged 84 to 92% RH. It is possible that high RH may have contributed to the longer than expected shelf life in this treatment. Storage temperature impacts on shelf life widened as storage duration increased. These patterns were very similar to trends observed in the previous season.

Residual shelf life remained at around 6 days or higher in all 3 and 5°C treatments, even after prolonged storage. However, for some of these long storage treatments, internal chilling issues were revealed when fruit were cut open at medium ripe.

Table 3. Remaining shelf life (days at 20°C) of small ‘Shepard’ avocados after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage						
	0	5	9	16	20	26	30
3			7.3	6.8	7.1	7.4*	7.7*
5			7.6		7.0	6.7	5.7
7			8.1		6.4		5.0
10			8.9		5.9		3.8
15		7.9	6.2				
20	10.2	5.2	1.1				

* Indicates treatments with substantial internal chilling damage (diffuse discolouration of >5% volume in >10% of treated fruit)

Shelf life in large fruit averaged 0.7 days longer than in small fruit. Large and small fruit followed similar trends in shelf life across the storage regimes tested (data not shown).

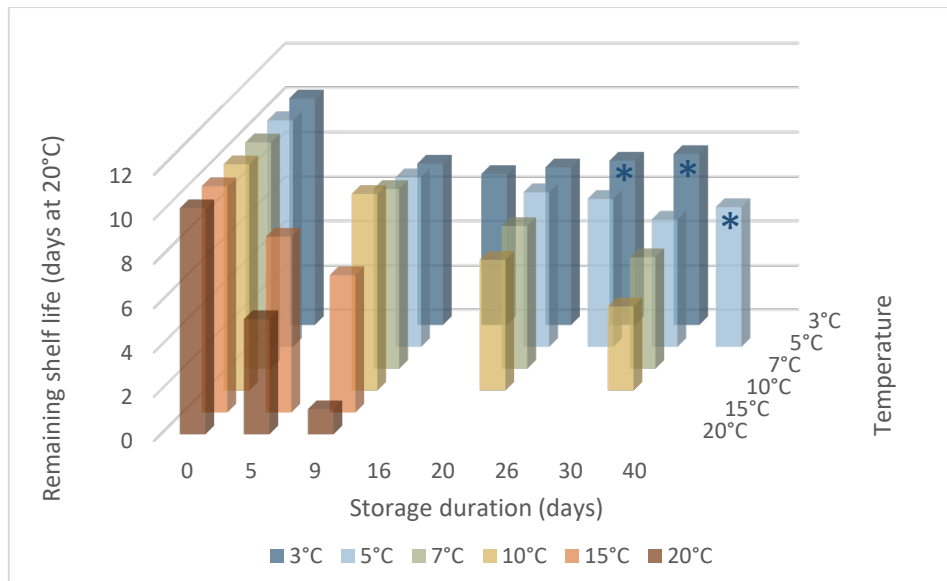


Figure 2. Remaining shelf life at 20°C of small 'Shepard' avocados after storage at various temperatures

* Indicates treatments with substantial internal chilling damage
(diffuse discolouration of >5% volume in >10% of treated fruit)

Shrivel

Shrivel was observed in many fruit at medium ripe, particularly where moisture loss exceeded 10%. Small fruit were more prone to shrivel than large fruit, as has been observed in previous trials. Shrivel occurred in both long cool stored fruit and fruit stored at 20°C. The relatively low RH of 65% during 20°C shelf life assessment accelerated moisture loss and the risk of shrivel.

Skin chilling injury

Chilling injury on the skin was characterised by dark mottled sunken areas, particularly around the lenticels. At 3°C, very minor skin chilling was observed in fruit stored for 20 days or longer. In this trial, storage at 5°C did not result in any significant skin chilling.

Skin darkening

The development of skin darkening was reasonably common, with 24% of small fruit showing symptoms exceeding 5% SA at medium ripe. The symptoms of skin darkening and skin chilling injury were difficult to differentiate, particularly as fruit ripened. Each fruit was assessed for signs of skin chilling injury following removal from storage. At medium ripe stage, the surface area of any skin darkening was recorded. Skin darkening was particularly prevalent when fruit ripened after long duration storage (Table 4). A noticeable increase in skin darkening occurred when storage duration was 20 days or longer (Table 5).



Fig 3. Skin darkening symptoms on 'Shepard' avocado

Table 4. Incidence of skin darkening exceeding 5% SA in small ‘Shepard’ avocado fruit at medium ripe, following various storage conditions (% of fruit)

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	5	9	16	20	26	30	40
3			3	3	17	40	47	
5			7		13	30	13	37
7			7		23		30	
10			7		30		43	
15		3	7					
20	7	0	3					

Table 5. Severity of skin darkening (average % surface area across all fruit) on small ‘Shepard’ avocados at medium ripe, after various storage conditions

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	5	9	16	20	26	30	40
3			0.6	1.1	6.0	8.6	16.1	
5			2.9		4.3	6.2	6.4	9.3
7			1.0		6.3		6.4	
10			1.2		7.5		9.2	
15		0.9	1.3					
20	1.4	0.6	0.6					

Large fruit were much more susceptible to skin darkening, as has been observed in previous trials (Table 6). The incidence and severity of skin darkening in large fruit increased with long duration storage. In fruit kept at 5°C for 26 days or longer, most large fruit developed significant skin darkening, on average affecting around a quarter of the fruit skin.

Table 6. Skin darkening incidence and severity at medium ripe in large and small ‘Shepard’ avocados, after various storage conditions.

Storage temp (°C)	Storage duration (days)	Skin darkening incidence (% of fruit with >5% SA)			Skin darkening severity (average % SA across all fruit)		
		Large	Small	p-value	Large	Small	p-value
20	0	30	7	0.019	8	1	0.035
3	16	17	3	nsd	5	1	0.045
5	9	23	7	nsd	4	3	nsd
5	20	40	13	0.019	11	4	nsd
5	26	70	30	0.002	28	6	<0.001
5	30	63	13	<0.001	24	6	0.003
5	40	77	37	0.001	44	9	<0.001

Nsd indicates no significant difference between paired large and small fruit treatments at p<0.05

Internal chilling injury

Severe internal chilling injury was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed was also considered an early sign of internal chill damage / long storage deterioration. Large fruit in this trial were much more prone to internal chilling damage than small fruit (Table 7). Symptoms of diffuse

discolouration were more common and more severe in large fruit across all paired treatments. This response was not seen in the previous season, where large and small fruit from this farm showed similar low levels of damage. However, greater susceptibility to chilling in large fruit has been observed previously in 'Shepard' avocados from other sites.

In small fruit, very mild internal chilling was first seen after 20 days at 3°C. Significant symptoms started to develop after 26 days storage at 3°C, and these worsened after 30 days. At 5°C, very mild damage was seen after 26 days, and significant internal chilling occurred following 40 days of storage. Large fruit showed mild chilling after 16 days at 3°C, and significant chilling in all 5°C treatments of 20 days or longer.

Table 7. Incidence and severity of internal chilling damage (diffuse discolouration of the flesh) in small and large 'Shepard' avocado fruit at medium ripe, following various storage conditions

Storage temperature	Storage duration (days)	Internal chilling incidence (% of fruit)		Internal chilling severity (average % volume across all fruit)	
		Large	Small	Large	Small
3°C	16	13	0	1.4	0
	20		7		2.3
	26		20		2.8
	30		43		11.1
5°C	20	20	0	3.2	0
	26	40	3	4.0	0.1
	30	33	0	4.3	0
	40	80	33	32.8	2.8
7°C	30		3		0.1

Large fruit that came out of cold storage slightly softer were more prone to internal chilling damage. A weak to moderate correlation was shown between fruit firmness at removal and diffuse discolouration severity (*correlation co-efficient* -0.38¹). This effect has been observed in 'Hass' fruit in previous trials. A moderate correlation was also shown between internal chilling damage and skin darkening (*correlation co-efficient* 0.54), indicating that these two defects commonly occurred together in the same fruit.

Rots

The development of rots at medium ripe stage occurred to some extent across all treatments (Table 8). Large fruit were more prone to rots than small fruit, showing higher incidence and severity of both body rots and stem end rots.

Rot incidence was notably worse in 2024 than the previous season. Overall, 16.3% of small fruit showed signs of body rot at medium ripe in 2024, compared with 3.1% in 2023. Stem end rot incidence was also higher, at 12.6% in 2023 and 23.9% in 2024. A wetter than usual growing season, and heavy rainfall a week prior to harvest likely contributed to these issues.

Rot development tended to become progressively worse with longer storage duration. Both the incidence and severity of body rots was exacerbated by long storage duration. Stem end rots tended to worsen under warm storage temperatures and were particularly high following 10°C storage treatments. The very high RH in the 10°C cool room may have exacerbated these issues.

¹ The correlation coefficient measures the strength and direction of a linear relationship between two variables. The value can range from +1 (both variables increasing together in a perfect linear relationship) to -1 (a perfect negative relationship), with 0 indicating no correlation.

Table 8. Incidence and severity of rots in medium ripe small ‘Shepard’ avocados after various storage conditions

Storage temperature	Storage duration (days)	Body rot incidence (%)		Body rot severity (% vol)		Stem end rot incidence (%)		Stem end rot severity (% vol)	
		Large	Small	Large	Small	Large	Small	Large	Small
3°C	9		7		0.4		7		0.2
	16	30	7	1.6	0.1	30	10	3.6	0.6
	20		13		0.8		0		0
	26		23		1.3		13		1.7
	30		50		6.7		30		1.3
5°C	9	23	3	0.3	0.5	20	3	1.1	0.1
	20	60	3	3.6	0.1	50	13	2.6	0.4
	26	73	20	9.4	0.3	30	20	2.0	2.1
	30	70	17	9.1	0.7	47	3	4.0	0.1
	40	87	37	8.9	1.7	53	23	2.3	1
7°C	9		10		0.1		17		0.4
	20		10		0.2		13		0.4
	30		27		1.2		20		1.1
10°C	9		7		0.1		40		3
	20		20		0.5		53		2.8
	30		40		3.9		73		9.2
15°C	5		7		0.1		43		3.1
	9		20		0.3		43		1.8
20°C	0	43	7	1.4	0.2	47	13	4.8	1.6
	5		7		0.1		27		1.9
	9		10		0.1		37		1.2

Consumer tolerance

Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010²). The incidence of unacceptable fruit due to internal defect issues was highly variable across treatments (Table 9). Overall, the levels of unacceptable fruit were much higher than the previous season, with increased rot incidence the main cause. There was a tendency for longer storage duration to increase internal defect issues. Large fruit consistently showed much higher incidence of unacceptable defects than small fruit (Table 10).

² Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43

Table 9. Percentage of small ‘Shepard’ avocados with unacceptable internal defects at medium ripe stage, after various storage conditions.

Storage temperature (°C)	Storage duration (days) prior to ongoing 20°C storage							
	0	5	9	16	20	26	30	40
3			13	17	13	37	57	
5			7		17	33	20	53
7			27		20		43	
10			43		57		80	
15		47	53					
20	17	30	47					

Table 10. Effect of fruit size on percentage of ‘Shepard’ avocados with unacceptable internal defects at medium ripe stage, after various storage conditions.

Storage temperature (°C)	Storage duration (days)	Large	Small
3	16	43	17
5	9	37	7
5	20	70	17
5	26	87	33
5	30	77	20
5	40	93	53
20	0	67	17

Potential for 3°C market access treatment

A storage regime of 3°C for 16 days was included in the trial design to explore the impacts of a potential market access treatment on ‘Shepard’ avocado fruit quality. The treatment did not cause any issues with skin chilling or darkening, and did not cause any internal chilling damage in small fruit. Large fruit showed some minor internal chilling damage. Overall, fruit quality was generally comparable to the 5°C 20 day treatment. The ‘Shepard’ avocados used in this trial were able to tolerate a market access treatment of 16 days at 3°C. However, this test was very preliminary in nature. Chilling susceptibility can vary widely due to pre-harvest conditions, so further rigorous testing of this regime would be essential prior to adoption.

Fruit quality under controlled atmosphere (CA) versus air

Controlled atmosphere storage (2% O₂ and 5% CO₂) was compared with air storage for both large and small fruit sizes. Paired treatments with and without CA were held at 5°C for periods of 20 to 40 days. CA tended to slightly reduce weight loss compared with air. Average weight loss under air was 4.2% and under CA was 3.8%. This effect has been observed in many previous trials, including ‘Shepard’ storage trials on fruit from this farm the previous season.

CA treatment prevented the slight softening that occurred in fruit stored for long durations in air (Table 11). Small fruit showed slightly more softening than large fruit during storage in air, so the benefits of CA were more pronounced. Significant effects were shown from 26 days onwards in small fruit.

Table 11. Durometer firmness of large and small ‘Shepard’ avocados stored under air or CA at 5°C for various durations

Storage duration (days)	Large fruit				Small fruit			
	Air		CA		Air		CA	
20	82.2	gh	82.9	h	82.0	gh	80.7	fg
26	80.9	fg	81.8	gh	77.2	cd	79.8	ef
30	79.5	ef	80.3	f	76.0	bc	78.6	de
40	74.7	b	76.3	c	71.5	a	76.1	bc

Different letters indicate a significant difference between treatments at $p < 0.05$

Treatment with CA slowed ripening to firm ripe stage, particularly in the longer duration treatments (Table 12). However, CA treated fruit softened from firm ripe to medium ripe slightly more rapidly (taking an average of 2.3 days, compared with 2.8 days in air stored fruit).

Table 12. Days at 20°C taken for ‘Shepard’ avocados to reach firm ripe after various storage treatments under air or CA at 5°C

Storage duration (days)	Large fruit				Small fruit			
	Air		CA		Air		CA	
20	4.8	fg	5.1	g	3.6	bc	4.9	fg
26	3.9	cd	4.5	ef	3.5	b	4.1	d
30	3.5	bc	4.1	de	2.6	a	3.3	b
40	2.6	a	4.3	de	2.4	a	4.3	de

Different letters indicate a significant difference between treatments at $p < 0.05$

Shelf life was slightly extended by CA for small fruit, while for large fruit shelf life was similar under CA and air (Table 13). After 20 days of storage, CA extended small fruit shelf life by 0.6 days. From 26 days onward, the shelf life of CA treated small fruit was around 1 day longer than under air.

Table 13. Remaining shelf life (days at 20°C) of large and small ‘Shepard’ avocados after various storage treatments under air or CA at 5°C

Storage duration (days)	Large fruit				Small fruit			
	Air		CA		Air		CA	
20	7.8	f	7.9	f	7.0	cd	7.6	ef
26	7.6	ef	7.9	f	6.7	bcd	7.6	ef
30	6.7	bcd	7.2	de	5.7	a	6.6	bc
40	6.9	bcd	7.1	cde	6.3	ab	7.2	cde

Different letters indicate a significant difference between treatments at $p < 0.05$

CA reduced skin darkening in large fruit stored for 26 days or longer (Table 14). Both the severity and incidence of skin darkening were significantly reduced by CA compared with air. Skin darkening incidence in small fruit was reduced by CA in the 40 day storage treatment.

Table 14. Skin darkening of ‘Shepard’ avocados at medium ripe stage, after storage under air or CA at 5°C for various durations

Storage duration (days)	Large fruit				Small fruit			
	Air		CA		Air		CA	
Skin darkening severity (average %SA across all fruit)								
20	11.3	cd	9.6	bcd	4.3	abcd	0.3	a
26	28.2	e	7.6	abcd	6.2	abcd	3.1	abc
30	23.9	e	6.1	abcd	6.4	abcd	3.4	abc
40	44.1	f	12.3	d	9.3	bcd	1.6	ab
Skin darkening incidence (% of fruit with >5%SA)								
20	40.0	de	40.0	de	13.3	ab	0.0	a
26	70.0	g	30.0	bcde	30.0	bcde	16.7	abc
30	63.3	fg	20.0	abcd	13.3	ab	16.7	abc
40	76.7	g	43.3	ef	36.7	cde	10.0	ab

Different letters indicate a significant difference between treatments at $p < 0.05$

Overall CA slightly reduced body rot severity and incidence compared with air, but the effect was not strong or consistent across treatments (data not shown). CA did not affect the development of internal chilling damage or stem end rot (data not shown). The total percentage of unacceptable fruit was also very similar under air and CA (data not shown). Overall, CA provided some minor improvements to shelf life and quality in ‘Shepard’ avocados, but these effects were not as striking as has been consistently seen in ‘Hass’.

Akorn™ fruit coating

Akorn™ coating treatment was tested under 2 different treatment regimes to determine effects on fruit quality and shelf life. The coating was tested at constant 20°C storage and at 7°C for 20 days prior to shelf life assessment at 20°C.

Use of Akorn™ reduced weight loss significantly (Table 15). Akorn™ reduced rates of weight loss by around 25% at 7°C. Total weight lost at medium ripe was also significantly lower in coated fruit. Following storage at 7°C for 20 days, coated fruit were slightly firmer than uncoated controls. Akorn™ delayed ripening by around 1 day, and extended shelf life by 1-2 days.

Table 15. Weight loss, firmness, ripening and shelf life in ‘Shepard’ avocados with and without Akorn™ coating.

Trait	At constant 20°C			7°C for 20days		
	No coating	Coating	p-value	No coating	Coating	p-value
Weight loss after storage (%)				2.2	1.6	<0.001
Weight loss at medium ripe (%)	9.7	8.7	0.009	7.8	6.7	<0.001
Durometer firmness after storage				73.5	78.7	<0.001
Days to reach firm ripe	8.9	9.8	0.009	4.0	5.3	<0.001
Days from firm ripe to medium ripe	2.0	2.8	0.003	2.3	2.0	nsd
Shelf life following storage	11.8	13.5	<0.001	7.3	8.3	<0.001

Nsd indicates no significant difference between coating and non-coating treatments at $p < 0.05$

Body rot severity was significantly reduced by Akorn™ coating under the 7°C regime, but was unaffected at 20°C. Stem end rots were not affected by the coating treatment (data not shown). Skin darkening incidence and severity were reduced by the coating, following 7°C storage. The coating treatment also reduced

shivel, with a significant effect shown in fruit kept at 20°C. However, coated fruit tended to have less gloss and appear more dull at medium ripe compared with untreated fruit.

Table 16. Defects in ‘Shepard’ avocados with and without Akorn™ coating.

Trait	At constant 20°C			7°C for 20days		
	No coating	Coating	p-value	No coating	Coating	p-value
Body rot severity (% volume)	0.0	0.1	nsd	1.3	0.5	0.029
Body rot incidence (% of fruit)	0	10	nsd	43	23	nsd
Skin darkening severity (%SA)	1.8	2.3	nsd	20.9	8.2	0.018
Skin darkening incidence (>5%)	10	13	nsd	60	33	0.039
Shrivel incidence (% of fruit)	80	53	0.029	23	7	nsd
Skin gloss score (1=glossy, 0=dull)	0.30	0.02	<0.001	0.28	0.10	0.006

Nsd indicates no significant difference between coating and non-coating treatments at $p < 0.05$

Shelf life models

A preliminary linear regression of shelf life against time temperature units (TTUs) is shown in Figure 4. Chill affected treatments were excluded from this plot (diffuse discolouration of >5% volume in >10% of treated fruit). The linear regression of tray average values plotted across all temperatures shows a moderate fit ($R^2=0.53$)³. The 20°C treatments show more rapid loss of shelf life against TTUs than cooler temperatures. This response was consistent with previous season data. Lower RH at 20°C may have contributed to the more rapid loss of shelf life per TTU. Excluding the low RH data, a linear TTU model from 3 to 15°C shows a better fit ($R^2=0.72$). A simple TTU linear model may give an indication of ‘Shepard’ shelf life. Complex modelling approaches undertaken on multi-season data sets will provide more accurate predictions.

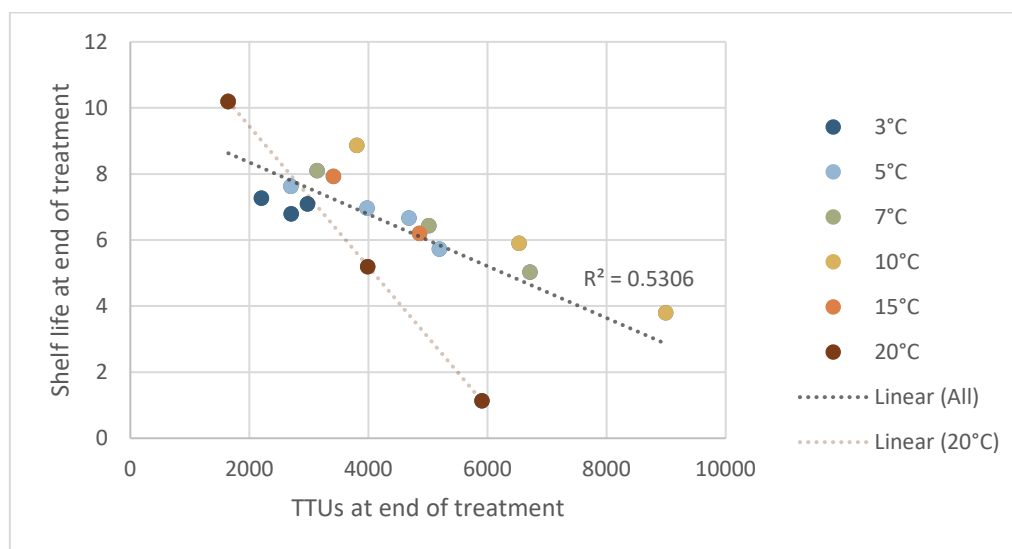


Figure 4 Preliminary linear regression of shelf life and TTUs across all storage temperatures for CQ ‘Shepard’ avocados (tray average values)

³ The R^2 value is a statistical measure of 0 to 1 that represents the proportion of the variance for a dependent variable (shelf life) that is explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.



4. Summary and recommendations

- Storage at 5-7°C is recommended for the best overall quality and shelf life in 'Shepard' avocados.
- Small fruit would be better suited to long storage, with large fruit developing more quality issues.
- For small fruit, substantial internal chilling injury emerged from 26 days at 3°C and 40 days at 5°C, while for large fruit issues occurred after 20 days at 5°C.
- The benefits of CA in extending shelf life and reducing skin darkening in this trial were slight and would need to be weighed up against the extra costs involved.
- Akorn™ coating could be worth considering for long storage. The product reduced weight loss and increased shelf life by 1-2 days, and at 7°C reduced body rots, skin darkening and shrivel. However, the coating resulted in duller skin appearance.
- Preliminary testing of a potential market access treatment (16 days at 3°C) was tolerated by 'Shepard' avocados.
- Simple linear regression using TTUs showed very good potential to predict shelf life in fruit stored at 3 to 15°C.
- Consistent outcomes across 2 seasons of 'Shepard' trials will provide a solid foundation for complex multi-season models.

5. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 39

NQ 'Shepard' avocado simulation trials report 2025



2025 North Queensland Grower Report

John Archer, Minh Nguyen, Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

This report summarises a small temperature trial conducted on 2025 North Queensland 'Shepard' avocados. Harvest dates for Trials 1 and 2 were 17 February 2025 and 18 March 2025, respectively.

The trial evaluated short-duration exposure to low temperatures, with fruit held at 1, 2, 3, 7 or 20°C for treatment-specific durations before final quality assessment. The main response variable was diffuse discolouration (DD), reported here as chilling injury (% flesh affected). Other defects included body rot, stem-end rot and vascular browning.

Key Performance Indicators (KPIs):

- **Shelf Life (SL):** Days to senescence, defined as the time until fruit reached medium-ripe stage (durometer firmness of 39 or less).
- **Defect Severity (%):** The average percentage of flesh or surface area affected by defects.
- **Diffuse Discolouration (DD):** A specific indicator of chilling injury.
- **Total Severity Volume:** The cumulative volume of all recorded defects.

Treatments resulting in an Average Total Severity > 10% are flagged.

Key findings

- Chilling injury was greatest at 1°C, reaching 20.9% of flesh affected after 2 days and remaining above 7.8% across all 1°C treatments.
- At 2°C, chilling injury ranged from 1.6% to 10.5%, with the highest impact observed after 1 day of exposure.
- At 3°C, diffuse discolouration remained low across the short durations tested, ranging from 0.6% to 1.7% flesh affected.
- The 7°C and 20°C comparison treatments recorded no diffuse discolouration in the supplied summary data.
- Treatments with average total severity above 10% were 1°C for 1-4 days and 2°C for 1 day.



1. Introduction

The Serviced Supply Chains II (AM21000) project provides decision support for horticulture supply chains by assessing post-harvest risks and identifying storage conditions that maintain fruit quality. This small trial was designed to describe the sensitivity of 'Shepard' avocados to short-duration low-temperature exposure, with a focus on chilling injury symptoms.

2. Materials and Methods

Fruit Selection and Harvesting

Commercially packed 'Shepard' avocados from North Queensland were used in the trial. The two harvest dates represented in the data were 17 February 2025 and 18 March 2025.

Fruit were exposed to temperature treatments of 1, 2, 3, 7 and 20°C. Storage durations were 1-4 days for the 1°C, 2°C and 3°C treatments; 9-10 days for the 7°C treatment; and 1-2 days for the 20°C treatment.

At final assessment, defects were recorded as average percentage of flesh affected. The summary table reports diffuse discolouration, body rot, stem-end rot, vascular browning, mean durometer firmness and total severity. Total severity was calculated as the sum of the supplied defect percentages.

Humidity Control

Relative humidity (RH) during cold storage was maintained at approximately 90% to simulate commercial cold chain conditions. Following removal from storage, fruit were held at 20°C and 65% RH to replicate retail shelf conditions.

Bareiss Firmness and Shelf Life Assessment

Fruit firmness was measured using a Bareiss firmness meter on both sides of each fruit at the equator. When fruit neared medium ripe (durometer firmness of 39 or less), a final assessment was undertaken. Skin defects were recorded, including discrete patches due to chilling injury. Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discoloration were expressed as the percentage of flesh volume affected.

3. Results

Diffuse discolouration increased substantially under the colder treatments. Fruit exposed to 1°C showed the highest chilling injury severity, with all storage durations exceeding 5% flesh affected and three of the four 1°C treatments exceeding 10%. In contrast, fruit exposed to 3°C showed consistently low levels of diffuse discolouration, while the 7°C and 20°C comparison treatments recorded 0% DD in the supplied data (**Figure 1**).

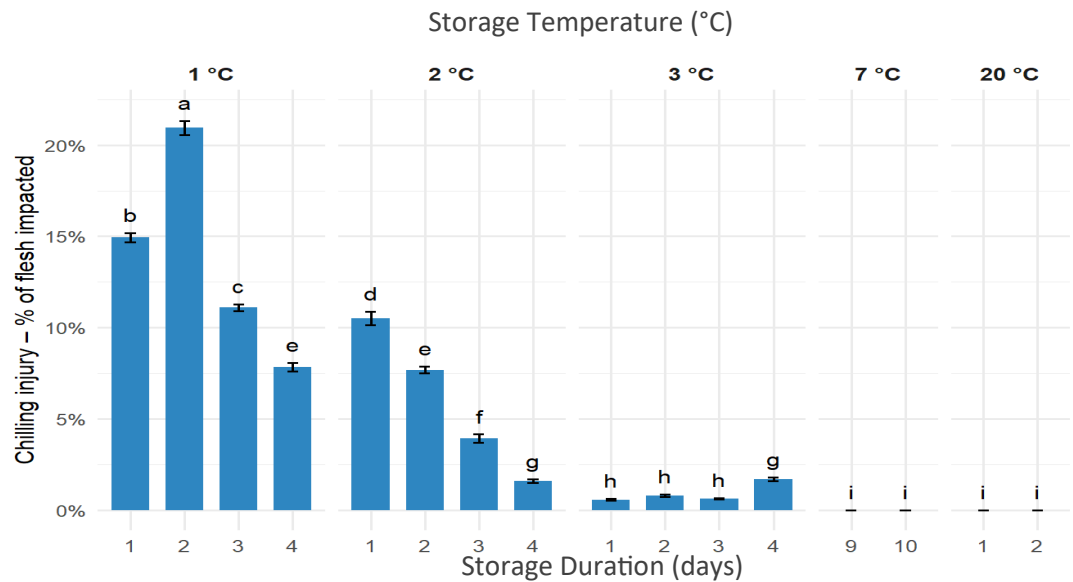


Figure 1 Average diffuse discolouration (chilling injury) in 'Shepard' avocados following short-duration temperature treatments. Letters are reproduced from the supplied figure grouping

Other post-harvest defects were generally low compared with diffuse discolouration. Body rot, stem-end rot, and vascular browning were typically below 2% flesh affected across most treatments. The primary quality risk identified in this trial was therefore chilling injury associated with exposure to the colder temperature treatments.

Using the report threshold of average total severity greater than 10%, the flagged treatments were 1°C for 1–4 days and 2°C for 1 day. The 2°C for 2 days treatment was close to the threshold at approximately 9% total severity (**Figure 2**).

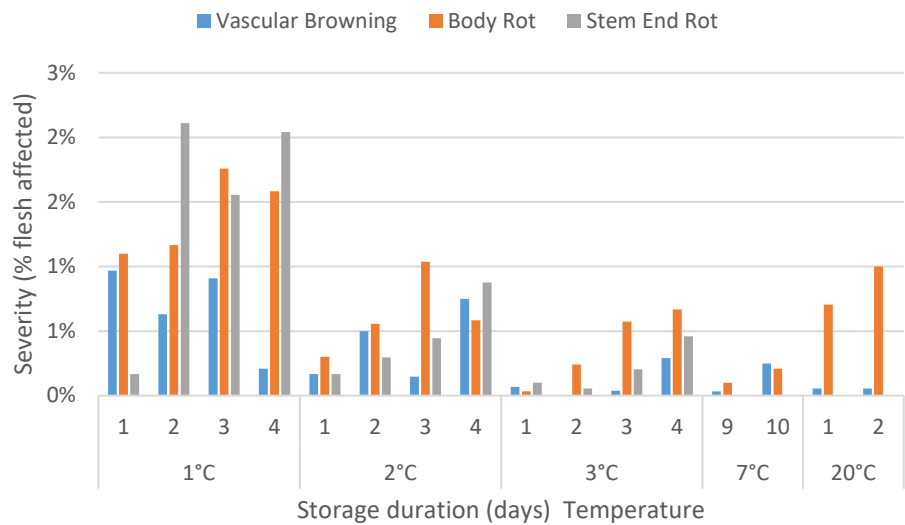


Figure 2 Average severity of vascular browning, body rot, and stem-end rot (% flesh affected) in 2025 'Shepard' avocados following short-duration temperature treatments



4. Conclusion

This small temperature trial indicates that 'Shepard' avocados were sensitive to short-duration exposure below 3°C. The 1°C treatments produced commercially meaningful levels of diffuse discolouration, and the 2°C treatments also showed elevated chilling injury in some durations. Storage at 3°C resulted in comparatively low diffuse discolouration across the short durations tested, while the 7°C and 20°C comparison treatments recorded no DD in the supplied summaries.

Practical recommendations

- Avoid exposing 'Shepard' avocados to 1°C, even for short durations, because chilling injury exceeded 7% in all 1°C treatments.
- Treat 2°C as a risk temperature for 'Shepard' fruit unless further trial data confirm safe exposure limits for specific maturity and handling conditions.
- For short-duration low-temperature handling, 3°C performed substantially better than 1 or 2°C in this dataset.
- Interpret results as indicative only because this was a small trial; additional replication across growers, maturity stages and harvest periods is recommended before setting commercial specifications.

Appendix 40

CQ 'Shepard' avocado simulation trials report 2025a



Controlled atmosphere storage of Shepard avocados

2025 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

Shepard avocado shelf life and quality were assessed following various storage scenarios with or without controlled atmosphere (CA). Fruit were stored at 5 or 7°C and approximately 90% relative humidity (RH) for periods ranging from 21 to 42 days, with and without CA. Sub-samples of fruit were regularly removed from storage and held at 20°C and approx. 65% RH to evaluate fruit quality and remaining shelf life.

Key observations from the simulation trials included:

- Without CA, fruit stored at 7°C softened in storage, resulting in increasing levels of internal chilling / aging damage.
- For storage exceeding 21 days, the use of CA at 7°C was highly beneficial in:
 - Maintaining firmness
 - Minimising internal chilling / aging damage
 - Reducing skin darkening
 - Minimising rots
 - Extending shelf life
- While CA showed some benefits in long 5°C storage, the key issue of internal chilling / aging damage was not reduced.
- For non-CA storage up to 21 days, 5 and 7°C resulted in similar quality outcomes.
- In this trial, CA storage for up to 28 days at 7°C maintained good fruit quality.
- Under longer storage periods up to 42 days, CA at 7°C minimised the risk of defects in Shepard avocados.



Introduction

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2025 Shepard avocado season. The main objective of the trial was to quantify fruit quality and shelf life responses of Shepard avocados to long supply chain durations with and without the application of CA. The trial investigated the impacts of time and temperature effects, CA storage, and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

Materials and methods

Commercially mature Shepard avocado fruit (targeting dry matter >21%) were sourced for the trial during the 2025 season. Fruit were harvested on 18th March 2025 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the same day. The following morning they were processed through the commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 28 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to a range of storage regimes designed to reflect potential sea freight conditions, as shown in Table 1. Fruit were stored for 21 to 42 days at 5 or 7°C, with or without CA at 2% O₂ and 5% CO₂. An 11-day treatment at 7°C was added as a baseline indication of quality under a shorter supply chain scenario. All treatments were applied to 3 replicate trays of 10 fruit. Fruit within this trial were not treated with ethylene at any stage. At the end of each treatment storage duration, fruit were shifted to retail simulation at 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored throughout the trial, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Storage conditions applied to Shepard avocados in 2025 CA trials.

Temperature	CA	Storage duration (days) prior to ongoing 20°C storage				
		10	21	28	35	42
5°C	-		x	x	x	x
5°C	+CA		x	x	x	x
7°C	-	x	x	x	x	x
7°C	+CA		x	x	x	x

+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

At trial commencement all fruit were weighed and firmness was measured on 30 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% of flesh volume. Skin defects were recorded, including chilling injury and % surface area (SA) of skin darkening. The SA of dull skin was recorded and shrivel was scored using a 0-3 scale (0=none, 1=mild, 2=moderate, 3=severe). Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

Results

Dry matter

Fruit oven dry matter (DM) averaged 22.7%. Low DM (less than 21%) was recorded in 30% of fruit, with 20% having oven dried DM of 18 or less. The relationships between NIR predicted DM and oven DM were strong in this trial, averaging $R^2=0.83$ (data not shown).

Weight loss

Fruit weight loss at cold removal increased with longer storage time (data not shown). Storage chambers held at 5°C averaged 91% RH, while those at 7°C averaged 97% RH. The higher humidity at 7°C resulted in lower levels of weight loss at cold removal. After 35 days of storage, non-CA fruit at 5°C lost 6% of their weight, while at 7°C the fruit lost only 3%. CA reduced the total weight loss by around 25% across all paired treatments.

Weight loss occurred more rapidly once fruit were transferred to 20°C, due to the higher temperature and lower RH. Fruit kept at 20°C lost an average 1.2% of their weight each day. Fruit assessed at medium ripe stage had typically lost around 11% of their original weight.

Firmness changes

CA consistently maintained fruit firmness, even after storage periods of up to 42 days (Figure 1). All fruit stored under CA retained hard to rubbery firmness on removal from storage. In contrast, fruit stored without CA softened during storage. Slight softening occurred in non-CA fruit stored at 5°C for 35 days or longer. At 7°C, softening occurred after 21 days and was much more rapid. After 42 days, non-CA fruit stored at 5°C were typically at the rubbery stage, while 7°C stored fruit were firm-ripe.

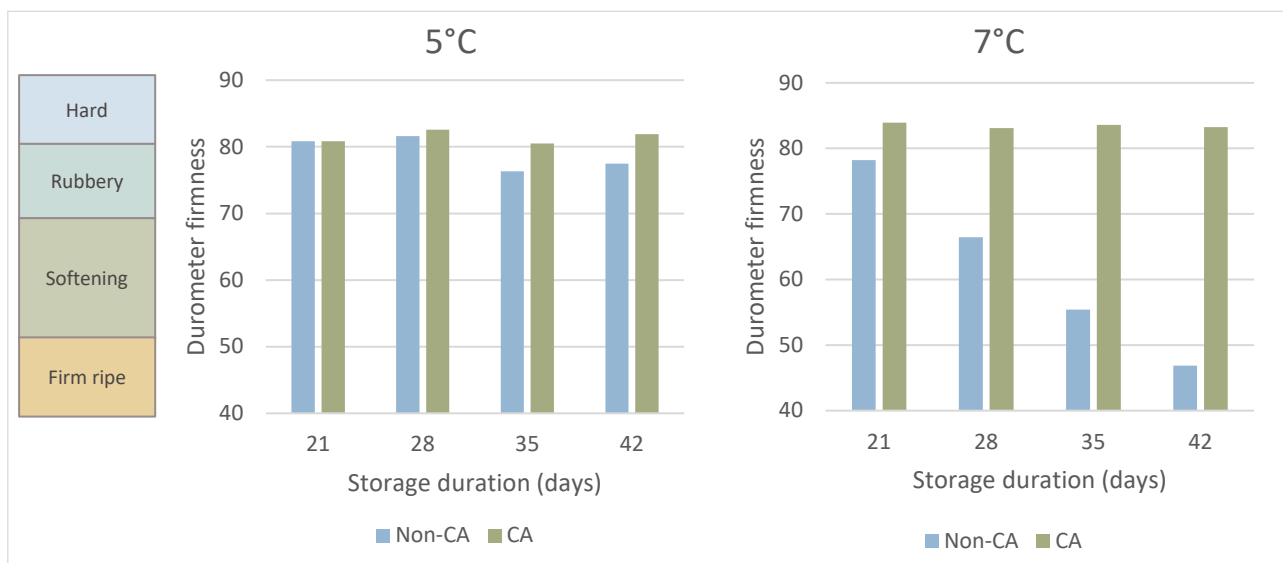


Figure 1. Firmness of Shepard avocados at removal from storage treatments at 5 or 7°C, with or without application of CA

Once transferred to 20°C, fruit typically took around 4 days to reach firm-ripe, and then another 2.5 days to reach medium ripe. These processes occurred more rapidly in fruit that had already softened during storage.

Internal chilling / aging damage

Internal damage due to chilling or aging was the key limitation to long storage of Shepard avocados. Severe damage was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed was also considered an early sign of internal chill / aging deterioration. These symptoms could occur without any obvious signs of damage on the outside of the fruit.

At 5°C, internal damage started to emerge after 21 days and progressively worsened with longer storage (Table 2). Commercially significant damage occurred in storage treatments of 28 days or longer. CA did not show any benefit in reducing internal chilling / aging damage at 5°C.

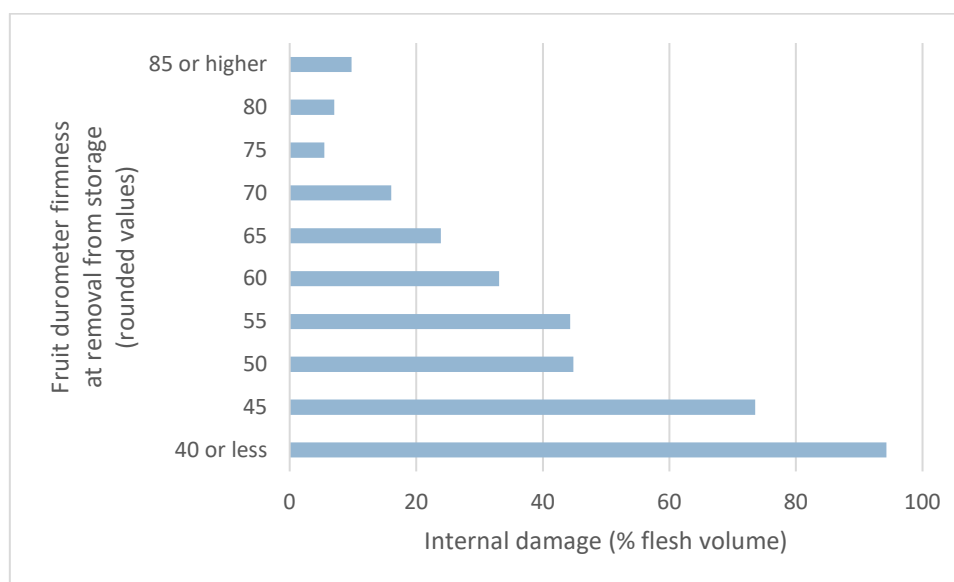
In contrast, CA was highly beneficial in mitigating the risk of damage at 7°C. Under CA storage at 7°C fruit stored for 28 days showed no significant symptoms of internal damage. At 35-42 days, commercially significant damage started to emerge, but was minimised by the use of CA.

In non-CA treatments, internal damage was worse at 7°C than at 5°C. While lower temperatures generally cause more chilling damage, softening fruit are particularly susceptible to injury. This is demonstrated in the relationship between firmness at removal and damage severity (Figure 2). Fruit stored at 7°C without CA softened during storage, resulting in high levels of damage. The combination of slightly higher temperature with the benefit of CA to slow ripening was optimal for long storage of Shepard avocados.

Table 2. Internal chilling / aging damage in Shepard avocados at medium ripe, after various storage conditions

Storage temperature	Storage duration (days)	Incidence (% of fruit with ≥10% volume damage)		Severity (average % flesh volume)	
		Non-CA	CA	Non-CA	CA
5°C	21	7	0	1.5	0.8
	28	27	27	9.2	8.4
	35	37	27	13.2	13.2
	42	53	70	17.8	30.5
7°C	11	0		0.0	
	21	3	0	0.5	0.0
	28	43	0	21.3	0.2
	35	70	13	37.6	4.7
	42	100	13	75.8	2.4

Figure 2. Relationship between fruit firmness at removal and internal chilling / aging damage severity



Shelf life

Quality traits measured at medium ripe were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots reached 10% flesh volume. Diffuse discolouration of the flesh was a key issue in many treatments. This disorder could not be detected until fruit were destructively assessed at medium ripe. Damage of 10% volume or greater at medium ripe was assumed to have ended shelf life at removal from treatment.

Shelf life was extended by the application of CA (Table 3). The shelf life of control fruit (stored at 7°C for 11 days without CA) averaged 8 days. Using CA, similar shelf life could be maintained following storage for 21 days at 5°C or up to 28 days at 7°C. Shelf life declined with longer storage durations, particularly in non-CA conditions. However, these impacts were minimised by 7°C storage under CA.

Table 3. Shelf life of Shepard avocados at 20°C following various storage treatments

Storage temperature	Storage duration (days)	Shelf life at 20°C (days)	
		Non-CA	CA
5°C	21	6.8	9.0
	28	5.1 *	6.4 *
	35	3.8 **	6.1 **
	42	2.9 **	2.6 ***
7°C	11	8.0	
	21	5.6	8.3
	28	3.3 ***	7.8
	35	1.3 ***	6.2
	42	0.0 ***	6.2

*Markings indicate mean diffuse discolouration volume in each treatment, averaging * >5% vol, ** >10%, *** >20%.

Skin darkening

The development of skin darkening in ripe fruit was common, with a third of trial fruit showing symptoms exceeding 5% SA at medium ripe. Skin darkening was particularly severe following storage periods of 28 days or longer without CA (Table 4). The addition of CA substantially reduced skin darkening issues. At 7°C with CA, no significant skin darkening occurred even after storage periods of up to 42 days.



Fig 3. Skin darkening symptoms on Shepard avocado

Table 4. Severity of skin darkening in Shepard avocado fruit at medium ripe, following various storage conditions

Storage temperature	Storage duration (days)	Skin darkening severity (average % surface area)	
		Non-CA	CA
5°C	21	3.5	1.8
	28	15.1	4.4
	35	10.5	2.7
	42	28.0	10.9
7°C	11	1.8	
	21	9.0	0.8
	28	22.7	1.9
	35	27.2	3.5
	42	26.8	2.3

Rots



Longer non-CA storage treatments showed some development of rots at ripe (Table 5). CA was beneficial in reducing the severity of rots. The use of CA at 7°C resulted in minimal rot development at ripe across all storage durations.

Table 5. Severity of rots in Shepard avocados at medium ripe, after various storage conditions

Storage temperature	Storage duration (days)	Body rot severity (% vol)		Stem end rot severity (% vol)	
		Non-CA	CA	Non-CA	CA
5°C	21	0.1	0.1	0.1	0.6
	28	1.9	0.0	0.5	0.2
	35	0.2	0.2	0.8	1.3
	42	9.2	1.3	3.4	1.8
7°C	11	0.0		0.1	
	21	0.4	0.0	0.3	0.2
	28	5.1	0.0	1.3	0.9
	35	10.1	0.9	2.9	0.4
	42	5.3	0.4	0.6	0.6

Consumer tolerance

Under CA, storage treatments up to 21 days at 5°C or 28 days at 7°C retained good fruit quality (Table 6). Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010¹). Long storage treatments without CA caused an increase in the levels of unacceptable internal defects in medium ripe fruit. All storage treatments of 21 to 42 days without CA exceeded consumer tolerance thresholds (>10% of fruit with unacceptable internal defects).

Table 6. Percentage of Shepard avocados within acceptable internal defect limits at medium ripe stage, after various storage conditions.

(Green shaded treatments met industry guidelines for consumer tolerance, while orange shaded treatments exceeded these limits)

Storage temperature	Storage duration (days)	Acceptable fruit %	
		Non-CA	CA
5°C	21	87	97
	28	63	73
	35	60	70
	42	27	23
7°C	11	97	
	21	77	100
	28	37	93
	35	13	83
	42	0	83

¹ Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43



Summary and recommendations

- CA maintained fruit firmness under long storage, for periods of up to 42 days at 5 and 7°C.
- Without CA, fruit stored at 7°C softened while in long storage.
- Softening during cool storage was associated with the development of internal chilling / aging defects.
- At 7°C, CA minimised the risk of internal chill / aging damage under long storage.
- CA reduced the development of skin darkening and helped to control body rots in long storage treatments.
- For periods up to 21 days without CA, storage at 5 or 7°C gave similar outcomes.
- For storage periods exceeding 21 days, 7°C with CA would be recommended for the best overall quality and shelf life in Shepard avocados.
- In this trial, storage for up to 28 days at 7°C with CA maintained good fruit quality.

Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support. This work was part of the broader Serviced Supply Chains II project (AM21000) that was funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland, Department of Energy, Environment and Climate Action, Victoria, Department of Agriculture and Fisheries, Northern Territory, Department of Primary Industries and Regional Development, Western Australia, Piñata Farms Pty Ltd and Summerfruit Australia Ltd.



Appendix 41

CQ 'Shepard' avocado simulation trials report 2025b



Controlled atmosphere storage of Shepard avocados

2025 season Central Queensland grower report

Pip Bryant, Hung Duong, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

Shepard avocado shelf life and quality were assessed following various storage scenarios with or without controlled atmosphere (CA). Fruit were stored at 5 or 7°C and approximately 90% relative humidity (RH) for periods ranging from 21 to 42 days, with and without CA. Sub-samples of fruit were regularly removed from storage and held at 20°C and approx. 65% RH to evaluate fruit quality and remaining shelf life.

Key observations from the simulation trials included:

- Without CA, fruit stored at 7°C softened in storage, resulting in increasing levels of internal chilling / aging damage.
- For storage periods of 21 days or longer, the use of CA at 7°C was highly beneficial in:
 - Maintaining firmness
 - Minimising internal chilling / aging damage
 - Reducing skin darkening
 - Minimising rots
 - Extending shelf life
- While CA showed some benefits in long 5°C storage, the key issue of internal chilling / aging damage was not reduced.
- In this trial, CA storage for up to 35 days at 7°C maintained ripe fruit quality within consumer tolerance thresholds.
- Under longer storage periods up to 42 days, CA at 7°C minimised the risk of defects in Shepard avocados.



Introduction

The Serviced Supply Chains II (AM21000) project is an RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers export simulation trial work completed during the 2025 Shepard avocado season on fruit grown in Central Queensland (CQ). The main objective of the trial was to quantify fruit quality and shelf life responses of Shepard avocados to long supply chain durations with and without the application of CA. The trial investigated the impacts of time and temperature effects, CA storage, and fruit maturity (dry matter). Data generated from the trial will assist in refining fruit quality and shelf life prediction models.

Materials and methods

Commercially mature Shepard avocado fruit (targeting dry matter >21%) were sourced for the trial during the 2025 season. Fruit were harvested on 25th March 2025 from a farm located near Childers, Queensland. The fruit were placed into field bins and transferred to a nearby packing shed on the same day. The following day they were processed through a commercial pack line. Fruit were treated with fungicide, sorted by size and quality, and packed into cardboard trays. Packed trays of count 28 size fruit were transported to the postharvest laboratory at Maroochy Research Facility in an air-conditioned van (approx. 25°C) for 3 hours and were then kept overnight at 20°C.

At the laboratory, the dry matter (DM) content was estimated for individual fruit using near-infrared spectroscopy (NIR) via Felix F-750 Quality Meters, based on a general avocado dry matter model. NIR measurements were taken on the ventral and dorsal sides of each fruit. All trial fruit were grouped by NIR predicted DM values. The categorised fruit were then assigned randomly and evenly to treatment trays. This ensured that each tray contained a normal distribution of DM from the population supplied. A sub-set of 20 fruit were also assessed for DM using the traditional oven drying method. NIR values were corrected based on the relationship shown between NIR predicted DM and oven dried DM measurements.

Treatment trays were assigned to a range of storage regimes designed to reflect potential sea freight conditions, as shown in Table 1. Fruit were stored for 21 to 42 days at 5 or 7°C, with or without CA at 2% O₂ and 5% CO₂. An 11-day treatment at 7°C was added as a baseline indication of quality under a shorter supply chain scenario. All treatments were applied to 3 replicate trays of 10 fruit. Fruit within this trial were not treated with ethylene at any stage. At the end of each treatment storage duration, fruit were shifted to retail simulation at 20°C and 65% RH for ongoing assessment.

The air temperature adjacent to fruit was monitored throughout the trial, commencing at the time of collection from the pack shed. Logged temperatures were used to calculate total time x temperature units (TTU) accrued from harvest until removal from storage treatments. Relative humidity (RH) inside cold rooms was maintained near 90%, while at 20°C the RH was held near 65% to mimic retail conditions.

Table 1. Storage conditions applied to Shepard avocados in 2025 CA trials.

Temperature	CA	Storage duration (days) prior to ongoing 20°C storage				
		10	21	28	35	42
5°C	-		x	x	x	x
5°C	+CA		x	x	x	x
7°C	-	x	x	x	x	x
7°C	+CA		x	x	x	x

+CA treatments were stored in controlled atmosphere of 2% O₂ and 5% CO₂

At trial commencement all fruit were weighed and firmness was measured on 30 fruit. Fruit firmness was measured using a Bareiss HPE III Fff durometer (Oberdischingen, Germany) with 5mm spherical tip on 1 second reading. When fruit were removed from storage treatments, weight and firmness were measured in all fruit. Any observed skin chilling injury was also recorded, according to the scale below:

Skin chilling injury rating scale

0 = None

1 = Very mild; generally affecting less than 5% of the surface area (SA) and having minimal impact on visual quality.

2 = Mild; generally affecting less than 10% SA and having a slight impact on visual quality.

3 = Moderate; Slightly to moderately objectionable, approximately 10-25% SA, with fruit remaining marketable.

4 = Severe; Excessive defect, approximately 25-50% SA, with fruit becoming unmarketable.

5 = Extreme; resulting in extremely poor visual quality, generally more than 50% SA.

After fruit were shifted to 20°C for shelf life assessment, fruit quality was monitored at least every 2 days. The date at which each fruit reached firm ripe (durometer firmness of 51 or less) was recorded. A final assessment was undertaken when fruit neared medium ripe (durometer firmness of 38 or less) or if rots were anticipated to exceed 10% of flesh volume. Skin defects were recorded, including chilling injury and % surface area (SA) of skin darkening. The SA of dull skin was recorded and shrivel was scored using a 0-3 scale (0=none, 1=mild, 2=moderate, 3=severe). Each fruit was cut in half and the seed and skin were removed. The severity of internal defects including body rot, stem-end rot, vascular browning, bruising and diffuse discolouration were expressed as the percentage of flesh volume affected.

Results

Dry matter

Fruit oven dry matter (DM) averaged 25.8% and was highly variable, ranging from 18.5 to 33.4%. Low DM (less than 21%) was recorded in 30% of fruit. The relationships between NIR predicted DM and oven DM were very strong in this trial, averaging $R^2=0.91$ (data not shown).

Weight loss

Fruit weight loss at cold removal increased with longer storage time (data not shown). Storage chambers held at 5°C averaged 92% RH, while those at 7°C averaged 97% RH. The higher humidity at 7°C resulted in lower levels of weight loss at cold removal. After 35 days of storage, non-CA fruit at 5°C lost 4.5% of their weight, while at 7°C the fruit lost only 2.5%. CA reduced the total weight loss by around 25% across all paired treatments.

Weight loss occurred more rapidly once fruit were transferred to 20°C, due to the higher temperature and lower RH. Fruit kept at 20°C lost an average 1% of their weight each day. Fruit assessed at medium ripe stage had typically lost around 10% of their original weight.

Firmness changes

CA consistently maintained fruit firmness, even after storage periods of up to 42 days (Figure 1). All fruit stored under CA retained hard to rubbery firmness on removal from storage. In contrast, fruit stored without CA softened during storage. Slight softening occurred in non-CA fruit stored at 5°C for 35 days or longer. At 7°C, softening occurred after 21 days and was much more rapid. After 42 days, non-CA fruit stored at 5°C were typically at the rubbery stage, while 7°C stored fruit were nearing firm-ripe.

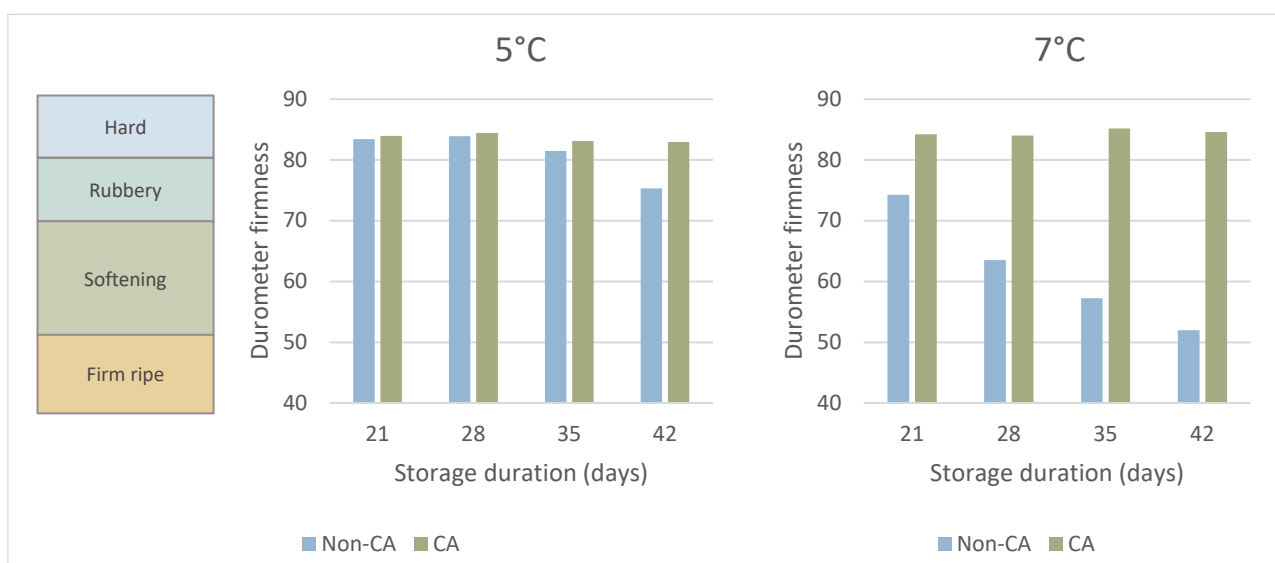


Figure 1. Firmness of Shepard avocados at removal from storage treatments at 5 or 7°C, with or without application of CA

Once transferred to 20°C, fruit typically took around 4-5 days to reach firm-ripe, and then another 2-3 days to reach medium ripe. These processes occurred more rapidly in fruit that had already softened during storage.

Internal chilling / aging damage

Internal damage due to chilling or aging was the key limitation to long storage of Shepard avocados. Severe damage was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed was also considered an early sign of internal chill / aging deterioration. These symptoms could occur without any obvious signs of damage on the outside of the fruit.

At 5°C, mild internal damage started to emerge after 21 days and significant damage occurred when storage duration was 28 days or longer (Table 2). CA did not show any benefit in reducing internal chilling / aging damage at 5°C.

In contrast, CA was highly beneficial in mitigating the risk of damage at 7°C. Fruit stored without CA at 7°C, developed significant internal damage after 28 days, which worsened with longer storage. In all paired treatments at 7°C, CA substantially reduced internal chilling / aging damage.

In longer non-CA treatments, internal damage was worse at 7°C than at 5°C. While lower temperatures generally cause more chilling damage, softening fruit are particularly susceptible to injury. This is demonstrated in the relationship between firmness at removal and damage severity (Figure 2). Fruit stored at 7°C without CA softened during storage, resulting in high levels of damage. The combination of slightly higher temperature with the benefit of CA to slow ripening was optimal for long storage of Shepard avocados.

Table 2. Internal chilling / aging damage in Shepard avocados at medium ripe, after various storage conditions

Storage temperature	Storage duration (days)	Incidence (% of fruit with ≥10% volume damage)		Severity (average % flesh volume)	
		Non-CA	CA	Non-CA	CA
5°C	21	3	10	2.4	3.0
	28	27	27	6.3	5.4
	35	23	23	6.2	14.8
	42	23	27	5.6	7.8
7°C	11	3		0.3	
	21	3	0	1.3	0.0
	28	20	0	4.8	0.2
	35	30	3	10.5	1.5
	42	63	10	25.0	2.0

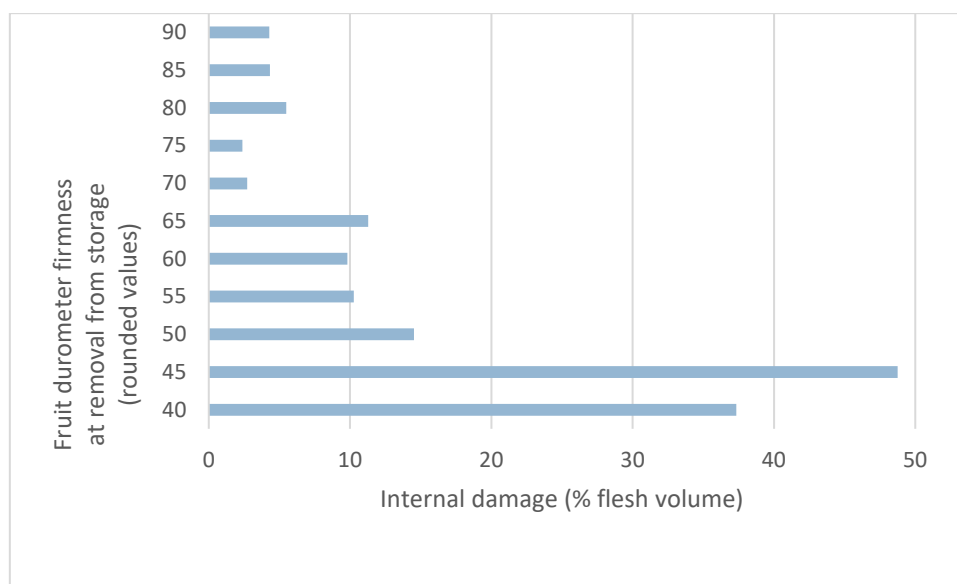


Figure 2. Relationship between fruit firmness at removal and internal chilling / aging damage severity

Shelf life

Quality traits measured at medium ripe were used to estimate when fruit would reach end of shelf life (ESL). Fruit were considered at ESL when oversoft (Bareiss firmness of 29 or less) or if rots reached 10% flesh volume. Diffuse discoloration of the flesh was a key issue in many treatments. This disorder could not be detected until fruit were destructively assessed at medium ripe. Damage of 10% volume or greater at medium ripe was assumed to have ended shelf life at removal from treatment.

Shelf life was extended by the application of CA (Table 3). The shelf life of control fruit (stored at 7°C for 11 days without CA) averaged around 9 days. Using CA, similar shelf life could be maintained following storage for 21 days at 5°C or up to 35 days at 7°C. Shelf life declined with longer storage durations, particularly in non-CA conditions. However, these impacts were minimised by 7°C storage under CA.

Table 3. Shelf life of Shepard avocados at 20°C following various storage treatments

Storage temperature	Storage duration (days)	Shelf life at 20°C (days)	
		Non-CA	CA
5°C	21	7.3	9.3
	28	5.5 *	6.8 *
	35	5.3 *	8.1 *
	42	5.6 *	6.7 *
7°C	11	8.9	
	21	6.6	9.7
	28	5.1 *	9.0
	35	3.8 *	8.4
	42	1.6 **	7.0

*Markings indicate diffuse discolouration incidence ($\geq 10\%$ vol) in each treatment, * 20-30% of fruit, ** >30% of fruit.

Skin darkening

The development of skin darkening in ripe fruit was common, with a third of trial fruit showing symptoms exceeding 5% SA at medium ripe. CA showed strong benefits in reducing skin darkening, averaging around a 70% reduction in the disorder compared with non-CA treatments (Table 4). Most long storage treatments without CA resulted in skin darkening exceeding 10% SA, while all treatments with CA averaged less than 10% SA.



Fig 3. Skin darkening on Shepard avocado

Table 4. Severity of skin darkening in Shepard fruit at medium ripe, following various storage conditions

Storage temperature	Storage duration (days)	Skin darkening severity (average % surface area)	
		Non-CA	CA
5°C	21	6.0	4.1
	28	14.5	6.0
	35	13.7	9.6
	42	17.1	1.9
7°C	11	2.6	
	21	24.2	1.9
	28	19.6	2.5
	35	11.7	1.2
	42	33.1	6.7

Rots

Body rots in ripe fruit tended to worsen with longer storage duration and were consistently reduced by CA (Table 5). Stem end rot severity showed inherent variability across treatments, being more strongly influenced by pre-harvest factors rather than storage. Overall, CA treatments at 7°C resulted in the lowest levels of rot development in ripe fruit.

Table 5. Severity of rots in Shepard avocados at medium ripe, after various storage conditions

Storage temperature	Storage duration (days)	Body rot severity (% vol)		Stem end rot severity (% vol)	
		Non-CA	CA	Non-CA	CA
5°C	21	2.1	0.2	0.5	1.2
	28	2.7	1.5	0.2	0.1
	35	3.6	0.6	0.4	3.3
	42	4.3	0.6	0.3	0.3
7°C	11	0.1		0.0	
	21	2.5	0.5	3.6	0.4
	28	4.2	0.6	0.6	0.4
	35	4.6	0.8	1.1	0.3
	42	13.8	0.4	3.2	0.2

Consumer tolerance

Storage treatments of up to 35 days at 7°C with CA showed the potential to retain good fruit quality (Table 6). Fruit were considered unacceptable when internal defects exceeded 10% flesh volume. Previous research has shown that Australian consumers desire to purchase avocados was negatively impacted by this level of damage (Gamble, 2010¹). Long storage treatments at 5°C caused a gradual increase in the levels of unacceptable internal defects in medium ripe fruit. Regardless of CA application, all 5°C treatments of 21-42 days exceeded consumer tolerance thresholds (>10% of fruit with unacceptable internal defects). At 7°C without CA, fruit quality was excellent after 11 days, but progressively worsened as storage duration increased. With the addition of CA, fruit quality was retained over storage periods of 21 to 35 days.

Table 6. Percentage of Shepard avocados within acceptable internal defect limits at medium ripe stage, after various storage conditions.

(Green shaded treatments met industry guidelines for consumer tolerance, while orange shaded treatments exceeded these limits)

Storage temperature	Storage duration (days)	Acceptable fruit %	
		Non-CA	CA
5°C	21	87	80
	28	73	73
	35	67	53
	42	60	70
7°C	11	100	
	21	77	93
	28	60	97
	35	47	93
	42	3	83

¹ Gamble, J., et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* **57**: 35-43



Summary and recommendations

- For storage periods exceeding 21 days, 7°C with CA would be recommended for the best overall quality and shelf life in Shepard avocados.
- In this trial, storage for up to 35 days at 7°C with CA maintained good fruit quality.
- CA maintained fruit firmness under long storage, for periods of up to 42 days at 5 and 7°C.
- Without CA, fruit stored at 7°C softened while in long storage.
- Softening during cool storage was associated with the development of internal chilling / aging defects.
- At 7°C, CA minimised the risk of internal chill / aging damage under long storage.
- CA reduced the development of skin darkening and helped to control body rots in long storage treatments.

Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support. This work was part of the broader Serviced Supply Chains II project (AM21000) that was funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland, Department of Energy, Environment and Climate Action, Victoria, Department of Agriculture and Fisheries, Northern Territory, Department of Primary Industries and Regional Development, Western Australia, Pinata Farms Pty Ltd and Summerfruit Australia Ltd.



Appendix 42

CQ 'Shepard' avocado 3°C tolerance trials report 2023/24

'Shepard' avocado fruit quality and shelf life following 3°C storage

Summary report 2023-24

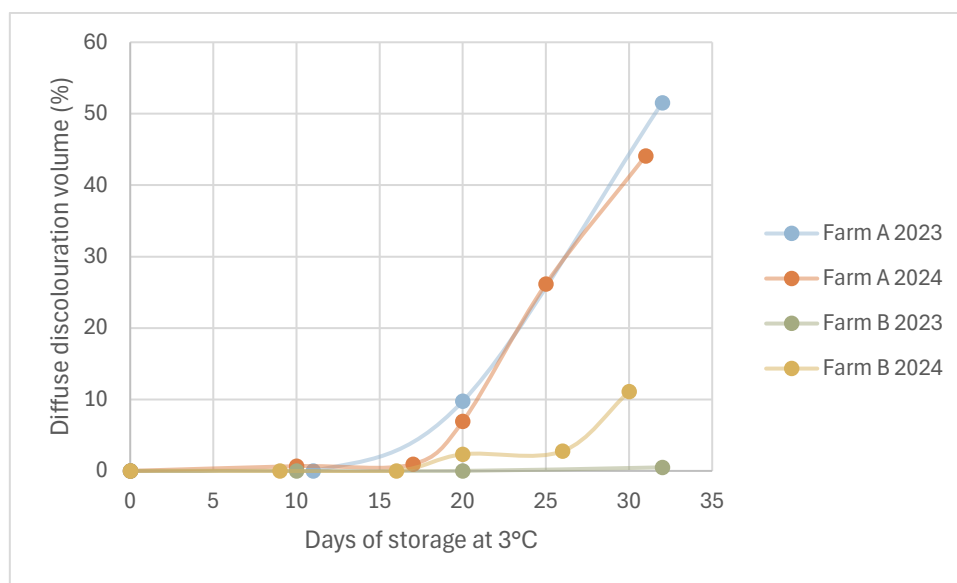
Pip Bryant, Boyd Tarlinton, Lawrence Smith, Hung Duong, John Archer and Andrew Macnish

Department of Primary Industries

Storage of 'Shepard' avocados for 16 days at 3°C was proposed as a possible market access treatment, with the potential to expand industry options for export. While 7°C is a commonly recommended temperature for 'Shepard' storage, recent research has demonstrated that the fruit can tolerate 5.5°C (Marques, Bryant et al. 2025), and 5.5°C storage has reportedly been adopted in South Africa for other green-skinned varieties (Lütge, Bertling et al. 2012). The current report explores 'Shepard' avocado fruit quality and shelf life responses to storage at 3°C for 16 days, drawing on trial work completed across 2023 - 2024 seasons.

Storage at 3°C did not change 'Shepard' avocado shelf life, but fruit quality declined with longer storage durations. Internal chilling injury was the major limitation to prolonged storage at 3°C.

Chilling susceptibility varied substantially between farms and seasons. In 2023, storage durations of 10 and 20 days at 3°C were tested on Shepard avocados from 2 different farms in Childers, Qld. Following 3°C storage, fruit were shifted to 20°C for ongoing assessment under simulated retail conditions. 'Farm B' fruit were very tolerant of 3°C storage. Fruit showed no signs of internal chilling following 20 days at 3°C, and minimal damage even after 32 days. In contrast 'Farm A' fruit developed an average of 10% diffuse discolouration following 20 days at 3°C. In the 'Farm A' 2023 trial, fruit were very susceptible to chilling damage, with some mild diffuse discolouration also seen following 20 days at 5 and 7°C (data not shown).



In 2024, 3°C storage was tested for 16 days. Similar differences were shown between the 2 farms, with 'Farm A' fruit much more susceptible to damage than 'Farm B'. Very little chilling damage was shown following 16-17 days at 3°C. However, internal chilling started to emerge as a significant issue after 20 days. Given the high degree of variation in chilling susceptibility shown in these results, the adoption of a 3°C 16 day market access treatment for 'Shepard' avocados is not recommended. For 'Shepard' avocados, fruit quality is typically best maintained by storage for 20 days or less at 5 to 7°C.

Appendix 43

CQ 'Shepard' avocado 5°C tolerance trials report 2023/24

‘Shepard’ avocado fruit quality and shelf life following 5°C storage

Summary report 2023-24

Pip Bryant, Boyd Tarlinton, Lawrence Smith, Hung Duong, John Archer and Andrew Macnish

Department of Primary Industries

Summary

Prolonged 5°C storage of ‘Shepard’ avocados as a market access treatment has the potential to expand industry options for export. While 7°C is a commonly recommended temperature for ‘Shepard’ storage, recent research has demonstrated that the fruit can tolerate 5.5°C (Marques, Bryant et al. 2025), and 5.5°C storage has reportedly been adopted in South Africa for other green-skinned varieties (Lütge, Bertling et al. 2012). The current report explores ‘Shepard’ avocado ripening, fruit quality and shelf life responses to prolonged 5°C storage, drawing on trial work completed across 2023 - 2024 seasons.

Fruit responses varied substantially between seasons, farms and blocks. Internal chilling injury was the major limitation to prolonged storage at 5°C. Very mild diffuse discolouration started to appear in some batches following 20 days of storage at 5°C. After 30 days at 5°C, commercially significant internal chilling occurred in around half of the batches tested. Fruit quality was best maintained by storage for 20 days or less at 5 or 7°C. Issues with internal quality tended to increase when storage was prolonged to 25 days. At 5°C, CA did not show any benefits in reducing internal defects compared with air storage.

Ripening responses and shelf life

Slight softening of ‘Shepard’ avocados occurred during long storage at 5°C, but fruit typically remained within the hard to rubbery stage for up to 45 days. Following 5°C storage, fruit were shifted to 20°C for ongoing assessment under simulated retail conditions.

Prolonged storage at 5°C resulted in slightly faster ripening and a small loss of shelf life. An extra 10 days of storage at 5°C resulted in fruit ripening around 1 day faster when shifted to 20°C. Typically, fruit stored at 5°C for 10 days ripened to firm soft in around 6 days, compared with 5 days following 20 day storage. The average shelf life was also reduced by around 0.5 days following an additional 10 days at 5°C.

Skin defects

Chilling injury on the skin was characterised by dark mottled sunken areas, particularly around the lenticels. In some trials, very minor skin chilling started to emerge after 20 days at 5°C. Commercially significant levels of skin chilling damage were observed in some trials following storage at 5°C for 30 days.

The symptoms of skin darkening and skin chilling injury merged as fruit ripened. Each fruit was assessed for signs of skin chilling injury following removal from storage. At medium ripe stage, the surface area of any skin darkening was recorded. Susceptibility to skin darkening was highly variable between different trials. Skin darkening was particularly prevalent when fruit ripened after long duration storage. Significant issues with skin darkening often emerged following storage durations of 25 days or longer. In most trials relatively low levels of skin darkening were shown following 20 days at 5°C. However, in one trial, an average 18% of the skin surface showed skin darkening in small fruit stored for 20 days at 5°C. Large sized fruit were typically more prone to skin darkening issues than small fruit.



Internal chilling damage

Severe internal chilling injury was characterised by dark brown-grey diffuse discolouration of flesh surrounding the seed. Light grey-brown vascular discolouration originating from the base of the seed was also considered an early sign of internal chill damage / long storage deterioration.

Following 20 days at 5°C some mild diffuse discolouration of the fruit flesh emerged in around half of all batches tested. The volume of flesh affected typically averaged 2% or lower. After 30 days, significant internal chilling damage emerged in around half of the batches tested. In some batches the volume of flesh affected averaged greater than 10%. Following 40+ days at 5°C most batches showed substantial internal chilling.

In some trials, large fruit showed greater susceptibility to internal chilling damage than small fruit. Strong variation was also shown between farms and blocks.

Rots

Rot susceptibility was highly variable between farms and seasons. In trials with high susceptibility, rot development at medium ripe tended to progressively worsen with longer storage duration. In some trials, large fruit showed greater susceptibility to rot development than small fruit.

Overall internal quality - consumer tolerance

Fruit internal quality was best maintained by storage for 20 days or less at 5 or 7°C. Issues with internal quality exceeding consumer tolerance tended to increase when storage was prolonged to 25 or 30 days. Storage for 40 days or longer resulted in very poor internal fruit quality at medium ripe. Overall, large fruit tended to be more prone to developing internal quality issues than small fruit.

Controlled atmosphere

The use of controlled atmosphere (CA) at 2% O₂ and 5% CO₂ slowed ripening and consistently extended shelf life by around 1 day compared with air storage. CA also minimised softening in storage, reduced weight loss and reduced skin darkening. However, at 5°C CA had little impact on internal defects in 'Shepard' avocados.

Appendix 44

CQ 'Hass' avocado nodule damage report 2023



Identifying factors associated with nodule damage (*'lenticel damage'*) in Hass avocados

Shanara Veivers, John Agnew, Andrew Mead

Department of Agriculture and Fisheries

2 August 2023

Executive Summary

Lenticels are pores on the skin of fruit that allows the passage of air and water vapour. In avocados, lenticel damage is caused by abrasion of the fruit skin during harvest and/or packing procedures. Hass avocado fruit packed in a Central Queensland (CQ) packing shed were showing symptoms of lenticel damage following packing. A preliminary trial investigating fruit quality of Hass avocado collected from five (5) different stages in the packing line was conducted.

A total of 53 avocado fruit were sampled from five stages sequentially along the packing line which spanned a distance of approximately 105m in August 2023. The fruit were transported to the Maroochy Research Facility near Nambour within 3 hours. Each sampled fruit received two assessments, the first at initial intake and the second assessment was conducted 22 days after storage at 5°C. The measurements conducted on each piece of fruit included weight (g), and nodule damage surface area (%). Following the second assessment, fruit were then stored at 20°C and once each fruit reached “medium-soft ripe” it was assessed for internal fruit quality.

A correlation between nodule damage score and time in packing line was observed. Lenticel damage progressively increases along the pack line as the fruit are exposed to multiple points of significant drop heights. Lenticel damage at stage 1, with a distance of 0m (the start of the packing line), scored an average damage rating of 12%. This suggests that farm management practices and/or the tipping of the bin onto the packing line (with a recorded drop height of 1.1m) has had an impact on fruit quality and has caused some level of lenticel damage to the surface of fruit. However, as fruit moves through the packing line, damage increases significantly.

Following the second assessment, fruit were stored at 20°C until reaching “medium-soft ripe” and an internal fruit quality assessment was conducted. Overall, the internal fruit quality assessments show minimal internal damage for each damage type across all samples, and stages of the packing line. The main internal defects recorded included a small proportion of fruit having body rot, minor amounts of vascular browning, diffuse discolouration, and bruising. The results appear to show no direct correlation between internal damage and stage in packing line.

To reduce further damage on fruit please consider the following:

- Minimise abrasion or mechanical damage at all times.
- Do not harvest fruit in the rain (or if fruit is turgid) and wait until fruit is dry before picking.
- Delay harvesting for 48 hours after heavy or prolonged rain.
- Consider making modifications to packing line to reduce damage to fruit.
- Reduce drop heights throughout pack line.
- Inspect bins, rollers, and brushes (if any) and make modifications accordingly.
- Examine how fruit move on the packing line. Sometimes the system can cause fruit to rub against each other excessively.
- Ensure fruit are stored and ripened at a minimum relative humidity of 85%, which prevents rapid water loss from fruit and helps maintain lenticels in a healthy condition.
- Sample fruit again from the packing line after modifications are made and inspected for damage.
- Contact QDAF to retest fruit if modifications are made and/or damage is still an issue.

Introduction

Lenticels are pores on the skin of fruit that allows the passage of air and water vapour. The rough skin of Hass avocado is due to the presence of nodules, and most of these nodules have lenticels on them. Nodules are more prone to impacts of mechanical damage because they project out from the skin. Lenticel damage is caused by abrasion during harvest and/or packing procedures. It can be caused by fruit rubbing against other fruit, as well as impacts with hard surfaces such as bins, rollers or stiff brushes (or a combination of all). Hass avocado fruit packed in a CQ packing shed were showing symptoms of lenticel damage when being packed into trays. A preliminary trial investigating fruit quality of Hass avocado collected from different stages in the packing line was conducted. All fruit samples were taken from one bin, from the same batch, tipped at 11:26am on 02-08-2023.

Methodology

A total of 53 avocado fruit were collected from five stages of the packing line on 2 August 2023. Three grapefruit were placed in the packing line when the bin entered the line to indicate when to collect the samples at various points as the “parcel” moved down the line. The five sampling stages along with images of the packing line are outlined in figure 1 and table 1 below.

The fruit collected from each stage of the packing line were placed in avocado trays, labelled with their respective sampling stage number (total of 5 different trays). The 5 trays were transported in an air-conditioned vehicle, stored overnight in air conditioning at approximately 17 °C and driven to Maroochy Research Facility (MRF) in Nambour the following day. At MRF, each piece of fruit was assessed at “intake” (03/08/2023). The intake assessments conducted on each piece of fruit included: weight (g), and nodule damage surface area (%).

Following the intake assessments, the fruit was then stored in a controlled temperature cold room at 5°C for 22 days. Following the 22 days, fruit were removed from storage and a second assessment of nodule damage was conducted (25/08/2023). The “removal” assessments conducted on each piece of fruit included: weight (g), and nodule damage surface area (%).

Following the removal assessment, fruit were then stored at 20°C and once each fruit reached “medium-soft ripe” it was assessed for fruit quality. Not every fruit reached “medium-soft ripe” at the same time, therefore each fruit was inspected daily due to variable ripening.

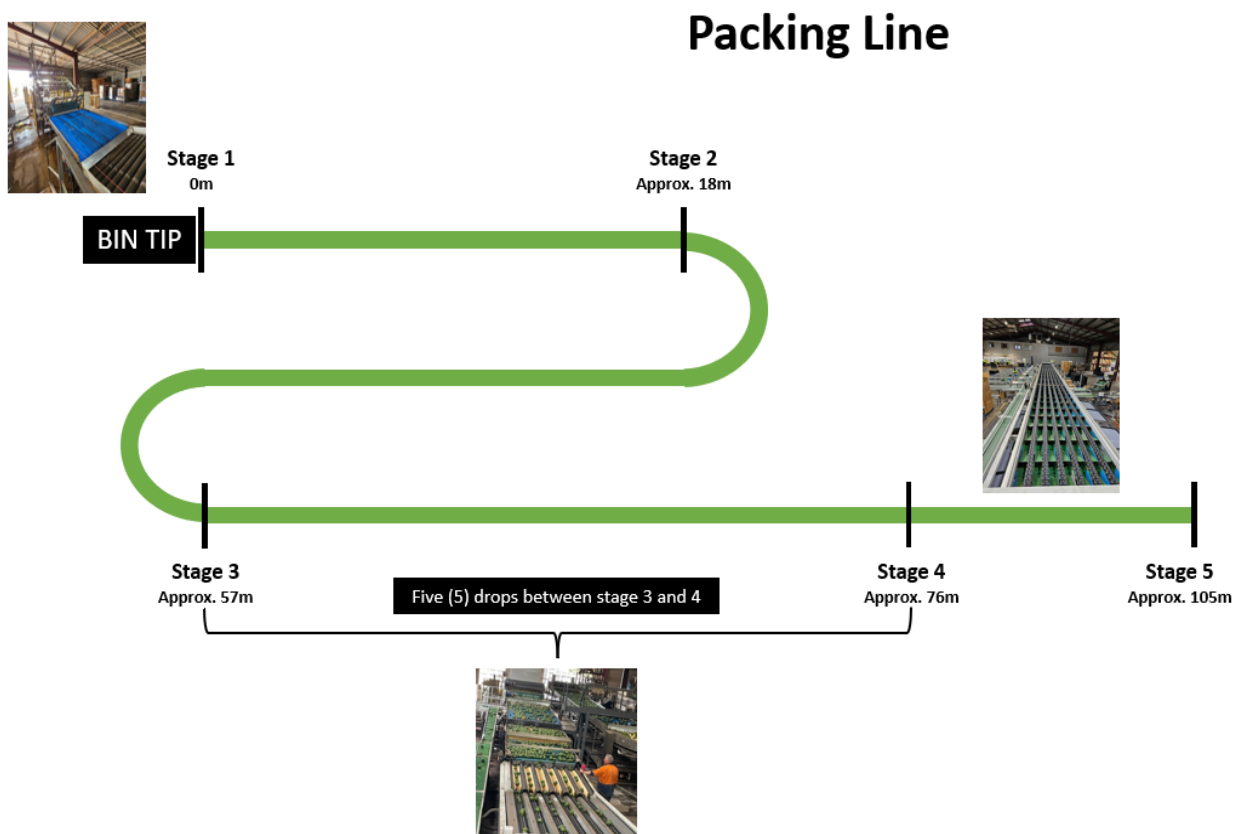
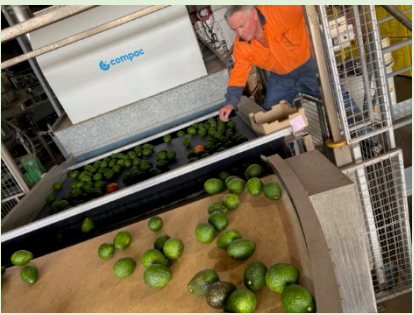
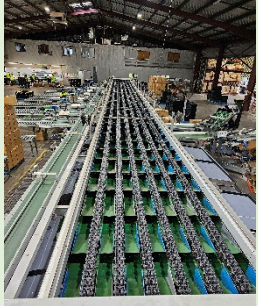


Figure 1: Diagram of packing line.

Table 1: The different stages of the packing line and sample collection points. Images of fruit taken at collection time.

Stage 1			Pack line height → 1.1m Distance between sample points → 0m Pack line total distance → 0m
Stage 1: 10 pieces of fruit were collected from the “blue” belt after being tipped, approximately halfway through the tipping of the bin.			
Stage 2			Pack line height → 1.9m Distance between sample points → 18m Pack line total distance → 18m
Stage 2: 10 pieces of fruit were collected after the Interstate Certification Assurance.			

Stage 3			Pack line height → 1.3m Distance between sample points → 39m Pack line total distance → 57m
Stage 3: 11 pieces of fruit were collected before entering the waxer.			
Stage 4			Pack line height → 1.35m Distance between sample points → 19m Pack line total distance → 76m
Stage 4: 11 pieces of fruit were collected at the singulator.			
Stage 5			Pack line height → 1.1m Distance between sample points → 29m Pack line total distance → 105m
Stage 5: 11 pieces of fruit were collected at tray filler 3. Fruit size 16s to match the approximate sample sizes taken at the various points.			

Results and Discussion

Nodule damage (external)

A correlation between nodule damage score and time in packing line was observed. The results show that at stage 1, average nodule damage (% surface area) of assessed fruit was 12%. Whereas, by stage 2, 3, 4 and 5, nodule damage was 14%, 26%, 55% and 46% respectively (Figure 1). This demonstrates that damage progressively increases along the pack line as the fruit are exposed to multiple points of significant drop heights.

It is important to note that nodule damage at stage 1, with a distance of 0m (the start of the packing line), still scored an average damage rating of 12%. This shows that farm management practices such as, harvesting fruit in wet conditions and not allowing to completely dry before picking, and/or the tipping of the bin onto the packing line (with a recorded drop height of 1.1m) has had an impact on fruit quality by causing some level of nodule damage to the surface of fruit. However, as fruit moves

through the packing line, nodule damage increases. It is important to note that the increase in damage along the line, is cumulative with each specific point contributing to the issue.

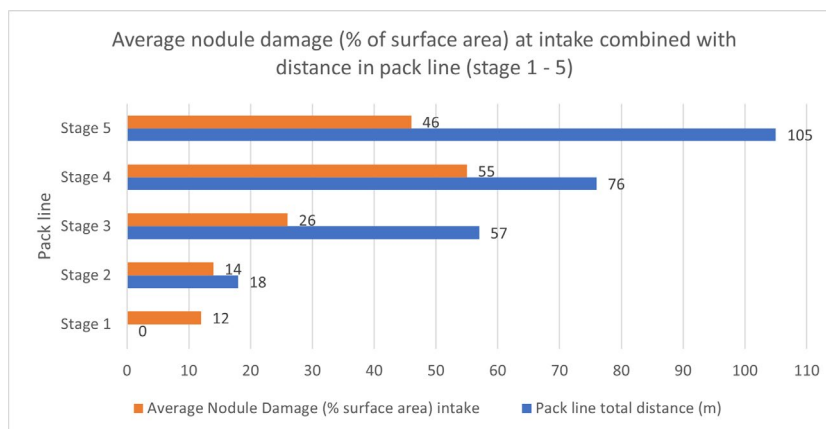


Figure 1: Nodule damage recorded at 5 points along the packing line. Orange bars represent average nodule damage (% surface area of fruit impacted for each stage of packing line). Blue bars outline distance along the packing line for each stage.

The results from the second assessment on the same fruit at “removal” (after fruit had been stored at 5°C for 22 days) shows very slight increases for some of the average damage scores (Figure 2). However, overall the results show that storage time did not significantly increase damage scores.

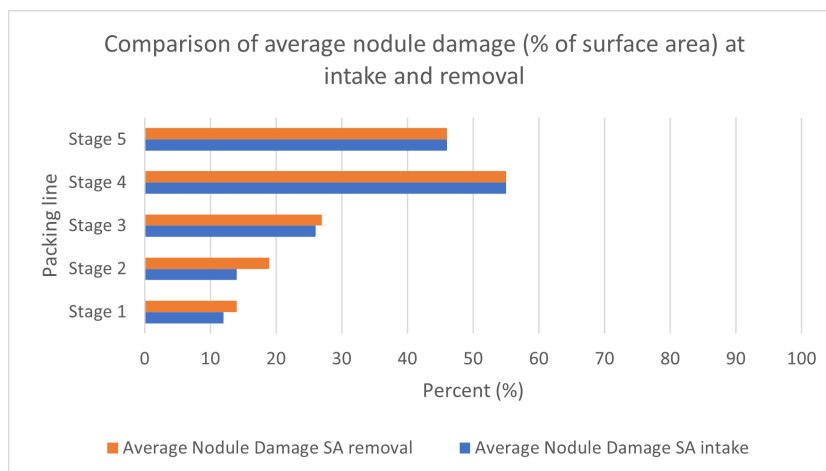


Figure 2: A comparison of nodule damage (percentage of surface area (SA)) at intake assessment (soon after packing) and again at removal (after fruit had been stored at 5°C for 22 days).

Fruit quality (internal) at medium-soft ripe

Fruit were stored at 5°C for 22 days, followed by storage at 20°C until reaching “medium-soft ripe” when an internal fruit quality assessment was conducted. Overall, the internal fruit quality assessments show very minimal internal damage for each damage type across all samples, and stages of the packing line. The main internal defects recorded included a small proportion of fruit having body rot (less than 10% average damage for each stage in pack line), minor amounts of vascular browning, diffuse discolouration, and bruising. It appears that stage 1 (where fruit travelled the least amount of distance) had fruit with generally less internal damage. However, stage 5 (where fruit travelled the most distance in pack line) also had very low levels of internal damage for each

damage type. The results appear to show no direct correlation between internal damage and stage in packing line.

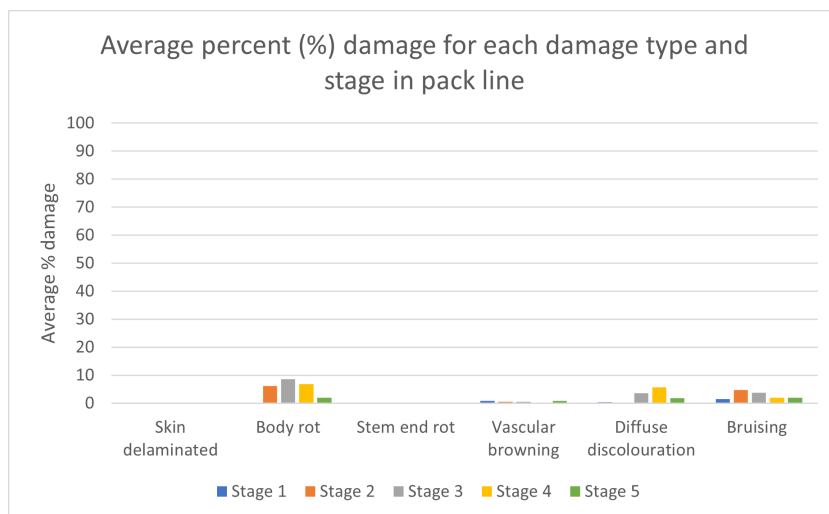


Figure 3: Average percent damage for each damage type and stage in packing line.

Recommendations

Lenticel damage (and damage to nodules on Hass) is caused by abrasion during harvest and/or packing procedures - fruit rubbing against other fruit, as well as impacts with hard surfaces such as bins, rollers, or stiff brushes (or a combination of all). Please consider the following recommendations:

- Minimise abrasion or mechanical damage at all times.
- Do not harvest fruit in the rain (or if fruit is turgid) and wait until fruit is completely dry before picking.
- Delay harvesting for 48 hours after heavy or prolonged rain.
- Consider making modifications to packing line to reduce damage to fruit.
- Reduce drop heights throughout pack line.
- Bins, rollers, and brushes (if any) are inspected, and modifications are made accordingly. If using brushes, avoid brushing fruit, or brush for the minimum time ensuring that soft brushes are used and that they are replaced when worn.
- Examine how fruit move on the packing line. Sometimes the system can cause fruit to rub against each other fruit excessively. This can be rectified by minimising the number of brushes, adjusting brush rotation speed and/or using a system where fruit does not bump against other fruit to move along the line.
- Ensure fruit are stored and ripened at a minimum relative humidity of 85%, which prevents rapid water loss from fruit and helps maintain lenticels in a healthy condition.
- If modifications are made to the packing line, it is suggested that fruit samples are again collected at these different stages of the packing line and inspected for lenticel damage.
- It is recommended that if modifications are made and/or damage is still an issue, that the QDAF Supply Chain Innovation team conduct another trial on avocado fruit in the next season.

Images of trial fruit after being stored at 5°C for 22 days storage.



Fruit 1 – 10 at “removal” assessment after being held at 5°C for 22 days.



Fruit 11 – 20 at “removal” assessment after being held at 5°C for 22 days.



Fruit 21 – 31 at “removal” assessment after being held at 5°C for 22 days.



Fruit 32 – 42 at “removal” assessment after being held at 5°C for 22 days.



Fruit 43 – 53 at “removal” assessment after being held at 5°C for 22 days.

Daily Rainfall (millimetres)

CHILDERS SOUTH

Station Number: 039303 · State: QLD · Opened: 1979 · Status: Open · Latitude: 25.26°S · Longitude: 152.28°E · Elevation: 95 m

2023	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	0	0	0	0	0	0	0	0	↓	0	0	0
2nd	0	18.8	0	2.4	0	0	0	0	↓	0	0.4	0.4
3rd	0	16.4	9.0	0	0	0	0	0.4	↓	0.1	0	38.6
4th	0	0	1.0	0	0	0.8	2.8	0	↓	0	0	0.2
5th	11.4	0	0	0	0	0.6	29.4	0	7.2	0.4	0.6	15.8
6th	0	0	0	0	0	15.8	↓	0	0	3.2	0	
7th	0	0	0	44.6	0	0	0.2	6.8	0	0	3.2	
8th	0	0	0	0	0.2	0	0	0	0	0	2.2	
9th	0	0	0.4	0	0	0.4	0	↓	↓	0.8	0	
10th	0.8	0	6.8	0	0	0.2	0	↓	↓	0	0	
11th	0.2	0	27.2	0	0	0	0	↓	0.4	0	0	
12th	0	0	1.0	0	0	0.2	0	↓	0	0	0	
13th	1.2	0	17.2	0	7.8	0.2	0	↓	0	0	0	
14th	3.8	14.6	4.0	0	0.6	0.2	2.4	↓	0	0	0	
15th	3.8	20.2	0.2	0	0.6	0	0	↓	0	0	0	
16th	2.8	0	0	0	9.2	0	0	↓	0	0	0	
17th	11.6	0	6.8	0	0	0	0	↓	0	0	0	
18th	17.6	0	0	0	0	0	0	↓	0	0	0	
19th	0	0	0	0	0	0	0	↓	0	0	0	
20th	0	0.2	0.4	0	0	0	0	↓	0	0	22.4	
21st	0.6	2.0	0.6	0	0	0	0	↓	0.2	0	24.6	
22nd	0	4.6	0.4	0	0	0	0	↓	0	0	4.2	
23rd	0	0.6	14.0	0	0	0.2	0	↓	0	0	0.8	
24th	0	16.2	0	0.4	0	0.2	6.6	↓	0	0	2.4	
25th	0	0	0	1.8	0	0.4	2.6	↓	0	0	0	
26th	0	0	0	0.6	0	0.4	1.0	↓	0	0	0	
27th	0	0	0	0	0	0	3.0	↓	0	1.6	0	
28th	0	0	0	2.0	0	0	0	↓	0	0	1.4	
29th	0.2		0	0	0	0	0	↓	0	0	42.4	
30th	0		0	5.4	0	0	0.2	↓	1.0	0	0	
31st	0		11.8		0			↓		0		
Highest daily	17.6	20.2	27.2	44.6	9.2	15.8	29.4	6.8	1.0	3.2	42.4	38.6
Monthly Total	54.0	93.6	100.8	57.2	18.4	19.6	48.2	7.2	8.8	6.1	104.6	

↓ This day is part of an accumulated total

Quality control: 12.3 Done & acceptable, 12.3 Not completed or unknown



Product code: IDCJAC0009 reference: 101572055

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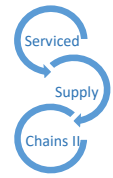
Contact us using details on <http://www.bom.gov.au/climate/how/contacts.shtml>.

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Appendix 45

CQ 'Hass' avocado nodule damage report 2024



Reducing nodule damage in 'Hass' avocados 2024

Andrew Mead, Hung Duong and John Agnew, Department of Agriculture and Fisheries

November 2024

1. Summary

- At intake (initial) assessment the incidence of damage (i.e. % of fruit with nodule damage) increased from 65% (at picking directly into trays) to 93% at packshed (top of field bin sample). Some nodule damage must have been present prior to picking and further damage occurred during transport of the field bin to the pack shed. The packing line minimally increased the incidence of nodule damage on fruit (up to 100% at bin tip).
- At intake assessment, there was a trend for increasing nodule damage severity (% skin surface area impacted) from picked fruit (direct into trays) through to the end of the packing line. It is important to note that the increase in damage along the line, is cumulative with each specific point contributing to the issue.
- At intake assessment, damage severity was low with no significant difference between ground pick, cherry pick, sample from top of field bin & bottom of the field bin sampled directly after bin tip. Pickers appear to be handling the fruit with care. Damage in transit from the field to the packshed is minimal with damage severity not increasing. ICA and pre-waxer samples had the same amount of damage severity (10%). Damage severity then increased to maximum (18.7%) at the end of the packing line.
- There was a significant increase in damage severity between the waxer and the tray filler samples (i.e. from 10% to 18.7%). However, this was a major improvement over the 2023 trial result where the increase in severity was 29% (up from 26% at waxer to 55% at singulator).
- There was little change in damage severity ratings between intake and final external assessment (post 21 days storage at 5°C).
- Nodule damage severity in the 2024 trial was considerably less than in the 2023 trial at all coinciding sampling points along the packing line.
- After final external assessment avocados were kept at 20°C until "medium-soft ripe" when assessed for internal fruit quality. There was no difference in internal fruit quality at any of the sampling points.

2. Introduction

The rough skin of Hass avocado fruit is due to the presence of nodules. Nodules are more prone to impacts of mechanical damage because they are a projection of the skin. In avocados, nodule damage is usually caused by abrasion of the skin during harvest and/or packing procedures.

Modifications to a Central Queensland (CQ) avocado packing line were made following a 2023 DAF trial which showed that unacceptable levels of nodule damage were occurring. The business wanted a follow-up trial to determine if their changes had improved fruit handling and lessened nodule damage. This occurred in late August 2024.

In the 2023 trial fruit was sampled from five points along the packing line including: (1) bin tip, (2) post ICA, (3) pre-waxer, (4) pre-singulator and (5) tray-filler. Most of the abrasion occurred between points (2) and (4). Sampling pre-singulator showed that nodule damage, defined as % skin surface area impacted, had peaked at 55%. The section of packing line above the singulator included a series of five drops (Image 1). This section was replaced, as well as levelling out another section of the line between ICA and the waxer. Hard plastic baffles at all drop points on the line were replaced with soft brush-type baffles.



Image 1. Section of the CQ packing line (which included five drops) replaced in response to significant nodule damage noted in the 2023 DAF trial

3. Methods

Trial treatments entailed sampling 30 Hass fruit at each of seven “locations”. Treatments 1 (cherry-picked) and 2 (ground-picked) were sampled in the orchard in the morning of 21/8/24 by the harvest crew. Fruit was picked and placed directly into trays. A field bin from the same vicinity was filled, tagged with experimental tape and transported to the packshed. Treatments 3-7 were sampled in the morning (between 8:30 & 9am) of 22/8/24. To ensure sampling of only the trial bin fruit, oranges were placed on the conveyor at the start of bin tip and at the end of bin tip as markers. Sampled fruit was carefully handled and placed into trays. Fruit was transported from Childers to Maroochy Research Facility (MRF) by air-conditioned vehicle immediately post-trial. A “real-time” temperature and humidity logger (Copeland/Emerson #7102022592) was inserted into one of the trays prior to departure. At MRF an intake assessment was conducted on the afternoon of 22/8/24, which included measuring the fresh weight and nodule damage (% skin surface area impacted) of each piece of fruit. Trays were then placed into cold storage at 5°C for 21 days. At removal from cold storage, a final external assessment was conducted on 12/9/24. Avocados were then stored at 20°C and at “medium-soft ripe” they were assessed for internal fruit quality. Table 1 lists treatments (sampling points) and their images.

Table 1. Treatments (sampling points) and associated images

Treatment	Image
cherry-picker (1)	2
ground level picked (2)	N/A
top of field bin (3)	3
directly after bin tip (4)	4
post ICA (5)	5
before waxer (6)	6
tray filler (7) *	7

*(multiple sites sampled to obtain a range of fruit sizes)

**Image 2. Trial fruit harvested by cherry picker and placed directly into trays****Image 3. Field bin from which fruit were sampled from the top layer****Image 4. Fruit sampled at bin tipper**

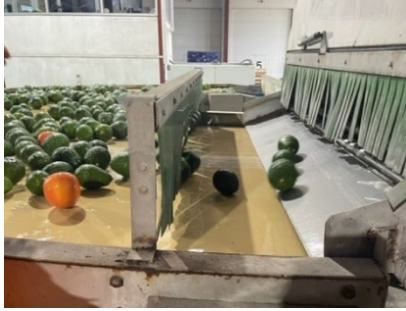


Image 5. Fruit sampled post ICA



Image 6. Sampling point at pre-waxer

4. Results

At intake (initial) assessment the incidence of damage (i.e. % of fruit with nodule damage) increased from 65% (at picking directly into trays) to 93% at packshed, in a sample from the top of the field bin sample (Table 2). Some nodule damage must have been present prior to picking and further damage occurred during transport of the field bin to the pack shed. The packing line minimally increased the incidence of nodule damage on fruit (up to 100% at bin tip). A similar damage incidence result was recorded at removal assessment.

Damage severity is the more important measure of nodule damage. It is defined as the percentage of skin surface area impacted by nodule damage. At intake assessment, damage severity was low with no significant difference between ground pick, cherry pick, sample from top of field bin and bottom of the field bin sampled directly after bin tip (Figure 1.). Pickers appear to be handling the fruit with care. Damage in transit from the field to the packshed is minimal with damage severity not increasing. ICA and pre-waxer samples had the same amount of damage severity (10%). Damage severity then increased to maximum (18.7%) at the end of the packing line. There was little change in damage severity ratings between intake and removal (final) assessment (post 21 days storage at 5°C).

Fruit weight loss from intake to removal was low and the virtually same for all treatments. Ground picked weight loss was significantly lower than cherry picked and before waxer samples.

Table 2. Assessments of nodule damage at intake and removal from cold storage. Fruit weight loss at removal also included.

Treatment	Nodule damage at intake		Nodule damage at removal		Weight loss at removal (%)
	Incidence (%)	Severity (% of surface area)	Incidence (%)	Severity (% of surface area)	
Ground pick	63.3	1.7 ^a	80	1.8 ^a	1.7 ^a
Cherry Pick	66.7	1.3 ^a	80	1.5 ^a	2.4 ^b
Top bin	93.3	3.3 ^a	96.7	3.8 ^{ab}	2.3 ^{ab}
Bottom bin	100	5.2 ^a	100	5.7 ^b	2.1 ^{ab}
ICA	100	9.7 ^b	100	9.5 ^c	2.3 ^{ab}
Before wax	100	10 ^b	100	9.7 ^c	2.5 ^b
Tray filler	100	18.7 ^c	100	17.8 ^d	2.2 ^{ab}

Means with the same letter within each column are not significantly different (at $p < 0.05$) as tested by lsd

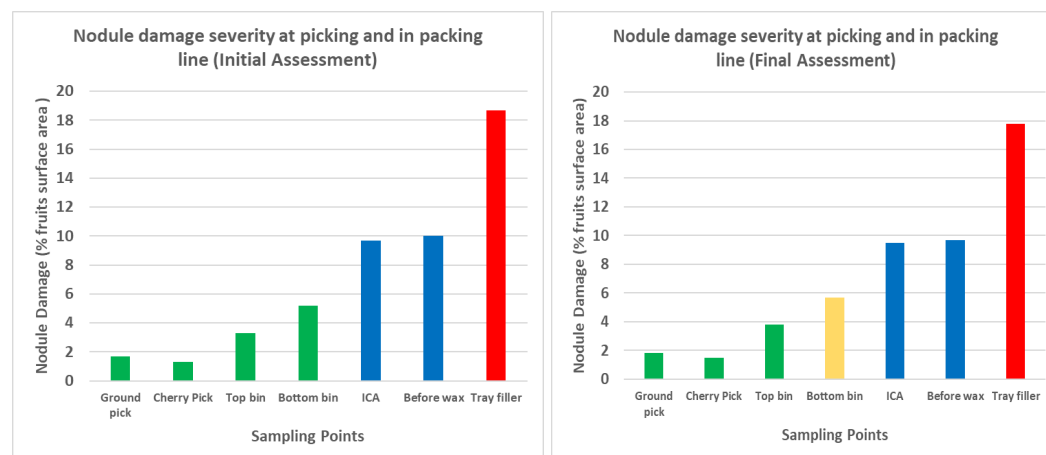


Figure 1. Avocado fruit nodule damage severity assessments at intake (left) on 22nd August and final (right) on 12th September 2024 (following 21 days cold storage) respectively. Bars with the same colour are not significantly different ($p < 0.05$)

As a result of the changes to the packing line, nodule damage severity in the 2024 trial was considerably less than in the 2023 trial at all coinciding sampling points along the packing line (Figure 2.).

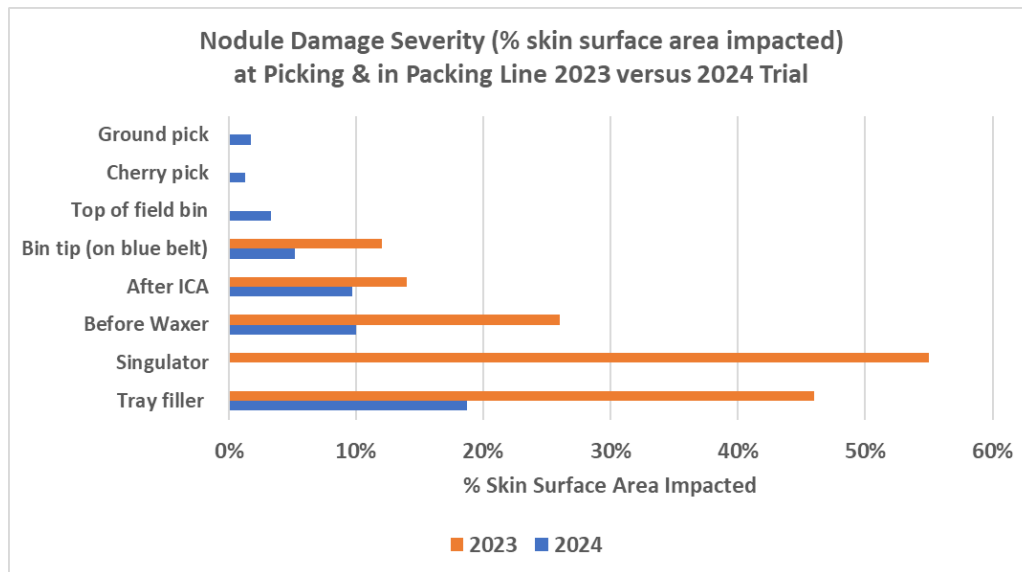


Figure 2. Comparison of nodule damage severity between 2023 and 2024 trials

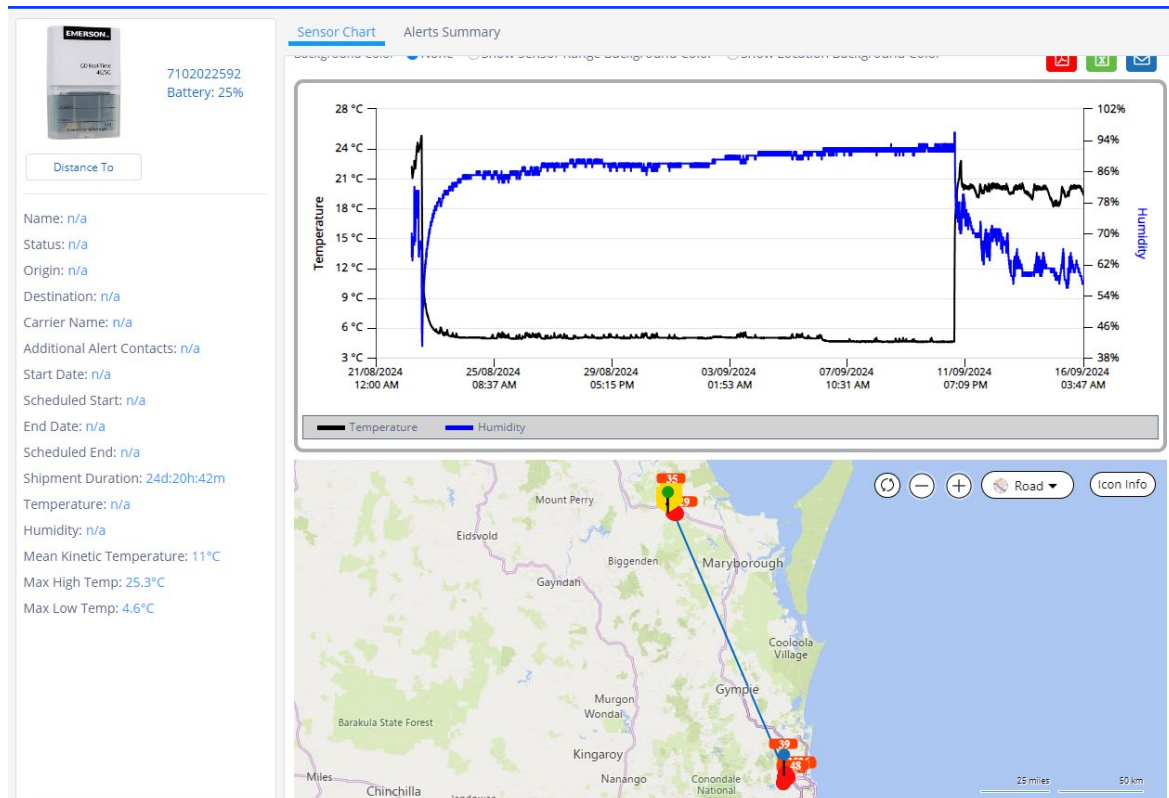
5. Conclusion

In the 2023 trial, nodule damage severity peaked at 55%. Most of the nodule damage occurred in a section of packing line above the singulator which included a series of five drops. This section was replaced, as well as levelling out another section of the line between ICA and the waxer. Hard plastic baffles at all drop points on the line were also replaced with soft brush-type baffles. These improvements to the packing line resulted in a 37% reduction in peak nodule damage, as measured in the 2024 trial.

6. Acknowledgments

We thank the grower and farm staff for supplying fruit for trials and for their technical advice and support.

Appendix 1 Emerson Go Real-Time 4G/5G Tracker showing temperature and humidity from packedsh departure (9:30am on 22/8/24) to MRF (12:30pm on 22/8/24 – 6:30am on 23/8/24).



Appendix 46

NQ avocado surface coating trials report



Efficacy of edible coatings to extend the shelf life of Australian avocados

Akorn Technology coatings efficacy findings 2023

John Archer, Minh Nguyen and Andrew Macnish

Department of Primary Industries

Summary

The efficacy of two proprietary surface coatings manufactured by Akorn Technologies to extend the shelf life of Hass and Shepard avocado fruit from north Queensland in Australia was tested. Key findings included:

- Application of coating 1 and 2 extended the shelf life of Hass avocados by 3-9 days following storage at 5°C and 20°C.
- The coating treatments delayed fruit ripening, softening and loss of green skin colour.
- Coated fruit were generally associated with a higher incidence of internal defects such as body rots once they reached full ripe.
- The coatings also extended the shelf life of Shepard avocados by 1-2 days when fruit were stored at 5°C but not at 20°C.

In summary, while the coatings were effective in extending fruit shelf life, the slower rate of ripening led to a higher level of internal flesh defects such as rots when fruit eventually reached full ripe. There may be potential to adjust the coating formulations to marginally reduce the shelf life extension function to ensure less internal fruit defects.

1. Introduction

Avocado (*Persea americana*) is a nutrient-rich fruit that is increasing in popularity among Australian consumers. Avocado production in Australia occurs year-round across the country's diverse climatic zones. In 2022, 122,197 tonnes were produced with a gross value of \$363.8 million AUD (Freshlogic Analysis, 2022). Production is set to almost double over the next 3 years due to recent extensive plantings occurring around the country. The state of Queensland accounts for approximately 48% of the nation's total yield.

The Hass variety represents about 80% of production while several green skin cultivars such as Shepard make up the balance. The primary harvest season for Hass in northern Queensland usually span from April to June, while Shepard fruit are picked from February to April. With increasing fruit production forecast over the next few years, there is interest among Australian growers to expand fruit exports by sea to markets in Asia. This will require careful attention to ensure fruit quality and shelf life meets the market expectation. Increasing the storage life of Australian avocados to withstand the rigours of long-distance seafreight handling through optimised supply chain efficiency or shelf life extension technologies will be essential.

The objective of this study was to test the efficacy of edible coatings to extend the shelf life of avocado fruit to support the delivery of premium quality product into new and existing export markets. This report

presents an evaluation of two protective coatings applied to Hass and Shepard avocados stored at 5°C and 20°C.

2. Methods

The study employed a 3x2 factorial experiment design to test the efficacy of two proprietary Akorn Technology coatings to extend the shelf life of two avocado varieties (Shepard and Hass). Three treatment groups were established: one group was treated with Akorn Coating 1 and another with Akorn Coating 2, with both applied according to the manufacturer's guidelines while the last group was left untreated as a control. Each treatment group was then subjected to two temperature conditions: 5°C and 20°C. The 5°C was stored for 30 days to mimic the typical shipping duration for seafreight. After this period, the fruit was transferred to 20°C to replicate the conditions it would face during consumer storage. The 20°C fruit were continuously maintained at 20°C to the end of shelf life to replicate potential domestic supply chain handling and retail display.

The end of shelf life (ESL) was determined by counting the number of days it took for the fruit, stored at 20°C, to reach a firmness of 39 shore units (medium soft-ripe), providing a measurable and standard criterion to evaluate the efficacy of the Akorn coatings.

The acceptability of the fruit was evaluated via a destructive testing method aimed at assessing internal defects, such as bruising, stem end rot, other rots, or chilling injury. If these defects accounted for more than 10% of the fruit's flesh volume, the fruit was deemed unacceptable.

Fruit weight loss was determined from the point of intake to the end of the shelf life. Weight measurements were taken regularly when the fruit was stored at 20°C.

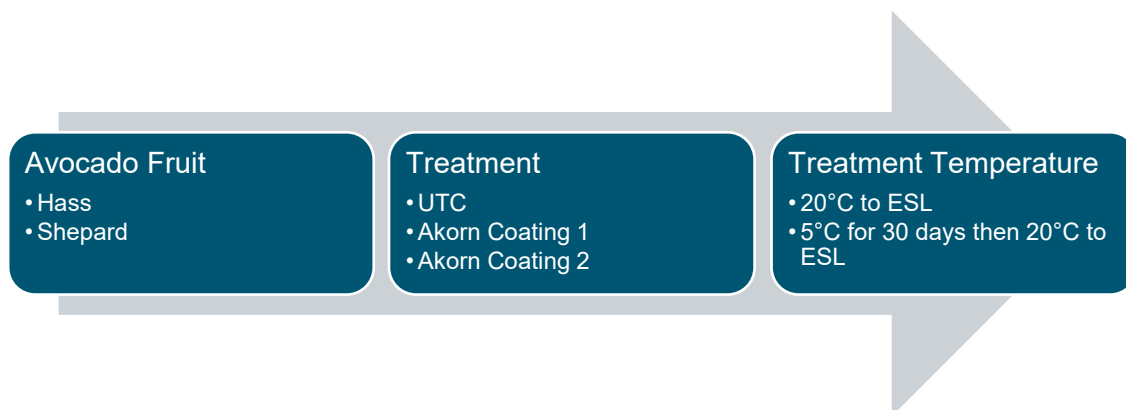


Figure 1 Layout of the Trial Fruit type, Storage Temperatures, and Treatments (UTC = untreated control)

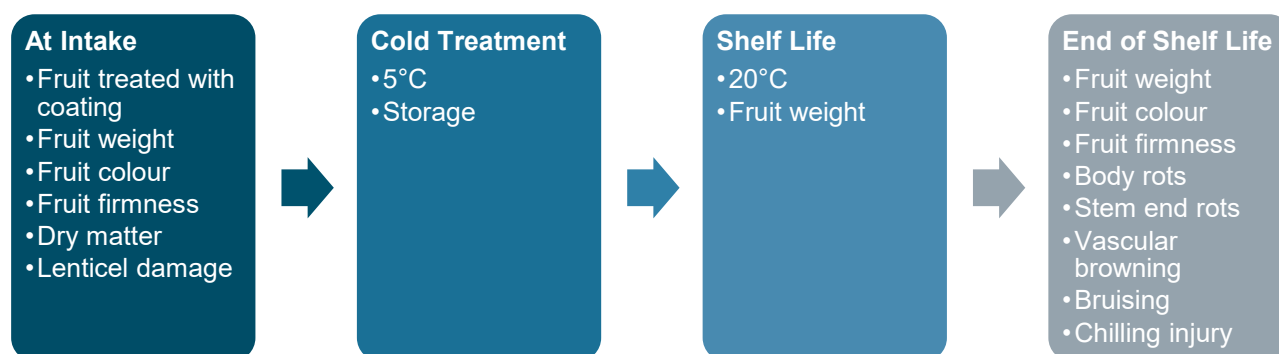


Figure 2 Assessment of Fruit Quality During Storage Trial

2.1 Fruit information

Table 1 Summary of Trial Parameters for Hass and Shepard Avocado Varieties

	Trial Start Date	Dry Matter at Intake (%)	Number of Fruits in Trial
Hass Trial 1	8/5/23	27.9	180
Hass Trial 2	9/6/23	30.1	120
Shepard Trial 1	10/2/23	21.9	120
Shepard Trial 2	9/3/23	24.8	180

Trial start date, Dry matter and fruit numbers

Table 2 Summary of Coating Names Utilised in Hass and Shepard Avocado Trials

Coating Name	Detailed Description	Lot Number
Akorn Coating 1	Akorn Natural Coating	Lot# DI2022361
Akorn Coating 2	Akorn Natural Coating, Avocado Formulation 2	Lot# AT2023075A

3. Results

Table 3 Results of Hass Avocado Trial 1 Focusing on Shelf Life and Quality Metrics

	Treatment	Days to ESL (SD)	% Fruit unacceptable (SD)	Weight loss (%) (SD)
5°C / 30 days	Control	5.5 (1.81)	37% (0.49)	2% (0.026)
	Coating 1	11.4 (4.32)	13% (0.35)	6% (0.030)
	Coating 2	9.9 (2.66)	58% (0.50)	4% (0.027)
20°C	Control	11.3 (1.15)	53% (0.51)	3% (0.010)
	Coating 1	15.3 (3.19)	76% (0.43)	5% (0.023)
	Coating 2	14.1 (1.83)	93% (0.25)	4% (0.007)

N.30, Harvest date 8/5/23, shelf life fruit was stored 20C, fruit was assessed at ESL/medium-soft ripe, Days to ESL in addition to treatment duration.

As shown by the data in Table 3, coatings 1 and 2 extended shelf life over the control fruit. Coating 1 was more effective than coating 2 in extending shelf life for fruit held at 5°C. Coating 1 also reduced the incidence of internal flesh defects that developed when 5°C fruit reached ripe. Otherwise, there was a risk of increasing flesh defects in association with the coating treatments. Because fruit shelf life was extended, weight loss by the ESL was greater than the control. Overall, the data suggests that while both coatings seem to prolong the shelf life of the avocados at both 5°C and 20°C when compared to the control group, the quality of the fruit, as indicated by the percentage of unacceptable fruit, fruit with >10% defects, varies significantly. This indicates that while the coatings may extend shelf life, they could compromise fruit quality in other ways.



Image 1 From left to right, Akorn coating 1, UTC and Akorn coating 2, 10 days after fruit was treated. (trial 1 Hass fruit results)

Fruit treated with the two different Akorn coatings appeared to retain a greener skin and remain less ripe during subsequent storage, as compared to the untreated control (UTC), as seen in the photo above.

Table 4 Impact of Different Treatments on Estimated Shelf Life, Quality, and Weight Loss of Hass Avocados in Trial 2

	Treatment	Days to ESL (SD)	% Fruit unacceptable (SD)	Weight loss (%) (SD)
5°C / 30 days	Control	10.7 (1.7)	10% (0.3)	8% (0.015)
	Coating 1	19.9 (7.7)	45% (0.5)	11% (0.035)
	Coating 2	15.0 (3.9)	35% (0.5)	9% (0.031)
20°C	Control	11.1 (1.7)	5% (0.2)	7% (0.015)
	Coating 1	18.4 (2.2)	65% (0.5)	7% (0.018)
	Coating 2	15.5 (2.3)	35% (0.5)	7% (0.013)

N.30, Harvest date 7/6/23, shelf life fruit was stored 20C

Table 4 shows the effect of the two Akorn coatings at two different storage temperatures on Hass avocados. Both coatings extended the time after treatment to end of shelf life by >4 days. However, both coatings were associated with a higher incidence of unacceptable fruit when they reached full ripe. This is likely due to the fact that the treated fruit undergoes destructive assessment at a later date compared to the control but at the same ripening stage. This additional time allows internal rots more opportunity to develop and reach the threshold of 10% of the fruit's mass, resulting in the fruit being classified as unacceptable. In this second trial, there were no consistent benefits of the coatings on fruit weight loss.

Table 5 Effects of Various Treatments on Estimated Shelf Life, Quality, and Weight Loss for Shepard Avocados in the Trial 1

	Treatment	Days to ESL (SD)	% Fruit unacceptable (SD)	Weight loss (%) (SD)
5°C/ 14 days	Control	5.0 (0.83)	0% (0.00)	9.36% (1.87)
	Coating 1	7.3 (1.73)	5% (0.22)	8.32% (1.66)
	Coating 2	6.4 (1.42)	10% (0.31)	7.74% (1.55)
20°C	Control	8.8 (0.64)	10% (0.31)	9.18% (1.84)
	Coating 1	9.1 (1.21)	0% (0.00)	6.91% (1.38)
	Coating 2	9.0 (1.12)	5% (0.22)	7.66% (1.53)

N. 20 Harvest date 6/2/23, fruit were stored at 5C for 14 days, shelf life fruit was stored 20C,

Table 5 outlines the outcomes of the first Shepard avocado trial, focusing on key variables like ESL, fruit quality, and weight loss under different treatments and temperature conditions. At 5°C for 14 days, the application of Coating 1 and Coating 2 both resulted in an extension of ESL and varied rates of fruit deemed unacceptable. Meanwhile, at 20°C, coatings marginally increased the ESL compared to the control and demonstrated a range of acceptability and weight loss. This data was collected from avocados harvested on February 6, 2023. Coating 1 resulted in fewer unacceptable fruits and less weight loss compared to Coating 2. The data suggests that avocados stored at 20°C had a longer shelf life, but also a higher percentage of unacceptable fruits, compared to those stored at 5°C.

Table 6 Impact of Various Treatments on Estimated Shelf Life and Quality of Shepard Avocados in the Trial 2

	Treatment	Days at 20°C until ESL (SD)	% Fruit unacceptable (SD)
5°C / 14 days	Control	4.9 (1.17)	0
	Coating 1	6.7 (1.22)	0
	Coating 2	6.3 (1.33)	0
5°C / 33 days	Control	4.6 (0.68)	20% (0.41)
	Coating 1	6.2 (1.57)	35% (0.49)
	Coating 2	6.2 (1.66)	40% (0.50)
20°C	Control	9.9 (1.46)	25% (0.44)
	Coating 1	11.1 (1.57)	10% (0.31)
	Coating 2	10.9 (1.77)	20% (0.41)

N. 20 Harvest date 5/3/23, fruit were stored at 5C for 14 days and 33 days, shelf life fruit was stored 20C,

Both coatings increased the shelf life of the avocados compared to the control group at both temperatures and both durations. Fruit acceptability did not appear to be impacted by coating.

Table 6 provides a detailed assessment of the second Shepard avocado trial, examining the ESL and the percentage of fruit deemed unacceptable under different treatments and storage durations. The table includes data for three distinct conditions: avocados stored at 5°C for 14 days, avocados stored at 5°C for 33 days, and those stored at 20°C. The table shows varying effectiveness of the coatings at different storage durations and temperatures. The avocados were harvested on March 5, 2023.

Table 7 Comparative Weight Loss of Shepard Avocados under Various Treatments Across Time Points in the Trial 2

	Treatment	Weight loss after Cold Storage	Weight loss 2 days after cold storage	Weight loss 4 days after cold storage	Weight loss 8 days after cold storage	Weight loss (%) (SD)
5°C / 14 days	Control	3.9% (0.007)		7.2% (0.011)		8.3% (0.015)
	Coating 1	3.4% (0.007)		6.0% (0.012)		8.0% (0.015)
	Coating 2	2.9% (0.007)		5.6% (0.013)		7.3% (0.012)
5°C / 33 days	Control	9.8% (0.017)	11.4% (0.019)			14.2% (0.023)
	Coating 1	8.0% (0.021)	9.2% (0.022)			12.2% (0.024)
	Coating 2	6.5% (0.014)	7.9% (0.017)			10.8% (0.018)
20°C	Control			3.5% (0.005)	6.4% (0.008)	8.0% (0.010)
	Coating 1			2.7% (0.004)	5.2% (0.008)	7.1% (0.011)
	Coating 2			2.9% (0.005)	5.3% (0.012)	7.1% (0.013)

N. 20 Harvest date 5/3/23, fruit were stored at 5C for 14 days and 33 days, shelf life fruit was stored 20C,



Table 7 outlines the effect of different treatments on the weight loss of Shepard avocados at multiple time intervals following cold storage. The table offers data for three distinct storage conditions: 14 days at 5°C, 33 days at 5°C, and room temperature storage at 20°C. Across these conditions, the data reveals that coatings tend to mitigate weight loss more effectively than the control group, particularly at lower temperatures. The avocados were harvested on March 5, 2023, and the standard deviations are also presented to understand the variability of the results.

4. Conclusion

Based on the trials conducted on Hass and Shepard avocados, it is evident that the Akorn coatings generally extended the shelf life and reduced weight loss of avocados compared to the control groups, especially when stored at 5°C. However, it's crucial to note that these coatings also often led to a higher percentage of unacceptable fruits with a higher % of rots, particularly in the Hass avocado trials.

This increase in unacceptable fruits due to coatings is likely because treated fruits were assessed destructively at later dates compared to the control groups although they were at the same ripening stage. This additional time may have allowed for internal rots and other deteriorations to reach unacceptable levels, which could be classified based on a certain percentage of fruit mass. Therefore, while the coatings appeared beneficial in delaying the ESL, they may present drawbacks such as increased susceptibility to spoilage over time.

Weight loss was another critical parameter that showed variations based on treatment and storage conditions. It was observed that while coatings generally reduced weight loss in the Shepard avocados, the benefits were most prominent at lower temperatures. It suggests that coatings could be particularly useful for longer cold storage periods.

The data collectively indicate that while coatings may extend the shelf life of avocados, they may also raise the incidence of fruits deemed unacceptable for consumption. Therefore, additional studies are needed to refine the composition and application process of these coatings to maximise their benefits while minimising potential drawbacks.

In summary, this research provides valuable insights into optimising storage conditions and treatments for avocados, potentially leading to longer shelf life and reduced waste. However, the implications regarding the quality of the fruit necessitate further studies for a holistic understanding the effectiveness and limitations of these treatments.

Appendix 47

NQ avocado low storage temperature trial report

Low storage temperature (1-3°C) tolerance of Shepard avocados

John Archer, Minh Nguyen, Pip Bryant, Hung Duong, Lawrence Smith, Boyd Tarlinton and Andrew Macnish

Department of Primary Industries

Summary

This report presents the findings from the North Queensland (NQ) 2025 Low storage temperature post-harvest storage trials. The study evaluates the impact of short duration low temperature on fruit quality.

Fruit held continuously at 7°C performed best overall, maintaining good external appearance and excellent internal quality. Fruit exposed to 3°C for up to four days generally remained acceptable, indicating a limited buffer for short-term temperature deviations. In contrast, fruit exposed to 1°C or 2°C showed a clear increase in chilling injury, including flesh browning and uneven ripening, which would reduce eating quality and marketability.

These results show that avocados can tolerate brief exposure to 3°C, but temperatures below this threshold substantially increase the risk of chilling injury. The findings reinforce the importance of maintaining fruit temperature as close as possible to the recommended 7°C during storage and transport.

Post-ripening assessments identified various defects, including body rot, stem-end rot, bruising, and vascular browning. While these non-chilling-related defects were generally more prevalent in fruit subjected to lower treatment temperatures, they remained at manageable levels due to the short storage duration. Trial 2 exhibited a higher incidence of these specific defects compared to the initial trial.

1. Introduction



The Serviced Supply Chains II (AM21000) project is a research, development, and extension (RD&E) initiative aimed at assessing and managing supply chain risks to improve the consistency and quality of fresh produce delivery. The project provides critical decision support for horticulture exporters, helping them maximize product value, reduce claims, and expand trade volume.

This report focuses on the tolerance of NQ Shepard avocados to short-duration low-temperature exposure during the 2025 season. The objective was to assess the effect of temporary exposure to 1–3°C on fruit quality and shelf life under conditions that simulate real supply-chain temperature shocks.

Although ideal storage conditions can usually be maintained in controlled systems, commercial supply chains often experience temperature fluctuations during loading, unloading, transfers between facilities, movement between coolrooms and handling delays. These deviations can expose fruit to short periods of colder-than-recommended temperatures, potentially reducing quality.

Over the past four years, the Serviced Supply Chains II project has monitored avocado consignments and conducted laboratory simulation trials to better understand how real supply chains affect fruit quality. In export systems, sea freight generally provides longer but more stable cooling periods, while air freight involves shorter transit times but a greater risk of temperature fluctuation. Even when consignments are otherwise well managed, temperature shocks can occur during transitions between transport and storage environments. This trial was designed to replicate short-duration exposure to low temperatures and quantify its impact on fruit quality.

2. Materials and Methods

Fruit Selection and Harvesting

Commercially mature Shepard avocados were harvested in 2025 by a commercial picking crew at a farm located in the Tablelands region, NQ. Following harvest, fruit were transported to a nearby packing facility, where they were graded and packed before being transported to Cairns for experimental assessment. Total transport time after packing was less than 24 hours. Harvest dates for Trial 1 and Trial 2 were 17 February 2025 and 18 March 2025, respectively.

Trial Design

The cold-treatment trials followed a structured 10-day storage program designed to reflect supply-chain conditions that may occur during domestic shipment or air-freight export.

The experiment was conducted twice. In Trial 1, fruit were exposed to 1°C, 2°C or 3°C for 1, 2 or 3 days. In Trial 2, the 1-day treatment was omitted because public holidays affected scheduling and fruit handling logistics, and a 4-day treatment was included instead.

Fruit were first preconditioned for 24 hours at 7°C before undergoing cold treatment. After the cold-treatment phase, fruit were returned to 7°C for the remainder of the 10-day storage period so that recovery or further symptom development could be monitored. At the end of storage, fruit were ripened at 20°C to assess final eating quality. Control fruit were held continuously at either 7°C or 20°C.

Table 1. Time × Temperature Matrix for ‘Shepard’ Avocados Under a Range of Potential Supply Chain Conditions

Temp (°C)	24 h*	48 h	72 h	96 h**	10 days
1	x	x	x	x	
2	x	x	x	x	
3	x	x	x	x	
7					x
20	x	x			

*24 h assessed in Trial 1 only.

**96 h assessed in Trial 2 only.

3. Results and discussion

Chilling Injury Results

Chilling injury was strongly influenced by storage temperature in both trials, although there was large variability in the response between trial runs, reflecting the inherently variable nature of chilling injury expression. In both cases, the greatest injury occurred in fruit exposed to the lowest storage temperatures, while fruit held at 3°C, 7°C or 20°C showed little to no injury.

In Trial 1, chilling injury remained relatively low overall, but symptoms were still most evident in fruit stored at 1°C and 2°C. Injury at 1°C was greatest after 1 day of exposure and then declined at the longer treatment durations. Fruit stored at 2°C for 1 or 2 days showed a similar level of injury, while fruit stored at 3°C showed less chilling damage.

In Trial 2, the treatment response was much stronger. Fruit exposed to 1°C developed the most severe chilling injury, peaking at approximately 25% flesh affected after 2 days, and remaining elevated after 3 and 4 days. Fruit stored at 2°C also developed chilling injury, with the strongest response observed after 3 days of exposure. By contrast, fruit stored at 3°C showed only minor injury, and fruit held at 7°C or 20°C remained essentially unaffected (Figure 2).

Although there was clear variation between Trial 1 and Trial 2, particularly at 1°C and 2°C, the overall temperature response was consistent. In both trials, storage below 3°C increased the risk of chilling injury, whereas fruit stored at 3°C, 7°C and 20°C showed minimal damage. This indicates that the effect of temperature on chilling injury was robust, even though the severity of the response varied between trial runs.

Visual assessment supported these results. Fruit exposed to lower temperatures showed a clear progression in symptom severity, from severe internal browning at 1°C, to moderate browning at 2°C, to only minor symptoms at 3°C. Fruit held at 7°C showed no visible chilling injury and retained a brighter, more uniform flesh appearance (Figure 1).



Figure 1 From left to right: 1°C, 2°C, 3°C, and 7°C—showing progression from severe chilling injury to no chilling injury.

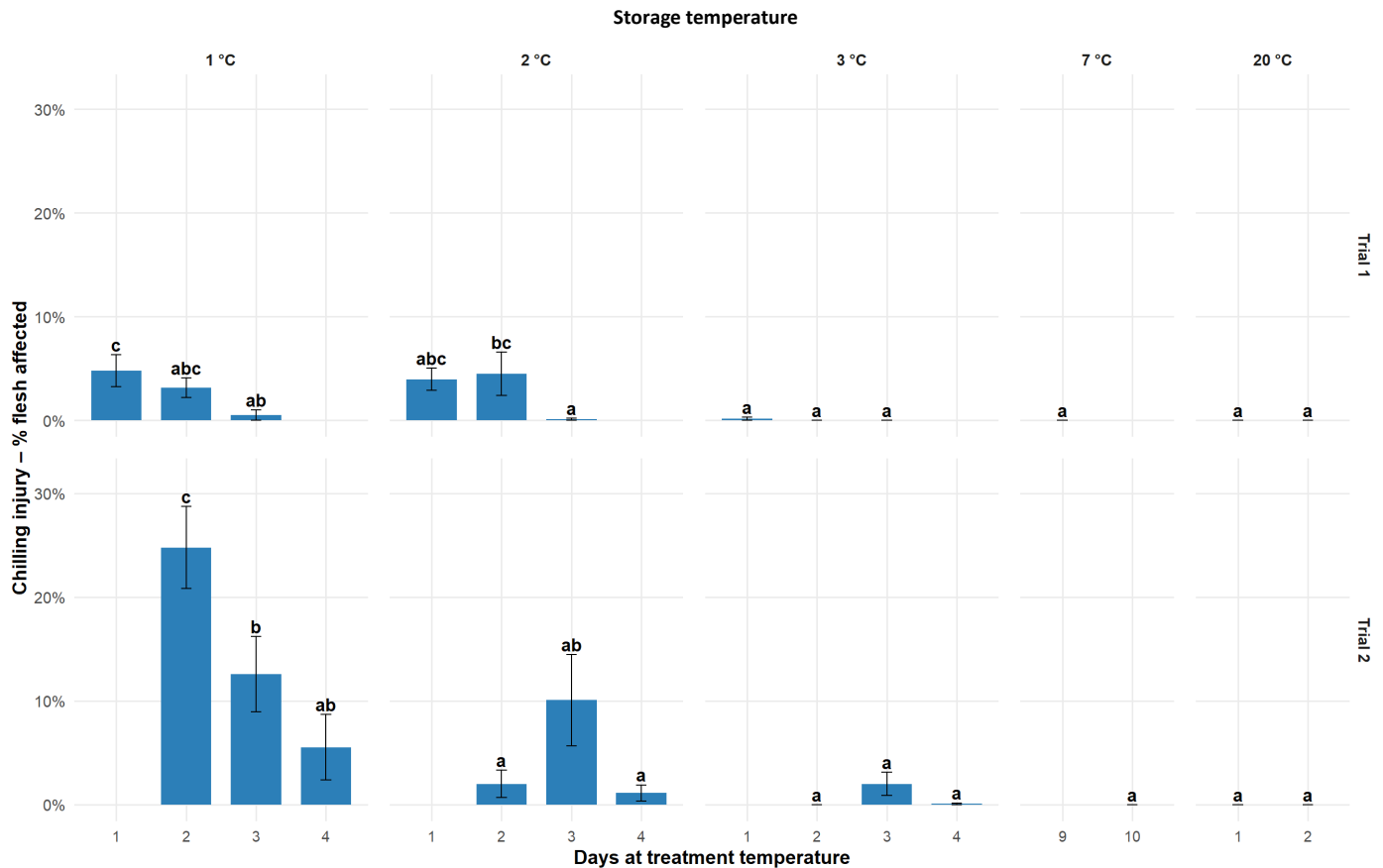


Figure 2 Chilling injury (% flesh affected) following storage at 1, 2, 3, 7 or 20°C and subsequent ripening. Results are presented separately for Trial 1 and Trial 2. Bars represent treatment means $\pm$ standard error, and different letters indicate significant differences among treatments. Lowercase letters indicate Tukey-adjusted pairwise groupings derived from analysis of treatment effects within each trial using a linear model (one-way ANOVA on treatment combinations). Treatments sharing at least one letter are not significantly different at $P < 0.05$.

Defect Severity (excluding chilling injury)

Defects, including body rot, stem-end rot, bruising and vascular browning, were also detected following storage and ripening. In general, these non-chilling defects were more evident in fruit exposed to the lower treatment temperatures particularly in Trial 2. However, their contribution to overall quality loss remained smaller than that of chilling injury (Figure 3).

In Trial 1, the combined severity of non-chilling defects remained low across all treatments and was generally below 2.5% flesh affected. In Trial 2, these defects were more pronounced, especially in fruit exposed to 1°C, where combined severity reached approximately 7–8% in the more severe treatments. Defect severity at 2°C and 3°C was lower, while fruit held at 7°C or 20°C showed only minor levels of non-chilling defects.

Although non-chilling defects were measured at higher levels under colder storage conditions, their total severity remained below the 10% threshold used in this study as a practical indicator of commercially unacceptable fruit quality. This suggests that consumers would be more likely to reject fruit because of chilling injury than because of body rot, stem-end rot, bruising or vascular browning under the short-duration temperature exposures assessed here.

The higher levels of non-chilling defects observed in Trial 2 compared with Trial 1 also indicate normal variability in background fruit condition between harvests and trial runs. Even so, the overall pattern was consistent: colder

storage increased defect pressure, but the principal quality risk associated with short-duration low-temperature exposure remained chilling injury, particularly at 1°C and 2°C.

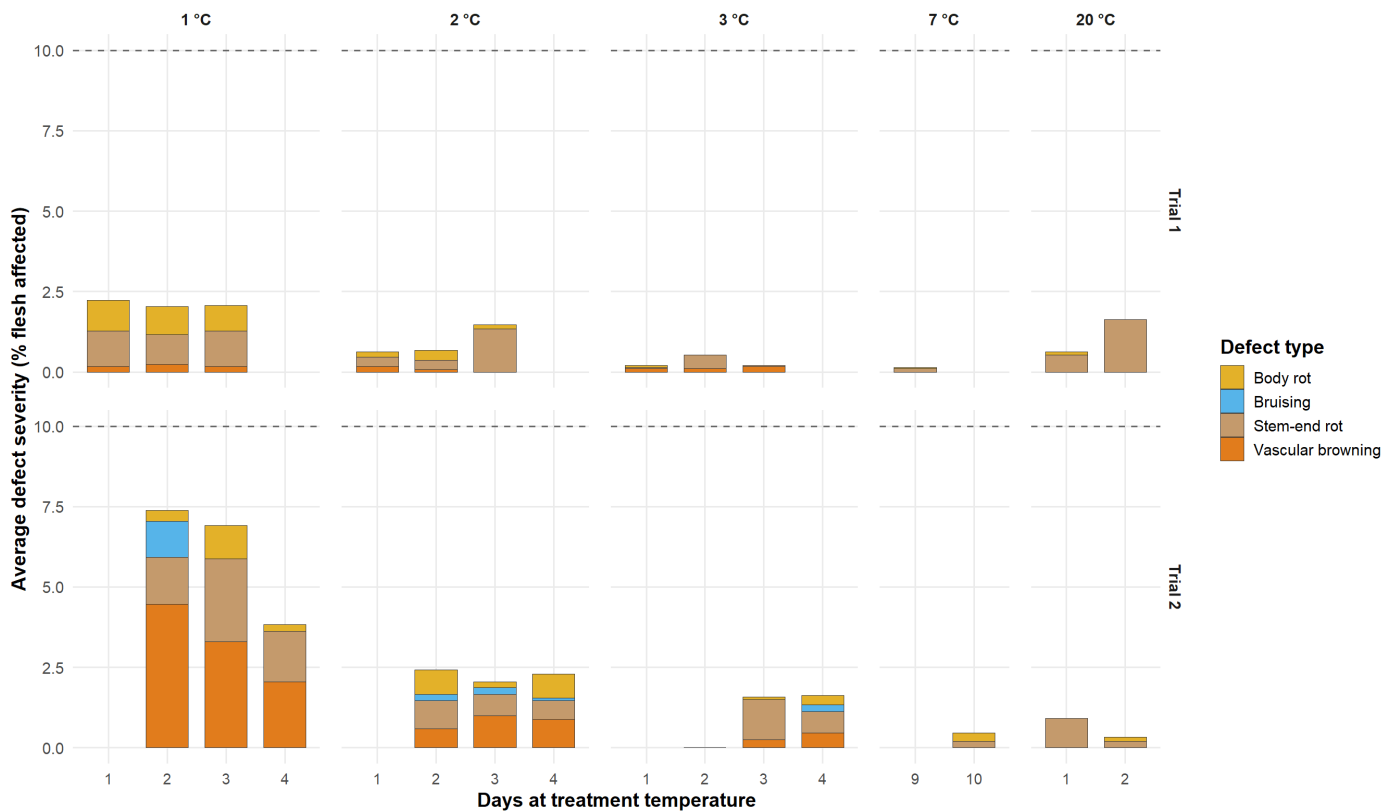


Figure 3 Contribution of body rot, bruising, stem-end rot and vascular browning to average defect severity in avocados stored at different temperatures and durations. Stacked bars show the contribution of each defect, and the dashed line indicates the 10% threshold for average total severity.

Real World Shipment

These temperatures represent a more extreme real-world avocado shipment example. The consignment was initially dispatched at 5°C, but during transit it briefly dipped to 1°C before recovering and stabilizing between 4.8°C and 3.5°C (Figure 4). This shipment travelled from Central Queensland to the Melbourne markets and illustrates how temperature shocks can occur even in well-managed supply chains. Such fluctuations can place stress on fruit, increasing the risk of chilling injury or subtle quality losses that may not be visible at dispatch but can emerge later during ripening or shelf life.

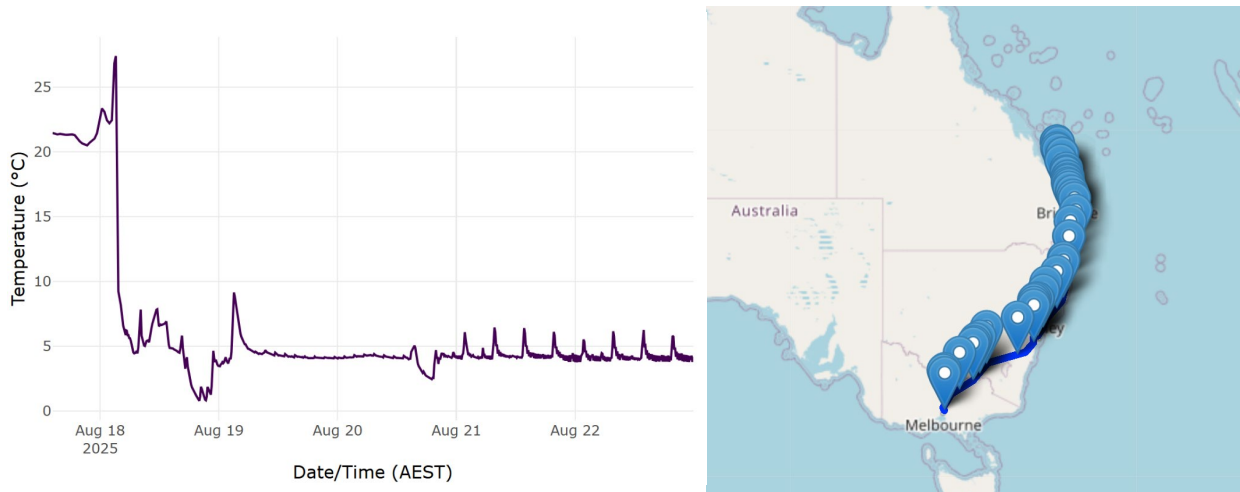


Figure 4 Real-world shipment temperature profile showing exposure to stress temperature ($\sim 1^{\circ}\text{C}$) for 12 hours (left), and shipment route from Queensland to Melbourne markets (right).

Practical Recommendations

Keeping Shepard avocados fruit as close as possible to 7°C is one of the simplest and most effective ways to reduce chilling injury in Shepard avocados. Temperatures below 3°C , even for a short time, can quickly damage the fruit and lead to problems that only show up later during ripening. This is especially important in air-freight or mixed-freight loads, where temperatures can change suddenly. Regularly checking temperature logs and using tools like real-time data loggers and tracking helps growers and transporters spot issues early and keep fruit in good condition all the way to market.

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Appendix 48

WA 'Hass' avocado ethylene assessment report 2024

Cold storage duration, temperature, and fruit size affect postharvest defects and ethylene production rate in ‘Hass’ avocado fruit

Amit Khanal, Declan McCauley, Dario Stefanelli

Introduction

The postharvest quality and marketability of avocado fruit are highly sensitive to storage conditions, particularly temperature, duration, and fruit physiological attributes such as size and maturity stage. Cold storage is a widely adopted strategy to extend shelf life and maintain commercial quality throughout the supply chain. However, improper cold storage temperatures and durations, especially when not aligned with fruit size or dry matter content, can compromise fruit integrity by increasing the risk of chilling injury (CI), suppressing ripening, promoting decay, and altering ethylene production dynamics (UC Davis Postharvest Technology Center, 2024).

Avocados (*Persea americana* Mill.) are unique among climacteric fruits in that they do not ripen on the tree. Ethylene production and ripening commence only after harvest, with ethylene levels rising sharply during ripening, often exceeding $100 \mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$ at 20°C (UC Davis Postharvest Technology Center, 2024). The recommended cold storage temperature for mature-green avocados ranges between $5\text{--}13^\circ\text{C}$ depending on cultivar and storage duration, while ripe avocados are best held at $2\text{--}4^\circ\text{C}$. Storing mature-green fruit below or above these thresholds—such as at $0\text{--}2^\circ\text{C}$ for more than 7 days, or at $3\text{--}5^\circ\text{C}$ for more than two weeks—can lead to physiological disorders like mesocarp browning, pulp spotting, vascular discoloration, failure to ripen, and increased susceptibility to pathogen attack (Zauberman et al., 1973; UC Davis Postharvest Technology Center, 2024).

Chilling injury symptoms typically appear during post-storage ripening rather than during cold storage itself (Zauberman et al., 1973), and their severity is influenced by cultivar, growing region, and ripeness stage at the time of storage. For example, semi-ripe or soft fruit tend to be more tolerant to chilling than firm fruit (Zauberman et al., 1973). Ripening kinetics following cold storage are also affected by temperature and duration. Fruit stored at 6°C often soften faster after removal, indicating some degree of internal ripening during storage, while fruit stored at $0\text{--}4^\circ\text{C}$ exhibit slower softening and extended shelf life (Zauberman et al., 1973; Eaks, 1976). Notably, the climacteric respiratory peak typically associated with ethylene production is disrupted after prolonged storage at low



temperatures; fruit stored for 4–5 weeks at 5 °C show elevated basal respiration but no distinct climacteric peak (Eaks, 1976).

Additionally, variability in the rate of ripening among fruit can affect disorder expression—fruit that ripen more slowly tend to develop more severe rots and internal browning (Hopkirk et al., 1994). Softening during cold storage, even without ethylene treatment, reduces the number of days needed to achieve full ripeness upon warming, though firmness loss remains minimal in unripe fruit over 28 days of storage (Arpaia et al., 2015).

The interplay between harvest maturity, postharvest handling, and storage regimes is therefore crucial for maintaining avocado quality. Factors such as dry matter content, oil concentration, and storage temperature transitions have been shown to impact both physiological and sensory outcomes (Lizana et al., 1992). While cold storage remains essential for managing long-distance export and market delays, practices such as partial ripening before storage, or staged temperature regimes, may mitigate defects and preserve quality under variable commercial conditions.

Despite significant progress, few studies have comprehensively examined how cold storage duration and temperature interact with fruit size to influence ethylene production and postharvest disorders under commercial-like conditions. Given the global reliance on extended cold storage during avocado distribution and marketing, especially for size-graded fruit held for weeks before ripening, a deeper understanding of these interactions is critical for optimizing postharvest management strategies.

Materials and methods

Fruit Harvesting and Handling

Fruit were harvested by trained commercial pickers from a commercial avocado orchard located near Busselton, Western Australia. After harvest, the fruit were transported to a commercial packhouse near Manjimup, Western Australia, where they underwent standard postharvest handling procedures (e.g., washing, grading, and packing).

From the packhouse, fruit were transported to the Manjimup Horticulture Research Station (Department of Primary Industries and Regional Development, DPIRD) laboratory for experimental setup and further analysis.

Fruit Weight, Firmness, and NIR-Based Dry Matter Assessment

The weight of each individual fruit was recorded using a digital weighing scale. Immediately after weighing, fruit firmness was measured using a Durometer.

For control fruit (not subjected to cold storage), fruit weight was recorded at regular intervals throughout the shelf-life period. For fruit subjected to cold storage, weight was first recorded prior to storage, then again on the day of removal from cold storage, and subsequently at defined intervals during shelf-life at ambient temperature.

Subsequently, non-destructive dry matter (DM) estimation of each fruit was performed using the Felix F-750 Produce Quality Meter (Felix Instruments, USA).

Fungicide Treatment

Fungicide treatment was not done in Experiment 1 and 2. However, due to a high incidence of disease observed in these trials, Experiment 3 included a fungicide application to minimize fungal infection during the experiment period-especially given the limited replication ($n = 5$ fruit per treatment).

Following the initial assessment, all individual fruit in Experiment 3 were dipped in Graduate A+ fungicide (Syngenta USA) solution to prevent fungal development that could interfere with ethylene production of the fruit. The aim of this treatment was to ensure that disease symptoms would not affect ethylene production of fruit and confound the results.

Treatments: Cold Storage Duration and Temperature

The experiment was conducted in three time in February 2024, September 2024 and November 2024. In each repetition, two fruit sizes were used, and the fruit were subjected to varying cold storage durations.

In the February 2024 experiment, the treatments included two fruit sizes-tray count 18 and 25-and six cold storage durations: no storage (control; fruit stored at 20 °C immediately after harvest until the end of shelf life), 1 week, 2 weeks, 3 weeks, 4 weeks, and 5 weeks. Storage temperatures included 3 °C, 5 °C, 10 °C, and a sequential treatment where fruit were stored at 5 °C and then transferred to 3 °C. Each treatment consisted of five replicate fruits. After the designated storage period, the fruit were transferred to a shelf-life room maintained at approximately 20 °C and monitored until the end of shelf life.

In the September 2024 and November 2024 experiments, two fruit sizes i.e., tray count 18 and 23, were used. Treatments included cold storage durations of 0 days (control; storage at 20 °C postharvest until the end of shelf life), 5 days, 12 days, 15 days, 20 days, 26 days, 30 days, and 46 days. A single cold storage temperature of 5 °C was applied across all durations.

Sample collection for Ethylene Assessment

After removal from cold storage, the fruit were allowed to equilibrate at room temperature (~20 °C) for approximately 4 hours to eliminate chilling effects. Surface moisture due to condensation was gently removed using tissue paper. Following this, each fruit was placed in an airtight plastic container and sealed for approximately 1 hour to allow for headspace gas accumulation.

To ensure proper mixing of headspace gases, the air inside the container was manually agitated by drawing and releasing the gas at least three times using a syringe through a rubber septum embedded in the lid. After mixing, 16 mL of headspace air was withdrawn and transferred into a pre-evacuated vacutainer. The vacutainers were stored at room temperature until analysis of ethylene concentration. This was done in specific days interval for individual fruit till the end of shelf life.

Gas Chromatographic Analysis of Ethylene

For ethylene concentration analysis, 1 mL of headspace gas was withdrawn from each vacutainer and injected into a **Thermo Fisher Scientific Gas Chromatograph** equipped with a **flame ionization detector (FID)**. The gas chromatograph was operated under the following conditions:

- **Column:** Stainless steel packed column (e.g., Porapak Q or equivalent, 2 m length × 1/8-inch diameter)
- **Carrier gas:** Nitrogen, at a flow rate of approximately 30 mL min⁻¹
- **Injector temperature:** 100 °C
- **Oven temperature:** 80 °C (isothermal)
- **Detector temperature:** 150 °C

The retention time for ethylene was determined using a certified ethylene gas standard, and sample peaks were identified and quantified by comparing their retention time and peak area to those of the standard.

Ethylene concentration values obtained from GC were normalized to account for differences in container volume, fruit weight, and the sealing duration used during headspace gas accumulation. The normalized ethylene production rate was expressed as $\mu\text{L kg}^{-1} \text{ h}^{-1}$.

Calibration of the GC was done by the standard concentrations of ethylene gas of 2, 10 and 100 ppm

Shelf-life Assessment

Firmness of individual fruit was measured using a Turoi Durometer. All fruit were assessed for firmness on the day they were received at the laboratory. For control fruit (not subjected to cold storage), firmness measurements were then taken at regular intervals until the end of shelf life. For fruit subjected to cold storage, firmness was measured on the day of removal from cold storage and subsequently at defined intervals during the shelf-life period at ambient temperature (~20 °C). A durometer reading below 40 units or any visible sign of defects was considered the threshold indicating the end of shelf life. Once this value was reached, the fruit was cut open and evaluated for the presence of disease symptoms and internal disorders.

Disease and Disorder Severity and Incidence

To assess disease and internal disorder severity and incidence, each fruit was first cut longitudinally through the middle. Each half was then further divided lengthwise, resulting in four equal longitudinal sections. The skin was carefully removed from each section to allow for clear observation of internal tissues.

Assessment of disorders was conducted using a subjective rating scale. Evaluations included stem-end rot, body rot, bruising, flesh browning, and vascular discoloration, following the criteria outlined in the Queensland Department of Agriculture and Fisheries (QDAF) Avocado Quality Manual. The fruit with more than 10% defects are considered unfit for the market.

Oven Dry Matter (DM) Assessment

Following the assessment of internal disorders, a core sample of the mesocarp (flesh) was collected from each fruit for dry matter (DM) analysis. Each sample was weighed immediately to obtain the fresh weight, then placed in a drying oven set at 65 °C. Samples were dried until they reached a constant weight. Once fully dried, the dry weight was recorded, and dry matter content was calculated using the following formula:

$$\text{Dry matter \%} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

All measurements were conducted using a precision digital balance (±0.001 g accuracy). Care was taken to avoid sample contamination and ensure consistency in sampling location within the fruit.



Data analysis

Shelf-life post storage, disease and defect incidence were subjected to the normality test (Shapiro-Wilk test) and the assumption was not met ($p < 0.05$). Then after the effect of fruit size on the shelf life and defects were assessed by non-parametric Mann-Whitney U test at 5% significance level.

Data on post-storage shelf-life, disease incidence, and defect incidence were first evaluated for normality using the Shapiro–Wilk test. As the assumption of normality was not satisfied ($p < 0.05$), non-parametric tests were applied for further analysis.

The effect of fruit size on shelf life and the incidence of defects was assessed using the Mann–Whitney U test, with significance determined at the 5% level ($p < 0.05$). To evaluate the effects of removal time and storage temperature on postharvest shelf life and defect incidence, the Kruskal–Wallis test was used at a 5% significance level.

All statistical analyses were performed using RStudio (R Core Team, 2025).

Analysis of variance (ANOVA) was conducted to examine the effect of cold storage duration and fruit size on the incidence and severity of postharvest diseases and internal disorders in ‘Hass’ avocado fruit. When significant treatment effects were observed ($p < 0.05$), Tukey’s Honest Significant Difference (HSD) test was applied for mean separation.

To assess the impact of fruit size on the incidence and severity of disorders, independent samples t-tests for pairwise comparisons between size categories at a 5% significance level.

Each treatment group comprised five replicate fruit.

Results and discussion

Fruit weight and Dry matter content distribution across experiments

The test revealed a significant difference ($p < 0.05$) in median fruit weights between the two size categories (tray counts 18 vs. 23 or 25) across three independent experiments (Table 1).

In the February 2024 experiment, the smaller fruit (tray count 25) exhibited significantly higher DMC (30.63%) compared to the larger fruit (tray count 18, 28.88%), indicating an inverse relationship between fruit size and DMC at harvest. In the September 2024 experiment, no significant difference in DMC was observed between the two size groups (31.27% for count 18 and 30.34% for count 23), suggesting that size-related variation in DMC was less pronounced under these experimental conditions. In contrast, the

November 2024 experiment revealed significantly higher DMC in the larger fruit (32.67% for count 18) compared to the smaller fruit (31.37% for count 23), reversing the pattern observed in the February 2024 experiment (Table 1).

Table 1: Comparison of fruit weight (Wilcoxon rank sum test) and dry matter content (DMC; two-sample t-test) between two fruit size categories at 5% significance level.

Experiment	Fruit count per tray	Weight (g)	DMC (%)
February 2024	18	299.50 ^a	28.88 ^b
	25	211.24 ^b	30.63 ^a
September 2024	18	293.03 ^a	31.27 ^a
	23	235.96 ^b	30.34 ^a
November 2024	18	297.89 ^a	32.67 ^a
	23	239.78 ^b	31.37 ^b

Different letters within each experiment indicate statistically significant differences at $p < 0.05$.

Effect of fruit size, cold storage temperature and duration in different defects and shelf life after cold storage

February 2024 trial

Fruit size had a significant effect on the incidence of body rots and the overall sum of postharvest defects (Table 2). Larger fruit had significantly higher body rots and overall sum of postharvest defects than smaller fruits (Table 3). However, other defects including flesh bruising, stem-end rot, vascular strand development as well as postharvest shelf life were not significantly influenced by fruit size. Cold storage temperature significantly affected the overall sum of postharvest defects and postharvest shelf life but had no significant impact on body rots, flesh bruising, stem-end rot, or vascular strands (Table 4). Among the parameters assessed, only postharvest shelf life was significantly influenced by cold storage duration (Table 5). No significant interaction effects were observed between fruit size and cold storage duration, between cold storage duration and temperature except for postharvest shelf life, or among fruit size, temperature, and storage duration for any of the evaluated postharvest quality attributes (Table 1).

Table 2: P-values for individual tests for the effect of fruit size, cold storage temperature and storage duration in severity of body rots, flesh bruising, stem end rot, vascular strands, total sum of defects, and postharvest shelf life of 'Hass' avocado in the February 2024 storage trial.

Factors	Body rots	Flesh bruising	Stem end rot	Vascular strands	Sum defects	Postharvest shelf life
Fruit size	<0.01	0.66	0.33	0.65	<0.01	0.34
Cold storage temperature	0.22	0.09	0.05	0.19	<0.01	<0.01



Cold storage duration	0.69	0.67	0.51	0.59	0.66	<0.01
Fruit size × Cold storage temperature	0.16	0.47	0.20	0.88	0.09	0.51
Fruit size × Cold storage duration	0.30	0.67	0.45	0.82	0.11	0.35
Cold storage temperature × Cold storage duration	0.24	0.96	0.07	0.19	0.47	<0.01
Fruit size × Cold storage temperature × Cold storage duration	0.64	0.96	0.47	0.99	0.69	0.41

Table 3. Effect of fruit size on body rots and total sum of defects of ‘Hass’ avocados stored in February 2024.

Fruit size	Body rots	Sum defects
18	8.18 ^a	10.65 ^a
25	3.18 ^b	6.02 ^b

Table 4. Effect of cold storage temperature on the sum of defects and postharvest shelf life in ‘Hass’ avocados stored in February 2024.

Cold storage temperature	Sum defects	Postharvest shelf life
20	11.21 ^a	15.92 ^a
10	12.63 ^a	4.88 ^c
5	3.54 ^b	7.92 ^b
3	7.83 ^{ab}	9.00 ^b
5+3	6.46 ^{ab}	9.29 ^b

Table 5. Effect of cold storage duration on postharvest shelf life in ‘Hass’ avocados stored in February 2024.

Cold storage duration (weeks)	Postharvest shelf life
0	15.92 ^a
2	10.38 ^b
3	8.29 ^c
4	6.58 ^d
5	5.83 ^d

September 2024 trial

In the September trial, cold storage duration had a significant effect on the incidence of body rots ($p<0.01$), diffuse discoloration ($p<0.01$), the total sum of defects ($p<0.01$), and postharvest shelf life ($p<0.01$), while fruit size and the interaction between fruit size and

cold storage duration did not significantly influence any of the evaluated parameters ($p > 0.05$) (Table 6).

Fruit stored for 47 days exhibited a markedly higher incidence of body rots (8.0%), diffuse discoloration (63.5%), and the highest cumulative defect score (70.5%), all significantly greater than those observed in fruit stored for shorter durations ($p < 0.01$) (Table 7). These findings suggest that prolonged cold storage, particularly beyond 29 days, is associated with elevated susceptibility to physiological and pathological disorders.

Postharvest shelf life showed a general declining trend with increasing storage duration. Fruit without cold storage had the longest shelf life (11.2 days), while fruit stored for 26 days exhibited the shortest shelf life (4.0 days). Fruit subjected to the longest storage duration (47 days) exhibited intermediate shelf life (7.0 days), though accompanied by a pronounced increase in postharvest disorders. These results indicate that while moderate cold storage durations (up to ~15–20 days) may be tolerated without substantial quality losses, prolonged storage (e.g., 47 days) significantly compromises both internal and external fruit quality.

Table 6. The effect (P-values) of fruit size, cold storage duration, and the interaction between fruit size and cold storage duration on body rots, flesh bruising, diffuse discoloration, the sum of defects and post-harvest shelf life. Results are from September 2024 air stored 'Hass' avocados.

	Body rots	Flesh bruising	Diffuse discoloration	Sum defects	Postharvest shelf life
Fruit size	0.32	0.45	0.34	0.36	0.64
Cold storage duration	<0.01	0.25	<0.01	<0.01	<0.01
Fruit size × Cold storage duration	0.14	0.33	0.22	0.20	0.52

Table 7. The average volume of body rots, diffuse discoloration, sum defects and post-harvest shelf life according to cold storage duration for 'Hass' avocado fruits stored in September 2024.

Cold storage duration (days)	Body rots	Diffuse discoloration	Sum defects	Postharvest shelf life
0	0.0 ^b	0.0 ^b	0.0 ^b	11.2 ^a
5	0.0 ^b	0.0 ^b	1.0 ^b	7.0 ^{bc}
12	0.5 ^b	0.0 ^b	0.9 ^b	8.0 ^b
15	0.0 ^b	0.0 ^b	0.0 ^b	5.0 ^{cd}
20	0.0 ^b	0.0 ^b	0.2 ^b	6.0 ^{bcd}
26	0.0 ^b	0.0 ^b	0.0 ^b	4.0 ^d
29	0.0 ^b	8.0 ^b	8.0 ^b	6.0 ^{bcd}
47	8.0 ^a	63.5 ^a	70.5 ^a	7.0 ^{bc}

November 2024 trial

In the November trial, cold storage duration had significant effects ($p < 0.01$) on flesh bruising, vascular strand, diffuse discoloration, sum of defects, and postharvest shelf life (Table 8). In contrast, fruit size and the interaction between fruit size and cold storage duration did not have a significant effect on any of the measured parameters ($p > 0.05$), indicating that storage duration, rather than fruit size, predominantly drove postharvest quality outcomes in this trial.

Mean comparison analysis revealed that fruit stored for **46 days** exhibited the highest severity across most quality parameters (Table 9). This group had the highest flesh bruising (5.0%), vascular strand browning (2.9%), and diffuse discoloration (32.5%), resulting in the greatest total sum of defects (79.2%). These values were significantly higher than those observed for fruit stored for shorter durations ($p < 0.05$), indicating a substantial deterioration in fruit quality following prolonged cold storage.

Conversely, fruit not stored exhibited the best overall quality. This group had the lowest incidence of postharvest defects and the longest shelf life (11.86 days), significantly exceeding that of fruit stored for 15, 30, or 46 days ($p < 0.05$). Notably, vascular strand browning was absent (0%) in all storage durations except the 46-day treatment, highlighting its strong association with extended cold exposure.

Table 8. The effect (P-values) of fruit size, cold storage duration, and the interaction between fruit size and cold storage duration on body rots, flesh bruising, diffuse discolouration, the sum of defects and post-harvest shelf life. Results are from November 2024 air stored 'Hass' avocados.

	Body rots	Flesh bruising	Stem end rot	Vascular strands	Diffuse discolouration	Sum defects	Postharvest shelf life
Fruit size	0.81	0.10	0.34	0.60	0.96	0.92	0.41
Cold storage duration	0.91	<0.01	0.60	<0.01	<0.01	<0.01	<0.01
Fruit size × Cold storage duration	0.74	0.08	0.62	0.27	0.41	0.93	0.16

Table 9. The average volume of body rots, diffuse discolouration, sum defects and post-harvest shelf life according to cold storage duration for ‘Hass’ avocado fruits stored in September 2024.

Cold storage duration (Days)	Flesh bruising	Vascular strands	Diffuse discolouration	Sum defects	Postharvest shelf life
0	1.0 ^b	0 ^b	0 ^b	12.75 ^b	11.86 ^a
5	2.5 ^{ab}	0 ^b	0 ^b	12.30 ^b	10.30 ^{ab}
12	1.6 ^b	0 ^b	0 ^b	16.30 ^b	9.70 ^{ab}
15	0.7 ^b	0 ^b	7.0 ^b	12.10 ^b	7.00 ^c
20	2.0 ^b	0 ^b	0 ^b	4.30 ^b	9.00 ^{bc}
26	2.2 ^{ab}	0 ^b	0 ^b	11.60 ^b	10.00 ^{ab}
30	1.8 ^b	0 ^b	1.0 ^b	3.69 ^b	7.00 ^c
46	5.0 ^a	2.9 ^a	32.5 ^a	79.20 ^a	7.00 ^c

Rate of ethylene production: influence of cold storage duration, temperature, fruit size

Ethylene production in ‘Hass’ avocado fruit demonstrated strong dependence on the duration of cold storage (Figure 1). Fruit not subjected to cold storage exhibited a typical climacteric rise in ethylene production. This early and sharp peak aligns with the normal ripening physiology of climacteric fruit under ambient conditions. Fruit stored up to 2 weeks in cold storage showed a delayed yet enhanced ethylene response, with a normal climacteric peak. This response likely reflects a cold-induced stimulation of ethylene biosynthesis upon rewarming, possibly mediated by stress-related signalling pathways. However, with increasing storage durations (>2 weeks), ethylene production became progressively suppressed. This trend suggests that prolonged cold storage negatively impacts ethylene biosynthesis, likely by disrupting the autocatalytic feedback mechanism or inducing chilling-related metabolic limitations.

Ethylene production was significantly influenced by fruit size across all trials and cold storage durations (Figure 2). Generally, larger fruit (count 18) exhibited higher ethylene production rates compared to smaller fruit (count 23 or 25) across most post-storage assessment dates. An exception was observed at the 2-week cold storage removal point (Feb trial), where smaller fruit showed elevated ethylene production relative to larger fruit. The size-dependent variation was particularly evident at shorter cold storage durations, during which larger fruit reached the ethylene climacteric peak both earlier and more abruptly than their smaller counterparts. These findings underscore the critical role of fruit size in modulating ethylene production dynamics and highlight the need to account for size-related physiological differences when designing postharvest ripening protocols and storage strategies in ‘Hass’ avocado.

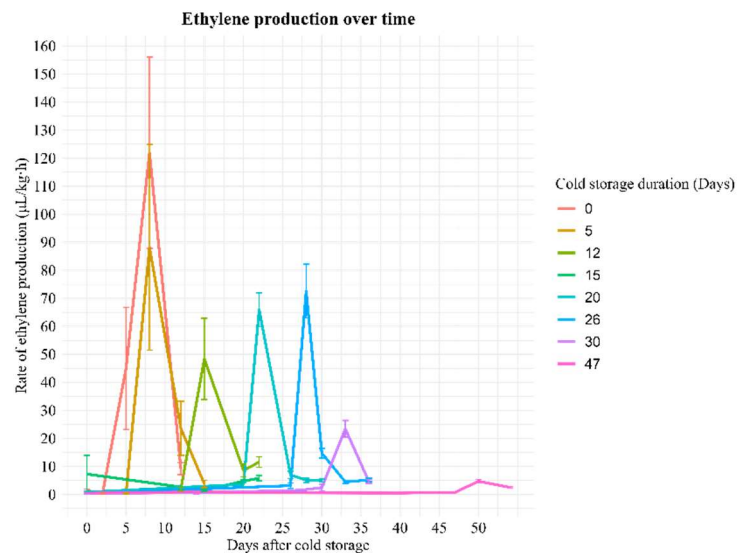
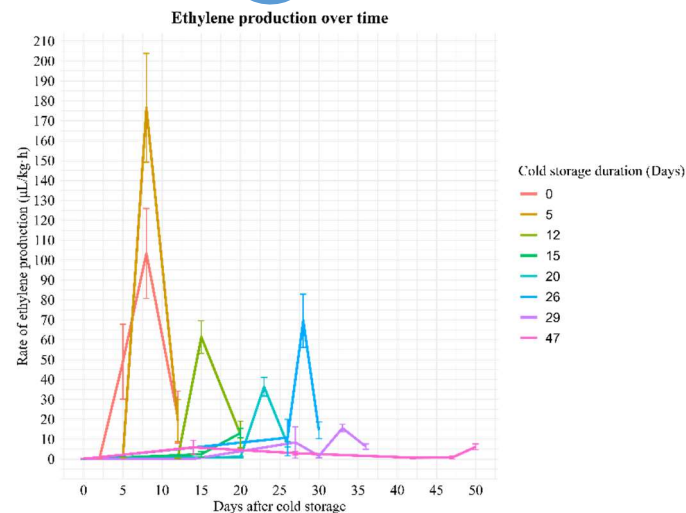
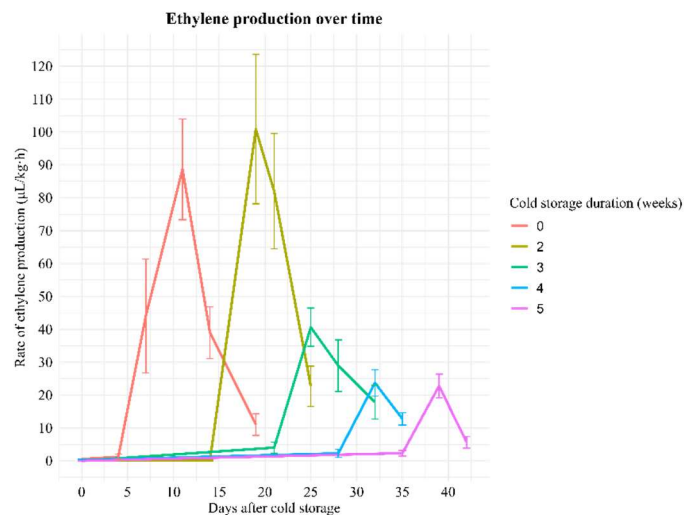


Figure 1: Effect of cold storage duration on the rate of ethylene production in ‘Hass’ avocado across three independent postharvest trials. Top-left panel: February 2024 trial; Top-right panel: September 2024 trial; Bottom panel: November 2024 trial. Each data point was the average of 10 fruit.

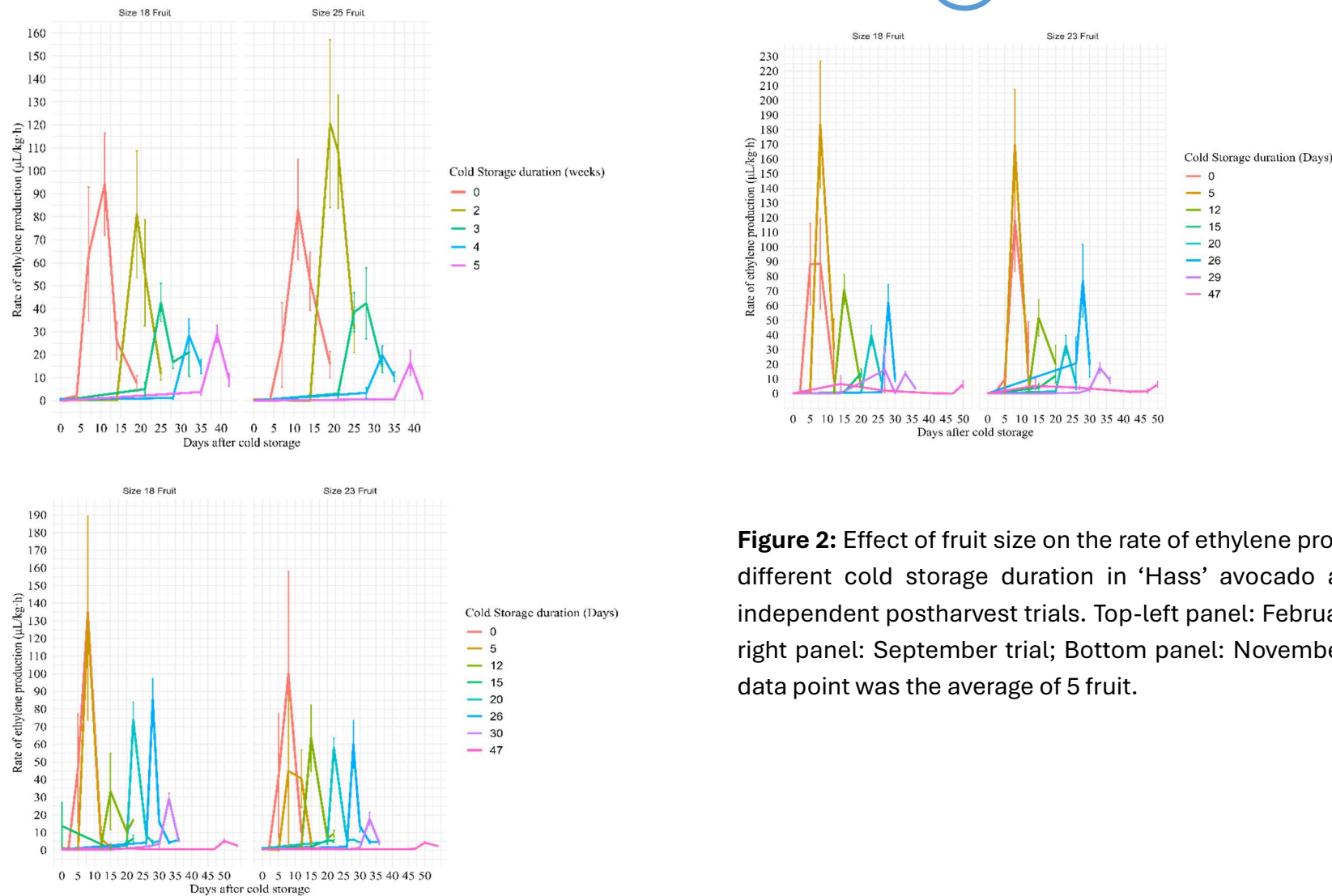


Figure 2: Effect of fruit size on the rate of ethylene production with different cold storage duration in 'Hass' avocado across three independent postharvest trials. Top-left panel: February trial; Top-right panel: September trial; Bottom panel: November trial. Each data point was the average of 5 fruit.

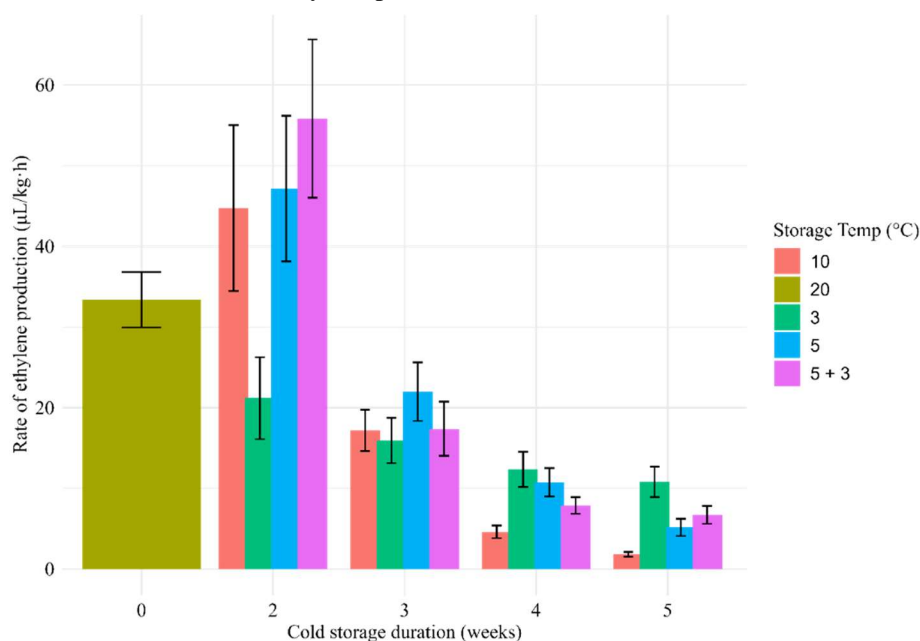
Effect of cold storage temperature on ethylene production

Storage temperature significantly influenced ethylene production. After 2 weeks of cold storage, fruit stored at (10 °C, 5 °C, and 5 + 3 °C) showed markedly higher ethylene rates (~40–60 $\mu\text{L kg}^{-1} \text{h}^{-1}$) than fruit stored at lower temperatures (3 °C) or ambient (20 °C). This suggests that short-term cold exposure at 5–10 °C may stimulate ethylene production upon rewarming than normal ripening of fruit at 20 °C.

As cold storage extended beyond 2 weeks, ethylene production declined across all temperature treatments. By week 5, mean ethylene production dropped below 15 $\mu\text{L kg}^{-1} \text{h}^{-1}$, with minimal differences among the temperature regimes. This consistent decline suggests that prolonged cold storage induces a generalized suppression of ethylene biosynthesis, regardless of the specific temperature applied. Importantly, the sequential cold treatment (5+3 °C) did not confer any advantage over constant temperatures, indicating that fluctuating regimes do not mitigate the suppression effects of extended cold exposure.

Collectively, these findings demonstrate that ethylene production in ‘Hass’ avocado is strongly regulated by an interplay of fruit size, cold storage duration, and temperature. Short-term cold exposure (≤ 2 weeks) at moderate chilling temperatures (3–5 °C) can enhance ethylene production upon rewarming, potentially aiding in more synchronized ripening. However, storage durations beyond 3 weeks consistently impair ethylene biosynthesis, especially in larger fruit, which may result in uneven or delayed ripening.

Figure 3. Effect of cold storage temperatures applied during the February 2024 storage trial to ‘Hass’ avocados on the rate of ethylene production.





These dynamics underscore the need for careful consideration of pre-ripening cold storage conditions in commercial supply chains. Optimizing storage regimes according to fruit size and target market timing could help maintain uniform ripening and minimize postharvest quality loss.

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Additional table. The individual shelf life outcomes of postharvest shelf life for temperature and storage durations for 'Hass' avocados stored in February 2024. Lowercase letters indicate significance groups.

Cold storage duration (Weeks)	Cold storage temperature (°C)	Postharvest shelf life (Days)
0	20	15.92a
2	10	9.50bcd
	5	10.50bc
	3	11.00b
	5+3	10.50bc
3	10	5.50ef
	5	7.66bcde
	3	10.33bc
	5+3	9.67bcd
4	10	3.83fg
	5	6.50def
	3	7.67bcde
	5+3	8.33bcde
5	10	0.67g
	5	7.00cdef
	3	7.00cdef
	5+3	8.67bcde

Appendix 49

WA 'Hass' avocado ethylene assessment report 2025

Report on ethylene production of 'Hass' avocado fruits air stored in November 2025.

Amit Khanal, Declan McCauley, Dario Stefanelli

Methods

'Hass' avocado fruits were collected from a Western Australian packshed on the 11th of November 2025. Fruits were from a farm located near Busselton, WA and were treated with Sportak at the packing shed. Fruits were transported to the laboratory at the Manjimup Horticultural Research Institute. Fruits were treated further with Graduate A+ fungicide before being allocated to different storage durations. The storage durations used are outlined in table 8. All fruit were weighed, assessed for firmness before storage (Turoi durometer), and had the first measurement of ethylene and respiration taken.

15 fruit were used for each storage duration with a total of 120 fruits. Fruits removed from the 5 °C storage were transferred to 20 °C and ripened. Weight and firmness were measured at removal and regularly afterwards as the fruit ripened. Fruits were progressively dissected as fruits reached the soft ripe stage (firmness<40) until no fruits were left.

Table 1. Storage conditions applied to 'Hass' avocados in November 2025.

Temperature	Storage duration (days) prior to ongoing 20°C storage							
	0	7	11	16	21	25	30	42
5 °C		x	x	x	x	x	x	x
20 °C	x							

Ethylene and respiration assessments were carried out before storage, during storage, and after storage. The basic method for ethylene assessments involved placing fruits in an airtight plastic container and sealing them in for approximately 2 hours to allow for headspace gas accumulation in the laboratory, and three hours when assessed in the coolroom. Fruits assessed during storage were not removed from the coolroom so the extra hour was a 'best bet' to ensure ethylene was able to be detected in the sample. For the assessment done immediately after removal from cold storage, the fruit were allowed to equilibrate at room temperature (~20 °C) for approximately 4 hours to eliminate chilling effects. Surface moisture due to condensation was gently removed using tissue paper.

After removal from storage ethylene was assessed every two business days (Monday, Wednesday, Friday) until all fruit had been dissected. Assessments during storage were also done every two business days until the fruit had been removed from storage. An extra assessment was done on the Saturday after the 17 day storage duration had ended.

To ensure proper mixing of headspace gases, the air inside the container was manually agitated by drawing and releasing the gas at least three times using a syringe through a rubber septum embedded in the lid. After mixing, 16 mL of headspace air was withdrawn and transferred into a



pre-evacuated vacutainer. The vacutainers were stored at room temperature until analysis of ethylene concentration.

Gas.Chromatographic.Analysis.of.Ethylene

For ethylene concentration analysis, 1 mL of headspace gas was withdrawn from each vacutainer and injected into a Thermo Fisher Scientific Gas Chromatograph equipped with a flame ionization detector (FID). The gas chromatograph was operated under the following conditions:

- Column: Stainless steel packed column (e.g., Porapak Q or equivalent, 2 m length × 1/8-inch diameter)
- Carrier gas: Nitrogen, at a flow rate of approximately 30 mL min⁻¹
- Injector temperature: 100 °C
- Oven temperature: 80 °C (isothermal)
- Detector temperature: 150 °C

The retention time for ethylene was determined using a certified ethylene gas standard, and sample peaks were identified and quantified by comparing their retention time and peak area to those of the standard.

Ethylene concentration values obtained from GC were normalized to account for differences in container volume, fruit weight, and the sealing duration used during headspace gas accumulation. The normalized ethylene production rate was expressed as $\mu\text{L kg}^{-1} \text{h}^{-1}$.

Calibration of the GC was done by the standard concentrations of ethylene gas of 2, 10 and 100 ppm

Respiration.measurements

Respiration was measured while fruits were still being held in the ethylene extraction container with a Q2 O₂/CO₂ analyser from Quantek instruments. Respiration measurements were done every time an ethylene assessment was done.

Results.of.ethylene.production.and.respiration

Ethylene production showed a trend of highest production in fruits that weren't stored or were stored for shorter durations. Ethylene production in the fruit that were not stored had the highest peak by a substantial amount. The peak occurred only two days after the ethylene was first detected and six days after the start of the trial. After the peak ethylene declined to roughly half of the initial peak. After storage was applied to fruits ethylene production was suppressed somewhat with the peak after 6 and 13 days of storage being less than half the peak of the 0 day treatment. The 6 day treatment also had two peaks-a small initial peak followed by a larger second peak four days later. The 15, 17, and 20 day storage durations also produced double peaks. After 15 days of storage ethylene peaks were smaller again as compared to the 6 and 13 day storage durations. Ethylene peaks did not grow smaller over time after this point, except for the 27 day storage which produced a negligible ethylene peak. Storage ethylene assessments showed a small amount of ethylene production in the 27 and 34 day storage durations, with

more ethylene being produced by the 34 day storage duration. After the peak, ethylene production declined in all treatments, but in storage durations of 15 days and longer ethylene production increased slightly before all the fruits were dissected.

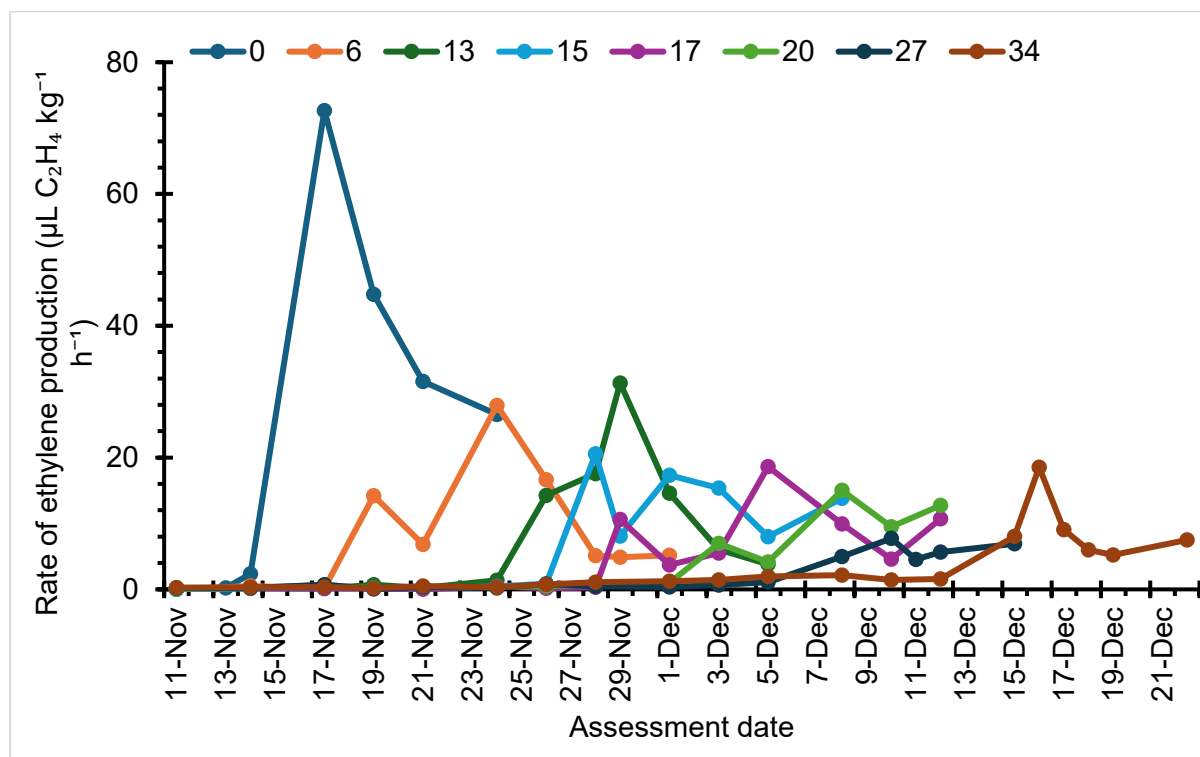


Figure 1. The rate of ethylene production of 'Hass' avocados stored in air storage from November 2025 to December 2025.

CO₂ production by avocados gradually increased as storage duration increased. CO₂ production had similar peaks at 0 and 6 day storage durations. CO₂ peaks were increasingly higher for 13, 15, 17, and 20 day durations. The CO₂ peak for the 27 day storage duration was smaller than the peak for the preceding 20 day duration, but higher than the peaks for 0 and 6 day durations. The 34 day duration had the highest CO₂ production peak in the trial. For all storage durations the trend of CO₂ production over time was very similar. CO₂ production was low, but not zero, during storage. After fruits were removed from storage CO₂ peaked within 2-6 days, and then declined to a level of production that was roughly half of the peak value.

O₂ production was not consistent across the different storage durations. It did not appear to increase gradually over time in the manner of the CO₂ production. O₂ production was lowest during storage and increased after storage ended. After 0, 6 days of storage O₂ consumption increased for 4-6 days and then plateaued. After 13, 15, 17, 20 and 27 days of storage O₂ production increased after the low of storage to a peak which was spread over multiple days. It took from 2 to 10 days for the peak to be reached. The highest peak occurred in the 20 day storage duration and the lowest peak was in the 15 day storage duration. The 34 day storage duration had a sharp peak over a single measurement time and declined to a level roughly two thirds of the peak. O₂ consumption during storage gradually increased the longer fruits were stored.

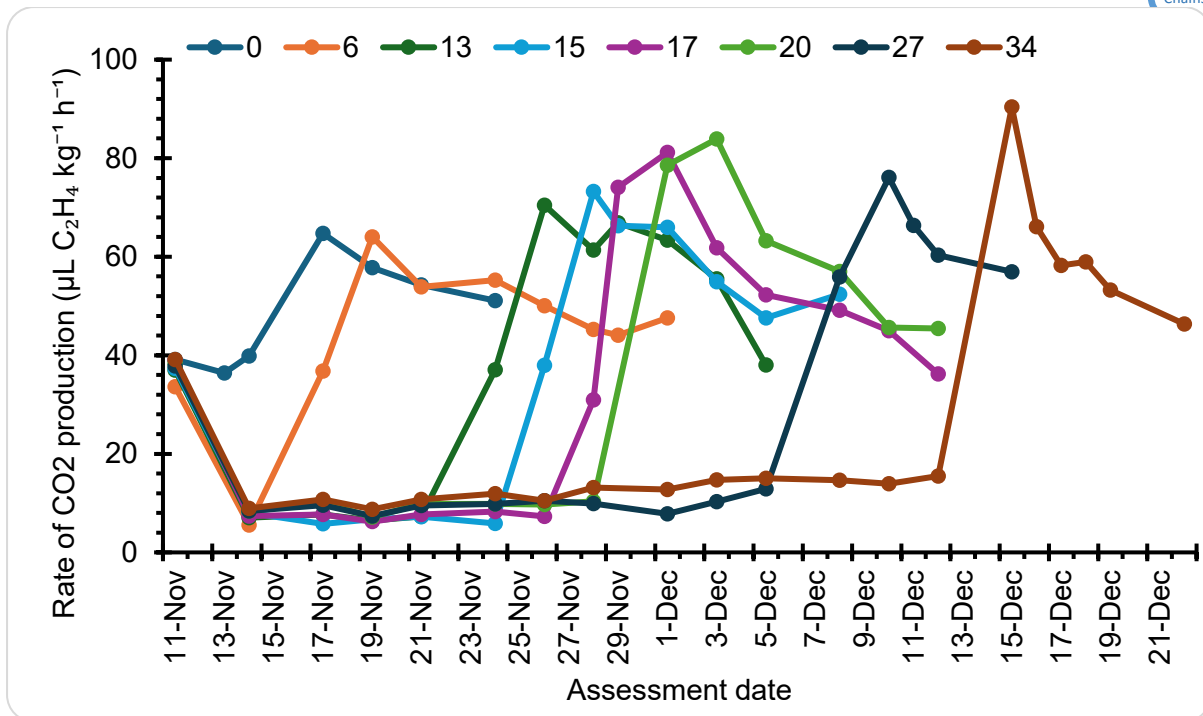


Figure 2. The rate of CO₂ production of 'Hass' avocados stored in air storage from November 2025 to December 2025.

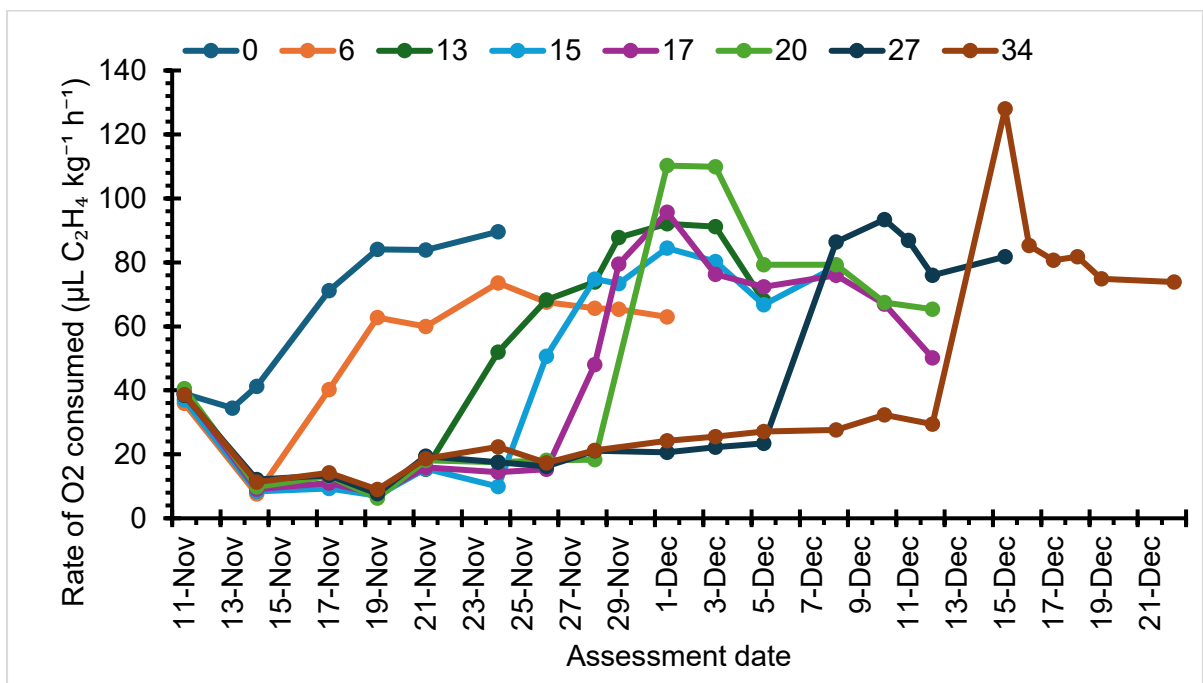


Figure 3. The rate of O₂ production of 'Hass' avocados stored in air storage from November 2025 to December 2025.



Discussion and conclusion

The trends in production of ethylene over storage duration and over time in the coolroom and ripening room track well with previous results from the 2024 trials. That is—peak ethylene production gradually becomes smaller as storage duration increases, with a very minor peak in ethylene production after the longest storage durations. One notable difference is that in the previous ethylene studies the peak of ethylene production after five days storage was higher than the peak of the fruit which weren't stored. This study did not see this trend with the peak of the six day storage being less than half of the peak of the non-stored fruits. The maximum un-stored peak for November 2025 was also lower than the other studies at $72.7 \mu\text{L kg}^{-1} \text{h}^{-1}$. Peak ethylene production in the other studies ranged from 100 to $200 \mu\text{L kg}^{-1} \text{h}^{-1}$). Lower overall ethylene production may be due to the lower dry matter of the November 2025 fruit. The November 2025 fruit had a dry matter of 24%, while the dry matter of the other studies from 2024 ranged from 29-30%.

Respiration was only recorded in this 2025 trial, and not in the 2025 studies. Respiration showed a trend of the fruit becoming more active as storage duration was increased. Fruits stored in the cool room at 5°C gradually produced more CO_2 and consumed more O_2 the longer they were left in the coolroom. Once removed from the cool room the fruits produced more CO_2 , and consumed more O_2 during the ripening period than fruits with relatively shorter storage durations.

Ethylene production and respiration appeared to work in opposite directions, as fruit were stored for longer durations ethylene production decreased, but respiration increased. We are not exactly sure why this occurs and cannot rule out that the ethylene is still being produced in the fruit but is not diffusing out of the ripening flesh. It is most likely however that the avocado fruits produce less ethylene due to gradual chilling injuries building up in the flesh. These injuries appear to not affect respiration. Further analysis of this data is required to elucidate how it sits with wider literature, and to determine possible mechanisms for the trends we found.

Appendix 50

Modelling shelf life of avocados report



Modelling Shelf Life of Avocados

Summary Report

Boyd Tarlinton, Saeedeh Taghadomi Saberi, Yiru Chen, Neil White and Andrew Macnish

Department of Primary Industries

Summary

We report on the development and testing of shelf-life and chilling injury prediction model for Hass and Shepard avocados.

- Models were trained on observations from over 10,000 pieces of fruit sampled across four harvest years in three major growing regions.
- Models support controlled atmosphere shipping for both varieties.
- Pre-conditioning is supported for Hass.
- Shelf-life outcomes include remaining time until medium soft or firm ripe.
- Chilling injury can also be predicted.
- Time x Temperature models can be used for simple and hypothetical shipments.
- Time-temperature unit approach allows for predictions from even the most complex real-world shipments.
- Validation against experimental data was performed to ensure model quality prior to real-world testing.
- Excellent performance of Hass models in predicting shelf-life in real-world shipments (± 1.3 - 1.6 days).
- Performance for Shepard avocados was less accurate, but still practically useful (± 3.0 - 3.8 days).
- Models are available through the Fresh Intel platform and via our partnership with Escavox.



1 Introduction

Herein we report on the development of a series of models designed to predict shelf life and chilling injury risk in Australian avocados. Using data from simulated supply chain experiments across four harvest years, we have fit models for Hass and Shepard varieties. Building on preliminary QDPI shelf-life modelling in the Serviced Supply Chains project, Serviced Supply Chains II (SSCII) aims to deliver reliable, decision-support models for fruit grown in Norther Queensland, Central Queensland, and Western Australia.

Our modelling approach is designed to provide insight into the shelf life and quality of fruit, which may be shipped to domestic or international markets by land, sea, and air. Prior projects have helped highlight the importance of temperature monitoring in avocado supply chains, but these models transform that temperature data into actionable insights about fruit quality. This will enable avocado growers and distributors to respond to unfavourable temperature conditions in real time, whether by altering storage conditions, rushing a produce to market, or even withholding the produce for a longer ripening period.

Trials replicated domestic and international handling and transport conditions, with tagged trays tracked for temperature and evaluated on arrival and during 20°C storage, with and without pre-conditioning (pre-con) or controlled atmosphere (CA) treatments, to support model development and validation under commercial conditions. We apply complementary Time x Temperature (TxT) and time-temperature unit (TTU) approaches.

We report the methods and results associated with the models that are live on the Fresh Intel platform at the time of writing (version 2.9.9). These are subject to change. This report should be taken as illustrative of our approach to modelling, and not as a definitive account of the models available on the platform.



2 Materials and methods

2.1 Model Development

The data used in model development is drawn from simulated supply chain experiments conducted on avocados over the life of the project. For details, please see appendices A2 and A3.

We developed a series of models to predict shelf life and fruit quality in stored avocados. For the sake of consistency, a table of fixed effect variables is defined once, and consistent variable and parameter pairings are used for all models (Table 1). For example, if a model does not include firmness, then β_4 is not included in that model. In addition to the variables defined in Table 1, we incorporated region r and year y as random variables.

Table 1 Fixed effects used in predictive models.

Label	Variable	Parameter	Units
Intercept	1	β_0	
DoY basis 1	j_1	β_1	
DoY basis 2	j_2	β_2	
Dry matter	m	β_3	%
Firmness	f	β_4	Shore
Duration	d	β_5	h
Duration × Temperature	$d \times t$	β_6	°C·h
TTUs	u	β_7	
Temperature	t	β_8	°C
Weight	w	β_9	

We calculated TTUs, u , as the average temperature above 0°C over a time interval multiplied by the duration of that interval. The day of year of harvest, j , was decomposed into a two-degree periodic basis spline with components j_1 and j_2 . All numeric predictors besides j were normalised, and missing predictors were median-imputed.

To predict days to a certain ripeness outcome, either medium soft (MS) or firm ripe (FR), we used a linear mixed model (LMM) with crossed random effects as defined in Equations 1 and 2.

$$y = \beta_0 + \beta_1 \cdot j_1 + \beta_2 \cdot j_2 + \beta_3 \cdot m + \beta_4 \cdot f + \beta_5 \cdot d + \beta_6 \cdot d \times t + \beta_7 \cdot u + \beta_8 \cdot t + \beta_9 \cdot w + u_y + u_r + \epsilon \quad (1)$$

$$\epsilon \sim \mathcal{N}(0, \sigma_\epsilon^2) \quad (2)$$

To predict chilling injury (CI) we used a generalised linear mixed model (GLMM), again using crossed random effects, specified in Equation 3 with a binomial link function (Equation 4).

$$\text{logit}(p) = \beta_0 + \beta_1 \cdot j_1 + \beta_2 \cdot j_2 + \beta_3 \cdot m + \beta_4 \cdot f + \beta_5 \cdot d + \beta_6 \cdot d \times t + \beta_7 \cdot u + \beta_8 \cdot t + \beta_9 \cdot w + u_y + u_r \quad (3)$$

$$p = P(\text{CI} = 1 \mid u) = \frac{1}{1 + e^{-\eta}} \quad (4)$$



For each combination of variety and outcome we fit both a TTU and a TxT model, except for CI which was only suitable for prediction in a TxT model. Instead of treating pre-con and CA treatments as categorical fixed effects, we fit separate models for treated fruit, allowing us to include or exclude explanatory variables or interactions separately for each individual model as appropriate. CA trials were performed for both Hass and Shepard varieties, while pre-con trials were performed for Hass alone. The list of models is presented in Table 2.

Table 2 Models assessed in this report.

Model	Variety	Input	Outcome	Class	Treatment
MA1	Hass	TTU	MS	LMM	—
MA2	Hass	TTU	MS	LMM	CA
MA3	Hass	TTU	MS	LMM	Pre-con
MA4	Shepard	TTU	MS	LMM	—
MA5	Shepard	TTU	MS	LMM	CA
MA6	Hass	TTU	FR	LMM	—
MA7	Hass	TTU	FR	LMM	CA
MA8	Hass	TTU	FR	LMM	Pre-con
MA9	Shepard	TTU	FR	LMM	—
MA10	Shepard	TTU	FR	LMM	CA
MA11	Hass	TxT	MS	LMM	—
MA12	Hass	TxT	MS	LMM	CA
MA13	Hass	TxT	MS	LMM	Pre-con
MA14	Shepard	TxT	MS	LMM	—
MA15	Shepard	TxT	MS	LMM	CA
MA16	Hass	TxT	FR	LMM	—
MA17	Hass	TxT	FR	LMM	CA
MA18	Hass	TxT	FR	LMM	Pre-con
MA19	Shepard	TxT	FR	LMM	—
MA20	Shepard	TxT	FR	LMM	CA
MA21	Hass	TxT	CI	GLMM	—
MA22	Hass	TxT	CI	GLMM	CA
MA23	Hass	TxT	CI	GLMM	Pre-con
MA24	Shepard	TxT	CI	GLMM	—
MA25	Shepard	TxT	CI	GLMM	CA

Models were fit using the lme4 package for R, with the tidymodels framework for pre-processing. Training scripts ingested data directly from the project database and prepared model objects for deployment to the Fresh Intel API. During training of each model, 25% of observations were excluded and used for model testing, stratified by region. Predictions were performed for each observation from the test set with harvest year, y , excluded. RMSE and R^2 values were calculated separately for each harvest date.



2.2 Predictions and Diagnostics

The latest version of model MA16 was retrieved. The R package `ggeffects` was used to plot predictions against raw data for several combinations of key variables, while the `performance` package was used to generate diagnostic plots. Predictors were transformed back to their original scale to aid visual interpretation.

2.3 Model Performance

The latest version of each avocado model was retrieved. Key model parameters and statistics derived from both model fitting and model testing were tabulated.

2.4 Real-World Validation

We used data from 26 Hass and Shepard avocado consignments from 2025 to validate the performance of these models. These shipments included exports to Japan, Singapore, Hong Kong, and Malaysia. Temperature data were typically obtained from data loggers placed within shipments. Logging intervals were selected to capture temperature variation throughout the journey while maintaining device battery life and storage capacity. Fruit quality was assessed by our export monitoring network.

Predictions were made for each shipment using the available data. The Fresh Intel API was accessed in the same way it would be by an external user. TxT models were used for the predictions, with shipments exhibiting relatively stable temperatures over their lives. Treatment- and variety-specific models were chosen as appropriate.



3 Results

3.1 Model Parameters

Here we present a summary of parameters associated with fixed and random effects for each model, grouped by outcome and input (TxT/TTU) (Tables 3-7). Given the scaling of the predictor variables, parameters in the LMMs (Tables 3-6) can be interpreted as the effect on remaining shelf life caused by a one standard deviation increase in the relevant variable. This excludes the DoY spline components, which were not scaled and should not be directly compared to other parameters. Where insufficient data for a given variable led to it being omitted from a model, no value is shown.

For our TTU models (Tables 3 and 4), increased TTU accumulation is associated with reduced time to medium soft or firm ripe in all models except MA5 where the correlation is significantly positive, if small. MA5 is a model of time to medium soft for Shepard avocados under CA conditions. Some of the remaining models, while negative, are not significantly so (MA2, MA3, and MA10). These three models were for CA or pre-con fruit, which are kept within a tight temperature range. With temperature essential fixed, TTUs essentially a proxy for duration. Given that the purpose of holding fruit at this temperature is to prolong shelf life, it logically follows that TTUs will be only weakly associated with shelf life. The TTU association is both very strong and highly significant in our untreated fruit models (MA1, MA4, MA6, and MA9).

The same patterns observed for our TTU models hold true for our TxT models. Time, temperature, and their interaction term are all highly significant for our shelf-life models (MA11, MA13, MA16, and MA19). This pattern is also apparent in the CI models (MA21 and MA24). Duration is a significant, but often weak predictor of outcomes in treated fruit, while temperature is neither strong nor significant. The exceptions to this pattern are the shelf-life models for CA Hass fruit (MA12 and MA17).

Other fixed effects such as weight and firmness vary greatly in strength and significance between varieties, outcomes, and treatments. The implications of these parameters and are challenging to discuss in isolation and are better explored through visual examination as in the example in section 3.2.

Both regional and seasonal variability were substantial contributors to the response of different shipments. Residual variability was similarly high, indicating substantial inherent variability between fruit within a given shipment.

**Table 3** Days to Medium Soft vs TTU model parameters. Significant parameters are shown in bold.

Label	Variable	Parameter	MA1 Hass	MA2 Hass (CA)	MA3 Hass (Pre-con)	MA4 Shepard	MA5 Shepard (CA)
Intercept	1	β_0	6.990	3.831	-2.957	9.040	-27.536
DoY basis 1	j_1	β_1	-0.073	7.675	13.977	0.656	32.960
DoY basis 2	j_2	β_2	8.801	6.019	17.065	-11.669	50.305
Dry matter	m	β_3	0.010	-0.089	-0.265	-0.010	—
Firmness	f	β_4	0.999	0.083	0.468	0.924	—
TTUs	u	β_7	-0.937	-0.027	-0.070	-1.142	0.122
Weight	w	β_9	-0.133	0.033	0.123	0.326	—
Year SD	y	σ_y	2.389	1.978	0.000	2.583	1.777
Region SD	r	σ_r	2.735	0.936	1.598	0.947	0.268
Year levels	y	J_y	4	4	2	3	3
Region levels	r	J_r	3	3	2	2	2
Residual SD	ϵ	σ_ϵ	2.769	2.187	2.495	1.939	1.456
Observations	n	n	7492	1831	741	3991	831

Table 4 Days to Firm Ripe vs TTU model parameters. Significant parameters are shown in bold.

Label	Variable	Parameter	MA6 Hass	MA7 Hass (CA)	MA8 Hass (Pre-con)	MA9 Shepard	MA10 Shepard (CA)
Intercept	1	β_0	-0.231	1.830	-9.454	9.964	3.032
DoY basis 1	j_1	β_1	4.316	3.041	21.201	-1.169	5.212
DoY basis 2	j_2	β_2	11.495	6.372	19.480	-20.530	-3.569
Dry matter	m	β_3	-0.057	-0.143	-0.330	0.005	-0.194
Firmness	f	β_4	0.759	0.046	0.251	1.076	0.173
TTUs	u	β_7	-1.154	-0.124	-0.283	-1.082	-0.022
Weight	w	β_9	-0.028	0.023	0.279	0.240	0.282
Year SD	y	σ_y	0.923	0.434	0.000	5.217	2.442
Region SD	r	σ_r	1.252	0.634	1.621	0.939	0.055
Year levels	y	J_y	4	4	2	3	3
Region levels	r	J_r	3	3	2	2	2
Residual SD	ϵ	σ_ϵ	2.126	1.139	2.186	6.446	1.237
Observations	n	n	7639	1953	741	3994	831

**Table 5** Days to Medium Soft vs TxT model parameters. Significant parameters are shown in bold.

Label	Variable	Parameter	MA11 Hass	MA12 Hass (CA)	MA13 Hass (Pre-con)	MA14 Shepard	MA15 Shepard (CA)
Intercept	1	β_0	5.387	4.069	-3.039	8.113	-29.043
DoY basis 1	j_1	β_1	1.171	7.368	14.745	0.980	34.203
DoY basis 2	j_2	β_2	7.649	4.521	16.775	-13.177	52.863
Dry matter	m	β_3	0.011	-0.121	-0.259	0.025	—
Firmness	f	β_4	0.853	0.084	0.458	0.783	—
Duration	d	β_5	-1.608	0.039	-0.160	-1.594	0.042
Duration × Temperature	$d \times t$	β_6	-1.949	-0.088	—	-1.932	—
Temperature	t	β_8	-1.891	0.530	—	-2.171	—
Weight	w	β_9	-0.305	-0.045	0.093	0.184	—
Year SD	y	σ_y	1.234	2.640	0.000	3.217	1.965
Region SD	r	σ_r	2.689	1.140	1.547	0.807	0.318
Year levels	y	J_y	4	4	2	3	3
Region levels	r	J_r	3	3	2	2	2
Residual SD	ϵ	σ_ϵ	2.674	2.167	2.492	1.835	1.459
Observations	n	n	7492	1831	741	3991	831

**Table 6** Days to Firm Ripe vs TxT model parameters. Significant parameters are shown in bold.

Label	Variable	Parameter	MA16 Hass	MA17 Hass (CA)	MA18 Hass (Pre-con)	MA19 Shepard	MA20 Shepard (CA)
Intercept	1	β_0	-1.885	1.706	-9.835	9.956	3.245
DoY basis 1	j_1	β_1	5.114	3.192	23.373	-1.563	5.032
DoY basis 2	j_2	β_2	11.670	6.514	19.032	-22.657	-3.903
Dry matter	m	β_3	-0.020	-0.139	-0.293	0.037	-0.195
Firmness	f	β_4	0.659	0.049	0.257	0.949	0.175
Duration	d	β_5	-1.918	-0.030	-0.365	-1.506	-0.067
Duration × Temperature	$d \times t$	β_6	-2.069	-0.089	—	-1.459	—
Temperature	t	β_8	-1.985	-0.031	—	-1.915	—
Weight	w	β_9	-0.152	0.025	0.232	0.153	0.283
Year SD	y	σ_y	0.329	0.495	0.000	5.718	2.458
Region SD	r	σ_r	1.475	0.611	1.482	0.787	0.064
Year levels	y	J_y	4	4	2	3	3
Region levels	r	J_r	3	3	2	2	2
Residual SD	ϵ	σ_ϵ	1.993	1.140	2.175	6.438	1.236
Observations	n	n	7639	1953	741	3994	831

Table 7 Chilling Injury vs TxT model parameters. Significant parameters are shown in bold.

Label	Variable	Parameter	MA21 Hass	MA22 Hass (CA)	MA23 Hass (Pre-con)	MA24 Shepard	MA25 Shepard (CA)
Intercept	1	β_0	-3.781	-3.484	-5.336	-4.983	-1.310
Dry matter	m	β_3	-0.016	-0.148	0.070	0.002	—
Firmness	f	β_4	-0.457	-3.210	-0.694	0.241	—
Duration	d	β_5	0.789	0.487	1.454	0.785	0.884
Duration × Temperature	$d \times t$	β_6	-0.528	0.088	—	-1.391	—
Temperature	t	β_8	-0.623	-0.717	—	-3.059	—
Weight	w	β_9	0.101	-0.118	0.913	0.149	—
Year SD	y	σ_y	0.281	0.924	1.703	0.478	0.310
Region SD	r	σ_r	0.527	0.416	2.405	0.507	0.000
Year levels	y	J_y	3	3	2	2	2
Region levels	r	J_r	3	2	2	2	2
Observations	n	n	5004	1164	567	3522	749

3.2 Example Predictions and Diagnostics (Hass Days to Firm Ripe vs TxT)

Rather than assessing the fit of all 25 models to the training data individually, we present a detailed assessment of a single model to provide insight into the methods used to assess performance during the model training process. We present MA16, predicting days to firm ripe from TxT data. This model is based on the greatest number of observations and allows us to showcase behaviour characteristic of our models.

Figure 1 contains several plots showing the relationship between one or more explanatory variables, and the remaining days to firm ripe. Raw data are shown plotted against model predictions. The plot of days to firm ripe against treatment duration, coloured by treatment temperature, clearly shows the time/temperature interaction that sits at the heart of our TxT models. The complementary plot with duration on the x-axis split by temperature shows the same. The plot of days to firm ripe shows firmness on arrival is a strong predictor of days to firm ripe, while dry matter is far less influential. The final panel in Figure 1 highlights that the variability throughout the year is captured well by the spline decomposition of the day of year. The use of a periodic basis spline ensures that the curve begins at the same value as it ends. This prevents abnormal behaviour at the boundaries of the range which can be a concern with other types of splines. An extreme outlier can be observed in all plots, causing the y-axis to extend well below zero.

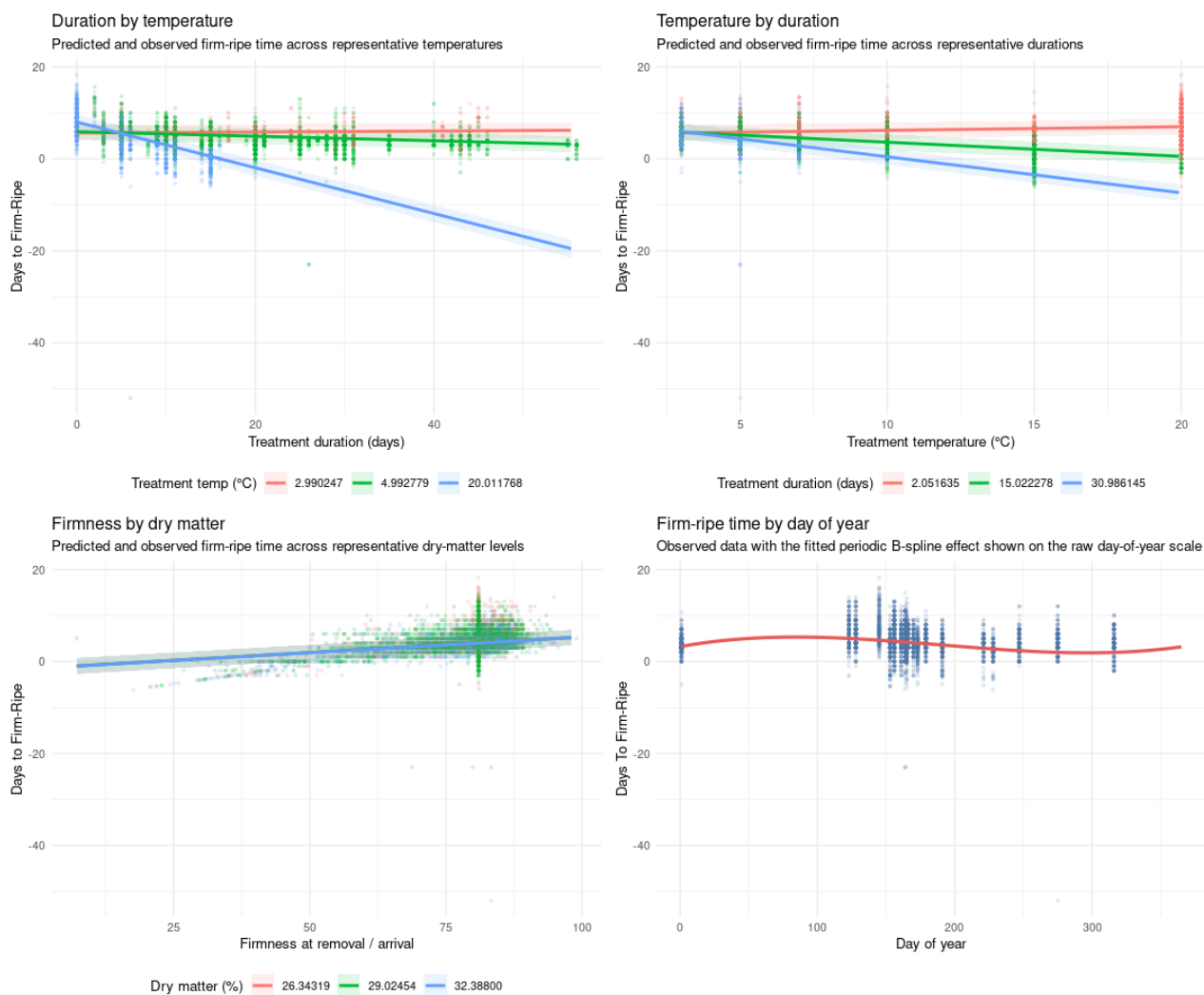


Figure 1 A series of plots of training data (points) against model predictions (solid lines with shaded 95% confidence intervals) from the model MA16.

Figure 2 includes several common diagnostic plots used to assess LMMs. The linearity and normality of residuals plots both show the model to be well-specified, while the lone extreme outlier is again obvious. The homogeneity of variance plot shows a banding pattern that is typical of continuous outcome variables where only integer values were observed. With the limited number of unique values of random effects in our data, little can be gained from the normality of random effects plots.

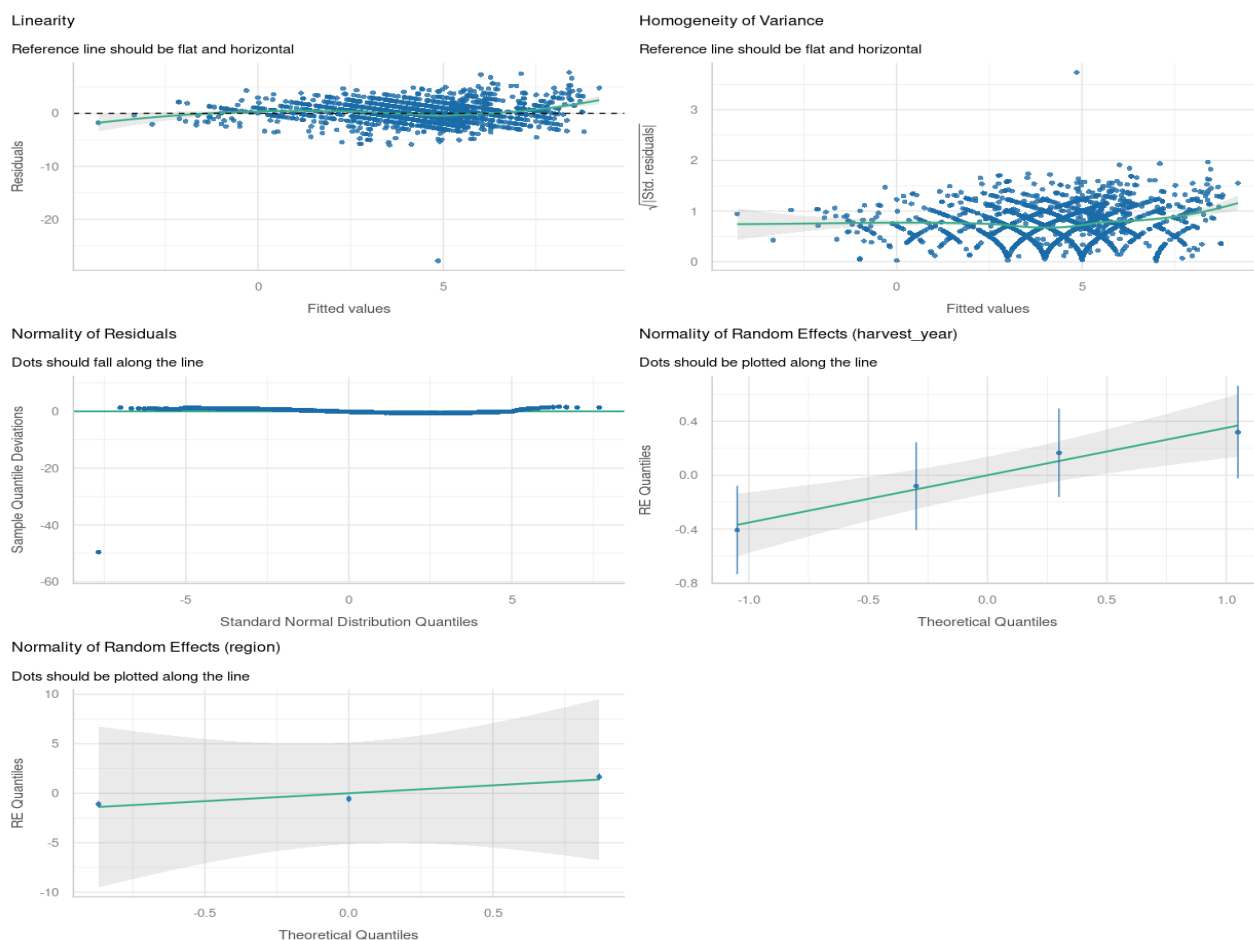


Figure 2 Diagnostic plots associated with model MA16.



3.3 Model Performance

Here we present model performance statistics for all 25 models, drawing upon statistics derived during the training process and calculated using our hold-out training data (Tables 8-12).

Marginal R^2 is the proportion of variance explained by the fixed effects only, while conditional R^2 incorporates random effects. The weighted R^2 calculated on the test data incorporates the effect of region, but not season, so is not directly comparable to either of the model-based R^2 . An R^2 of one is the theoretical optimum but should not be seen as a realistic target – variation between individual pieces of fruit is always a factor, so the practical upper limit is well below one, even in the training dataset.

Shelf-life models for untreated fruit tended to have higher R^2 values than similar model for treated fruit, while there was more variability between CI models. Notably, better R^2 values were observed in the test performance for Shepard than Hass.

RMSE reflects the average difference between observed and predicted values. In the model-based metrics, this tends to be dominated by variation between individual fruit within treatments, while the test data also incorporates prediction error.

Neither variety appears to have a consistently higher or lower RMSE associated with their models. Interestingly, RMSE is lower in shelf-life models for treated fruit compared to untreated, although there are exceptions such as MA7 and MA9. This pattern may reflect that the treatment reduces variability in shelf life for individual pieces of fruit within a shipment.

RMSE and R^2 tend to be similar between the pairs of similar TxT and TTU models for both the model-based and test metrics.

Table 8 Days to Medium Soft vs TTU Models

Metric	MA1 Hass	MA2 Hass (CA)	MA3 Hass (Pre-con)	MA4 Shepard	MA5 Shepard (CA)
Model-based fit					
Fit observations	7492	1831	741	3991	831
Marginal R^2	0.194	0.144	0.174	0.307	0.186
Conditional R^2	0.704	0.572	—	0.770	0.677
ICC	0.632	0.500	—	0.668	0.604
RMSE	2.767	2.180	2.482	1.936	1.450
Residual SD	2.769	2.187	2.495	1.939	1.456
Test performance					
Test observations	2564	639	258	1337	271
Date groups	21	19	12	10	8
Weighted R^2	0.292	0.089	0.137	0.511	0.139
Pooled RMSE	3.030	2.489	2.586	2.508	1.806

**Table 9** Days to Firm Ripe vs TTU Models

Metric	MA6 Hass	MA7 Hass (CA)	MA8 Hass (Pre-con)	MA9 Shepard	MA10 Shepard (CA)
Model-based fit					
Fit observations	7639	1953	741	3994	831
Marginal R^2	0.369	0.138	0.276	0.101	0.206
Conditional R^2	0.589	0.408	—	0.464	0.838
ICC	0.349	0.313	—	0.403	0.796
RMSE	2.124	1.135	2.174	6.438	1.230
Residual SD	2.126	1.139	2.186	6.446	1.237
Test performance					
Test observations	2527	684	258	1337	271
Date groups	22	20	12	10	8
Weighted R^2	0.418	0.106	0.224	0.591	0.103
Pooled RMSE	2.169	1.279	2.007	3.566	2.141

Table 10 Days to Medium Soft vs TxT Models

Metric	MA11 Hass	MA12 Hass (CA)	MA13 Hass (Pre-con)	MA14 Shepard	MA15 Shepard (CA)
Model-based fit					
Fit observations	7492	1831	741	3991	831
Marginal R^2	0.224	0.165	0.172	0.295	0.186
Conditional R^2	0.651	0.698	—	0.835	0.716
ICC	0.550	0.638	—	0.766	0.651
RMSE	2.671	2.158	2.478	1.833	1.453
Residual SD	2.674	2.167	2.492	1.835	1.459
Test performance					
Test observations	2564	639	258	1337	271
Date groups	21	19	12	10	8
Weighted R^2	0.329	0.082	0.144	0.561	0.144
Pooled RMSE	2.726	2.868	2.586	2.710	1.885

**Table 11** Days to Firm Ripe vs TxT Models

Metric	MA16 Hass	MA17 Hass (CA)	MA18 Hass (Pre-con)	MA19 Shepard	MA20 Shepard (CA)
Model-based fit					
Fit observations	7639	1953	741	3994	831
Marginal R^2	0.418	0.125	0.270	0.104	0.206
Conditional R^2	0.630	0.407	—	0.503	0.840
ICC	0.365	0.322	—	0.446	0.798
RMSE	1.991	1.136	2.163	6.428	1.229
Residual SD	1.993	1.140	2.175	6.438	1.236
Test performance					
Test observations	2527	684	258	1337	271
Date groups	22	20	12	10	8
Weighted R^2	0.459	0.104	0.224	0.614	0.099
Pooled RMSE	2.021	1.299	2.011	3.836	2.149

Table 12 Chilling Injury vs TxT Models

Metric	MA21 Hass	MA22 Hass (CA)	MA23 Hass (Pre-con)	MA24 Shepard	MA25 Shepard (CA)
Model-based fit					
Fit observations	5004	1164	567	3522	749
Marginal R^2	0.283	0.255	0.202	0.695	0.194
Conditional R^2	0.353	0.433	0.781	0.734	—
ICC	0.098	0.238	0.725	0.129	—
RMSE	0.237	0.214	0.220	0.256	0.407
Log loss	0.205	0.173	0.171	0.209	0.501
Test performance					
Test observations	2564	639	258	1337	271
Date groups	21	19	12	10	8
Weighted R^2	0.121	0.131	0.314	0.173	0.212
Pooled RMSE	3.491	3.881	4.070	5.378	1.855



3.4 Real-World Validation

The RMSE values calculated by comparing model predictions from the TxT models with observed shelf-life are reported in Table 13. Different models were used to account for treatments applied during handling, but these are not reported separately due to low numbers for some models. Overall performance was excellent for Hass and adequate for Shepard. The disparity in performance may be due to the greater number of observations included in the Hass dataset.

Table 13 RMSE values for each combination of outcome and variety.

Outcome	Hass	Shepard
Firm Ripe	1.3	3.8
Medium Soft	1.6	3.0

Caution should be taken when comparing these RMSE values to those presented in section 3.3. While the values for training and test data from laboratory trial include variability between individual pieces of fruit, here we only compare average observed shelf life for a shipment to a predicted average shelf life. Prediction of the average distribution of fruit within a shipment is supported by our models but not reported on here.



4 Discussion

By using a robust training pipeline with careful testing and validation we have developed a suite of models with high predictive power for Hass and Shepard avocados. Real-world performance was excellent, with most shelf-life predictions accurate to within ± 1.3 days (Hass, FR) to ± 3.8 days (Shepard, FR). These results are backed up by the testing performed as part of the model deployment pipeline.

A consistent theme across these models is that conditional R^2 is higher than marginal R^2 – that is to say, accurate predictions are highly dependent upon the random effects. Some models exhibit greater annual variability, while regional variability is greater in others. While we can offer region-adjusted predictions if provided the necessary data, we are unable to adjust based on season. Even with a rapid model training pipeline, harvesting of fruit for experimental purposes coincides with commercial harvests by design, precluding the ability to update the model in time to reflect the realities of the current season.

While harvest year was not made available as a prediction variable during real-world validation, the training data did contain experimental observations from 2025. This means that the model validation shipments were conducted during a period that is covered by the training. It is possible that performance will be different in future years, especially if conditions are outside those observed during the project.

Drawing on climactic and pre-harvest factors remains an interesting by which we could improve performance across seasons, and especially in new seasons not included in the training data. Similarly, accelerated ripening trials could be used to provide an early estimate of shelf-life changes at the beginning of a season, which could in turn be incorporated into the predictive models.

Our ongoing partnership with Escavox provides opportunities to validate our models in a greater number and variety of supply chains. It also opens the possibility to feed back data from these shipments and retrain our models on more complex temperature scenarios.

Another avenue which might be pursued to improve performance is individualised predictions per piece of fruit, rather than per shipment. Our models already support this, for example by supplying individualised dry matter values or firmness values on arrival in the market. Given the substantial residual error in our shelf-life model metrics from the training data, better predictors of individual performance need to be determined before this would realistically be useful.

Diagnostic and prediction plots like those shown in section 3.2 were made available through an internal dashboard, allowing for rapid review of newly trained models. This allowed us to review models at scale or spot-check models where aberrant behaviour was noticed.



5 Conclusion

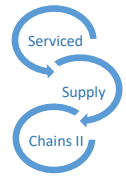
We demonstrated that our avocado models accurately predict shelf-life outcomes including time to firm ripe and medium soft. This can enable better decision making prior to, and even during shipment. Ensuring that fruit are shipped in supply chains with adequate temperature control for their duration is critical to ensuring quality, especially in overseas export markets. The ability to assess shelf-life for shipments at scale without manual intervention also enables distributors to ensure that the fruit closest to expiry is dispatched first, minimising waste and maximising quality.

Starting with carefully specified models based on our understanding of the data, combined with a comprehensive training and testing pipeline, we deploy models to Fresh Intel with confidence. Performance metrics from the training and testing datasets, as well as visual inspection of prediction and diagnostic plots allows us to verify that performance is stable, even as new data is incorporated in the model by semi-automated retraining scripts.

The pipeline that we have developed as part of this project can be readily extended to new varieties of avocados emerging onto the market, or to cover a greater range of popular post-harvest treatments. The focus on using reproducible training pipelines throughout the project has given us not just the ability to update models as new data becomes available, but to deploy new models with ease.

Avenues for further model improvement are available to be explored in future projects. These include use of preharvest and climactic variables, predictions at the level of individual fruit, and training on more complex real-world data instead of simulated shipments. Each of these would be substantial undertakings.

Even though initial performance in real-world shipments has been good, careful monitoring and continuing evaluation is required to ensure that this high standard is maintained. Ongoing performance should be tracked through our partnership with Escavox or as part of future projects to detect and remediate model or data drift.



6 Acknowledgments

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Appendix 51

‘Honey Gold’ mango simulation trials report 2021/22



Predicting the shelf life of 'Honey Gold' mango fruit

A 2021/22 season summary report

Hung Duong, Yiru Chen and Andrew Macnish, Department of Agriculture and Fisheries

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf-life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2021/22 mango season with two farms in NT and CQ. The main objective of the trials was to generate preliminary data sets to develop fruit shelf-life prediction models for 'Honey Gold' mango under varied supply chain conditions.

2. Materials and methods

Commercially mature (e.g., average dry matter range 17.0-19.5%) 'Honey Gold' mango fruit were sourced for trials during the 2021/22 season. Fruit were harvested on 18 November 2021 from farm A near Katherine, Northern Territory, and on 8 and 16 December 2021 from farm A near Bowen, North Queensland. Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby pack shed within 24 hours of harvest. The fruit were treated with a fungicide, sorted by size and quality, and packed into cardboard trays.

Due to a local covid-19 lockdown, the packed Northern Territory fruit were held at 16-17°C for 3 days at the pack shed until 22 November. They were transported the following day to a laboratory near Darwin in an air-conditioned car at ca. 22-25°C within 4-5 hours. Queensland fruit were transported to Townsville airport by car at 22°C within 2-3 hours of packing. They were air-freighted to Brisbane the same day. The trays were then transported by car at 22°C to a laboratory near Nambour, a distance of about 100 km. Upon arrival at each laboratory, the fruit were maintained overnight (i.e., 12-16 hours) at 20°C.

At the laboratory, fruit were randomised and assigned to storage treatments (**Table 1**). Each treatment was applied to one tray of eight fruit. The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL). After removal from different storage temperatures, fruit was kept at 20°C until they reached ESL. The fruit were not treated with ethylene. Fruit quality (i.e., fruit firmness, skin colour and defects) was recorded every 2 days. The fruit was considered to reach ESL when it was either oversoft (firmness <4N), rotten, or rated 'extremely poor' in visual appeal.

Table 1 Time x temperature matrix used to simulate supply chain handling of ‘Honey Gold’ mango fruit.

Storage temperature (°C)	Storage time days prior to transfer to 20°C					
10		4	8	12	16	20
12		4	8	12	16	20
14		4	8	12	16	20
16		4	8	12	16	20
20	0	4	8	12	16	20

3. Results

‘Honey Gold’ fruit from Northern Territory

Fruit picked from Katherine had an average dry matter (DM) of 19.5% at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 26.4 days from harvest to ESL (**Table 2**). Fruit with the longest postharvest life of 38.5 days were those stored at 12°C for 20 days prior to transfer to 20°C. In general, total fruit life was progressively extended by longer durations at cooler storage temperatures, until chilling injury emerged (e.g., 10°C storage for 12, 16 and 20 days).

Table 2. Average postharvest life (days) since harvest for ‘Honey Gold’ mango fruit picked from Katherine, NT and stored at different temperatures to reflect various handling regimes.

	Storage time days prior to transfer to 20°C					
Storage temperature (°C)	0	4	8	12	16	20
10		26.4	31.6	27.8	28.5	30.5
12		24.0	32.1	32.5	32.1	38.5
14		23.8	27.4	30.6	30.6	31.5
16		20.4	28.3	30.5	30.9	32.1
20	26.4	25.8	25.1	25.7	28.4	27.1

The average shelf life (SL) of fruit at 20°C after removal from storage treatments is presented in **Table 3**. Fruit SL was related to storage temperature and time. In general, SL decreased with longer storage time. Storage at 12°C was typically associated with the greatest SL. The percentage of fruit reaching ESL due to oversoft was 78.5%. Other reasons attributing to ESL include chilling injury (7.3%), shrivel (6.3%), under skin browning (4.4%) and stem end rot (SER) (<1%).

Table 3 Heat map of average shelf life of ‘Honey Gold’ mango fruit picked from Katherine, NT and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (Day) Temp. (°C)	Average of residual shelf life at 20°C (day) after storage					
	0	4	8	12	16	20
10	21.4	17.4	18.6	10.8	7.5	5.5
12		15.1	19.1	15.5	11.1	13.5
14		14.8	14.4	13.6	9.6	6.5
16		11.6	15.2	13.5	9.9	7.1
20		16.8	12.1	8.7	7.4	2.9

‘Honey Gold’ fruit from north Queensland

Fruit were harvested from the same block of trees early (8 Dec 2021) and later (16 Dec 2021) in the season from the NQ farm. The early-season fruit had an average DM of 18.1% whilst late-season fruit had a DM of 17%. The lower DM for the second harvest presumably represents fruit from a later flowering.

Most fruit reached ESL when they were oversoft (only 1 was due to SER in late harvest). No chilling injury was observed on fruit from both harvests even for those stored at 10°C for up to 20 days. The average postharvest life for fruit continuously held at 20°C was 22.1 (early harvest) and 22.8 days (late harvest). The longest life of 34 days was recorded for fruit stored at 10°C for 20 days before transfer to 20°C. Storage at 10°C was associated with maximum SL, particularly as the storage time increased (**Table 4**). These trials again proved that within the ‘biological safe range’ for mango, lowering fruit temperature results in extended SL (**Table** and **Table**).

Table 4 Heat map of average shelf life of early harvested ‘Honey Gold’ mango fruit from Bowen, NQ and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (Day) Temp. (°C)	Average of residual shelf life at 20°C (day) after storage					
	0	4	8	12	16	20
10	20.1	17.4	15.9	12.6	15.0	11.0
12		16.3	14.5	12.0	10.1	10.3
14		14.9	14.6	9.1	7.6	7.8
16		15.6	11.5	10.1	4.8	3.4
20		13.5	11.8	7.9	1.0	1.6

Table 5 Heat map of average shelf life of late harvested 'Honey Gold' mango fruit from Bowen, NQ and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (Day) Temp. (°C)	Average of residual shelf life at 20°C (day) after cold storage					
	0	4	8	12	16	20
10	20.8	16.9	14.6	14.5	14.0	12.1
12		17.8	14.1	12.9	11.9	10.3
14		15.4	13.5	11.6	9.3	9.0
16		17.6	11.1	9.0	5.9	4.8
20		17.5	12.3	6.8	6.0	2.4

Shelf-life models

'Honey Gold' time x temperature trials harvested from Katherine and North Queensland captured good to great quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) for Northern Territory fruit showed an acceptable linear regression ($R^{21}=0.69$, **Figure 1**) whereas models for North Queensland fruit displayed impressive R^2 of 0.9 and 0.93 for early and late harvest, respectively (**Figure 2** and **Figure 3**). These trials need to be repeated to confirm the model robustness. Such strong relationships will be instrumental in guiding the development of models to predict the response of fruit from different districts under variable supply chain conditions.

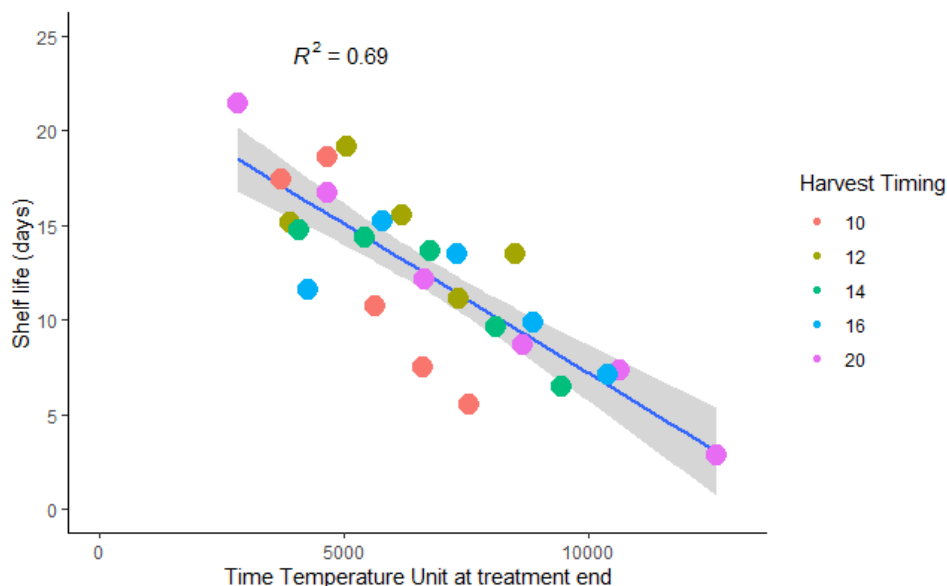


Figure 1 Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and shelf life (tray averages) in 'Honey Gold' mangoes harvested from Katherine, NT.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

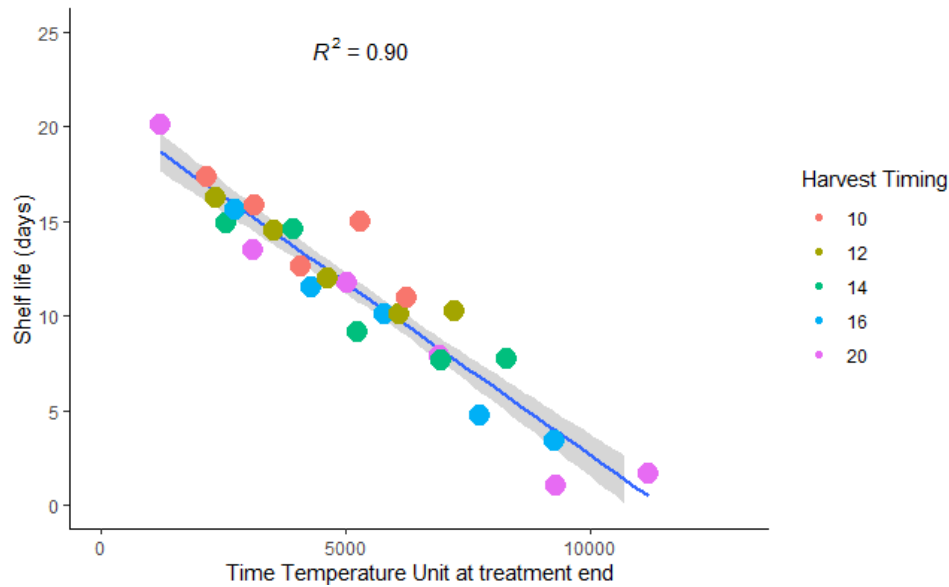


Figure 2 Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and shelf life (tray averages) in early harvested 'Honey Gold' mangoes from Bowen, NQ.

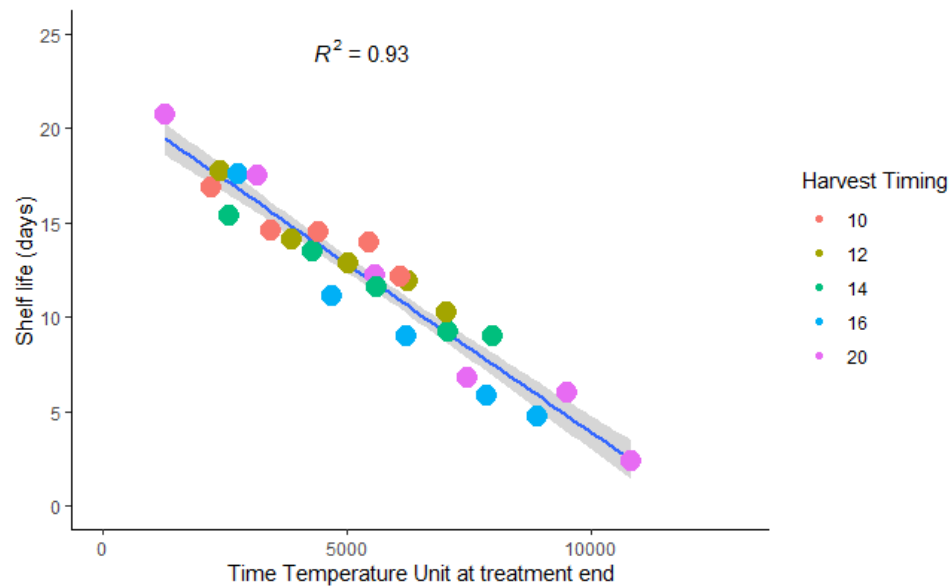


Figure 3 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures and shelf life (tray averages) in late harvested 'Honey Gold' mangoes from Bowen, NQ.

In predicting shelf life, we have considered DM as another independent variable (**Figure 4**). However, it does not explain the variation in SL from a statistical perspective for fruit from both Katherine and Bowen. For Bowen fruit, the average DMs (%) of both harvests were statistically different. The finding that early-season fruit with the highest DM displayed slightly longer SL was unexpected. For Katherine fruit, including DM slightly improved the predictive model ($R^2 = 0.69$ to 0.72) (**Figure 5**).

[$R^2 = 0.91$, RMSE = 1.46, PI (90%) = ± 2.81]

[$R^2 = 0.93$, RMSE = 1.16, PI (90%) = ± 2.23]

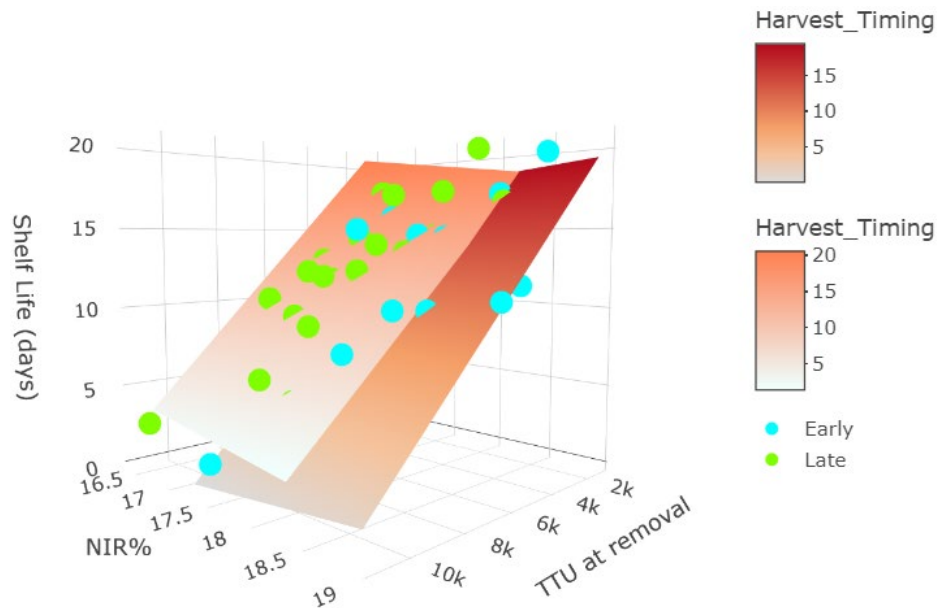


Figure 4 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures, fruit dry matter (DM) and shelf life (tray averages) in 'Honey Gold' mangoes from Bowen, NQ.

[$R^2 = 0.72$, RMSE = 2.41, PI (90%) = ± 4.64]

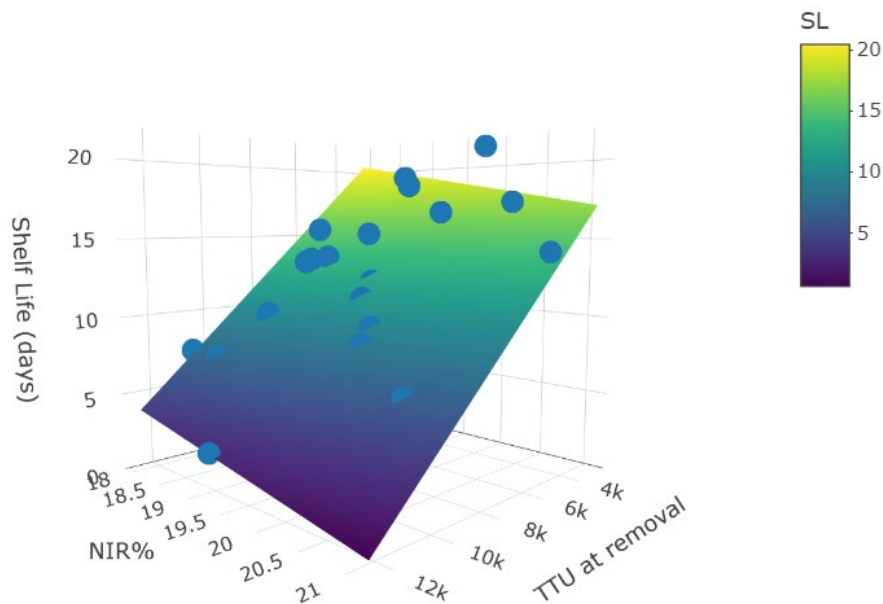


Figure 5 Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures, fruit dry matter (DM) and shelf life (tray averages) in 'Honey Gold' mangoes from Katherine, NT.



4. Recommendations

These trials demonstrated the importance of storing 'Honey Gold' fruit at low, non-chilling temperatures to extend overall postharvest life plus shelf life. Future trials will test the impact of lower storage temperatures (e.g. 8°C) on 'Honey Gold' shelf life and quality, compare fruit from other farms including Darwin and Mareeba, collect more DM data and repeat trials to confirm current findings.

5. Acknowledgments

We thank all growers for supplying fruit for trials and for their technical advice and support. We acknowledge Sohail Mazhar, Alan Niscioli, Salman Quddus and Saeeda Taghadimo-Saberi from the Northern Territory Department of Industry Trade and Tourism plus Lawrence Smith, John Archer and Minh Nguyen from the Queensland Department of Agriculture and Fisheries for assistance in managing trials and data collection.

Appendix 52

‘Honey Gold’ mango simulation trials report 2022/23a

Predicting the shelf life of 'Honey Gold' mango fruit

A 2022/23 season summary report

Hung Duong and Andrew Macnish, Department of Agriculture and Fisheries

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2022/23 mango season with farm A. The main objectives of the trials were to generate preliminary data sets to develop fruit shelf life prediction models for 'Honey Gold' mango under varied supply chain conditions, to investigate how much fruit shelf life is lost following ethylene treatment and explore chilling temperature threshold.

2. Materials and methods

The information on trial name, fruit source, harvest time and dry matter (DM) is presented in Table 1.

Table 1. Details of trial, fruit harvesting location and time and DM

Trial No.	Trial name	Fruit source	Harvest time	Trial location	DM (%)
1	Time x temperature plus C ₂ H ₄ treatment	Darwin, NT	11/11/2023	Darwin	16.1
2	Time x temperature	Katherine, NT	20/11/2023	Darwin	18.5
3	Chilling and ethylene treatment	Katherine, NT	20/11/2023	MRF	18.2

C₂H₄ is ethylene

Commercially mature (e.g. dry matter ≈16.1.0-18.2%) 'Honey Gold' mango fruit were sourced for trials during the 2022/23 season. Fruit were harvested from the farm A near Darwin and Katherine, Northern Territory. Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby pack shed within 24 hours of harvest. The fruit were treated with a fungicide, sorted by size and quality, and packed into cardboard tray. After that they were transported to a laboratory near Darwin in an air-conditioned car at ca. 22-25°C within 1h (Darwin fruit) or 4-5 hours (Katherine fruit). The fruit harvested from Katherine were also sent to Brisbane the same day by air freight, then transported by car at 22°C to a laboratory near Nambour, a distance of about 100 km.

Upon arrival at each laboratory, near-infrared spectroscopy (NIR) was measured on all trial and DM fruit as an index of dry matter content. NIR was measured using a Felix F-750 Quality Meter, based on a general mango dry matter model (generated by CQU). NIR predicted dry matter was measured on 2 sides of each fruit, near the cheek centre. The fruit were grouped into DM categories that differed by 0.5% DM (e.g. 14.6 – 15). These categorised fruit were then assigned randomly and evenly to treatment trays (ten fruit per tray). This is to make sure that every tray contains a normal distribution of the DMs in the population supplied. The

trays were placed to storage treatments (**Table 2**). Relative humidity (RH) was maintained at 85-90% during cold treatment.

Table 2. Time x temperature matrix used to simulate supply chain handling of 'Honey Gold' mango fruit.

Temp. (°C)	Removal time (days) to ongoing 20°C storage								
	0	4	8	12	16	20	24	28	32
8		X	X	X	X	X	X	X	X
10		X,X	X,X	X	X	X	X	X	
12		X,X	X,X	X	X	X	X	X	
14		X,X	X,X	X	X	X			
16		X,X	X,X	X	X	X			
20	X,X,X	X,X	X,X	X	X	X			

X trays (10 fruit/tray) were removed from the cold storage and held at 20°C plus 65% RH

X trays were removed from the cold storage and treated with 100 pm ethylene at 18°C for 2 days, then held at 20°C

Blue shaded area was for time x temp matrix

Green area was for chilling injury examination

The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL). After removal from different storage temperatures, fruit was kept at 20°C plus 65% RH until they reached ESL. Fruit quality (firmness) was recorded at intake and cold removal. Fruit firmness and skin defects (stem-end rot, body rot, under-skin browning, and chilling injury) were checked every 2 days. The fruit was considered to reach ESL when it was either oversoft (<38 TAD or firmness <4N), developed rots, or was rated 'extremely poor' in visual appeal.

3. Results

3.1 'Honey Gold' fruit from Darwin

Fruit firmness

Changes in firmness associated with ripening occurred more rapidly as storage temperatures increased (**Figure 1**). Minimal softening occurred while fruit were stored at 10°C. As temperatures increased from 12°C to 20°C the rate of softening gradually increased. For example, fruit stored at 16°C and 20°C reached the end of shelf life (oversoft stage) after 16 and 20 days, respectively.

Shelf life

Fruit picked from Darwin orchard had an average dry matter (DM) of 16.1% at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 13.4 days from harvest to ESL (**Table 3**). Fruit with the longest postharvest life of 30.5 days were those stored at 10°C for 28 days prior to transfer to 20°C. In general, total fruit life was progressively extended by longer durations at cooler storage temperatures. There was no chilling injury fruit from this trial.

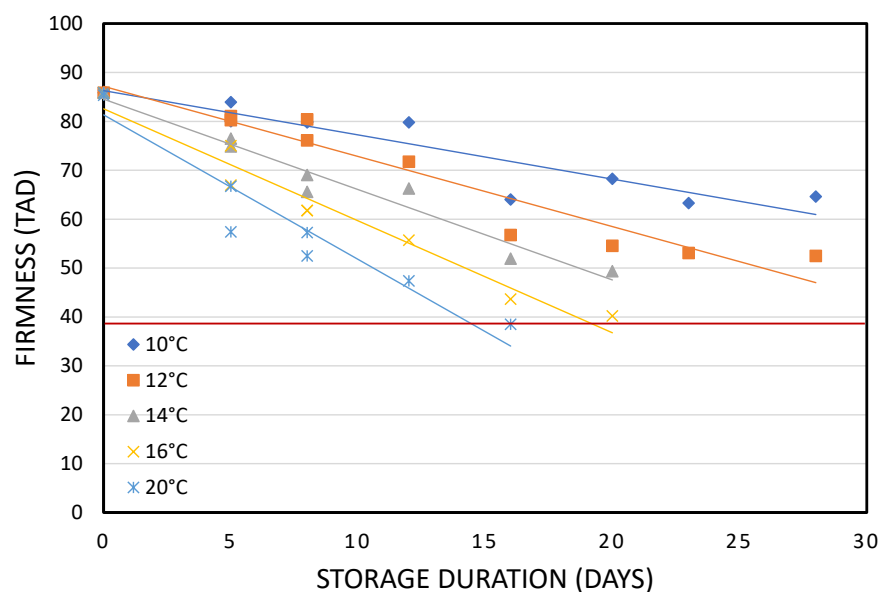


Figure 1: Firmness changes in ‘Honey Gold’ mangoes harvested from Darwin orchard during storage at various temperatures. The red line indicated fruit firmness cutoff when they are oversoft.

Table 3. Average postharvest life (days) since harvest for ‘Honey Gold’ mango fruit picked from Darwin, NT and stored at different temperatures to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C						
	5	8	12	16	20	23	28
10	16.3	19.5	19.0	22.0	24.6	26.6	30.5
12	14.5	16.4	18.7	20.6	22.9	23.9	28.0
14	14.0	14.6	18.5	18.6	20.9		
16	14.4	13.8	14.6	17.8	20.4		
20	13.5	12.4	12.3	16.4			

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 4**. Fruit RSL was related to storage temperature and time. In general, RSL decreased with longer storage time. Storage at 10°C was typically associated with the greatest RSL. The percentage of fruit reaching ESL due to body rot and oversoft was 45% and 38%, respectively. Other reasons attributing to ESL include stem end rot (16%), under skin browning (1%).

Table 4. Heat map of average of remaining shelf life of 'Honey Gold' mango fruit picked from Darwin, NT and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (days) Temp (°C)	Average of residual shelf life at 20°C (days) after storage							
	0	5	8	12	16	20	23	28
10	13.4	11.3	11.5	7.0	6.0	4.6	3.6	2.5
12		9.5	8.4	6.7	4.6	2.9	0.9	0.0
14		9.0	6.6	6.5	2.6	0.9		
16		9.4	5.8	2.6	1.8	0.4		
20		13.4	8.5	4.4	0.3	0.4		

Effect of ethylene treatment on fruit shelf life

As shown in **Table 5**, the HG fruit treated with ethylene reached firm soft stage after 3.4 days at 20°C which is a day faster than non-ethylene treated fruit. As a result, on average the shelf life of ethylene treated fruit was 1.3 days shorter than untreated fruit.

Table 5. Effect of ethylene treatment on the shelf life of HG fruit picked from Darwin orchard

Storage temperature (°C)	Storage duration (day)	Days to firmsoft at 20°C		Remaining shelf life (day)		Difference in shelf life (day)
		No C ₂ H ₄	C ₂ H ₄	No C ₂ H ₄	C ₂ H ₄	
10	5	5.5	4	11.3	9.1	2.2
	8	5.1	3	11.5	6.6	4.9
12	5	4.3	4	9.5	9.2	0.3
	8	5.2	3.5	8.4	6.3	2.1
14	5	4.1	4	9	7.2	1.8
	8	3	3.1	6.6	6.6	0.0
16	5	3.7	4	9.4	8.2	1.2
	8	3.2	0.7	5.8	6.6	-0.8
20	0	8.3	6.3	13.4	12.6	0.8
	5	3.6	4	8.5	7.5	1.0
	8	2.3	0.4	4.4	3.6	0.8
Ave		4.4	3.4	8.9	7.6	1.3

Shelf-life models

'Honey Gold' time x temperature trials harvested from Darwin, NT captured great quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x

time units (TTUs) showed an impressive linear regression ($R^{21}=0.9$). Such strong relationships will guide development of models to predict the response of fruit from different districts under variable conditions.

In predicting shelf life, we have considered DM as another independent variable (**Figure 3**). We found that there was a strong relationship between DM, TTU and fruit shelf life. It means that if fruit with lower DM and exposed to the same TTU, they will have a longer shelf life compared to those having higher DM.

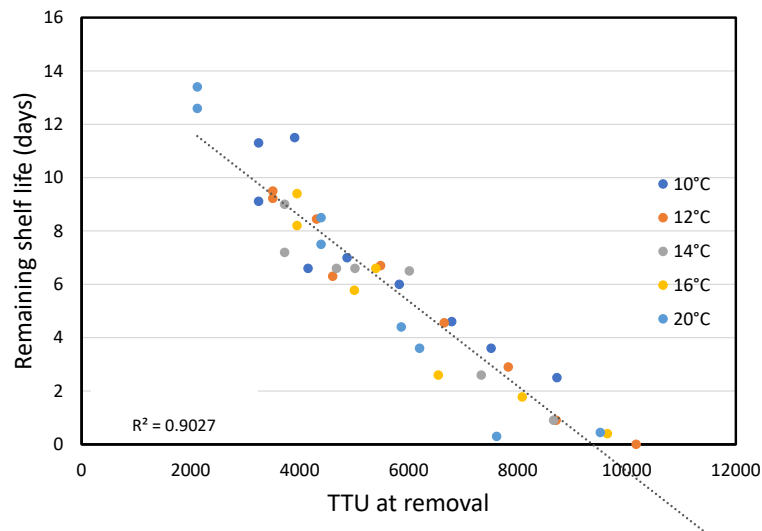


Figure 2. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from Darwin.

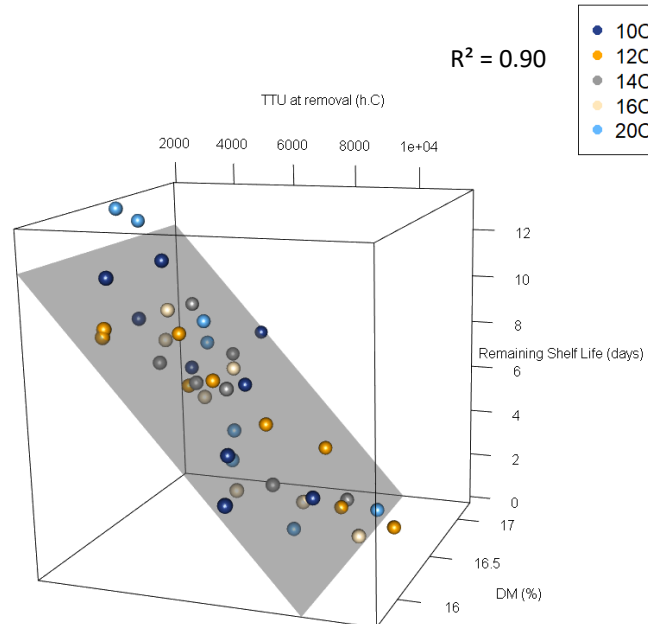


Figure 3. Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures, fruit dry matter (DM) and remaining shelf life (tray averages) in 'Honey Gold' mangoes from Darwin, NT.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

3.2 'Honey Gold' fruit from Katherine

Fruit firmness

Fruit picked from Katherine orchard had a similar trend in firmness changes which associated with ripening occurred more rapidly as storage temperatures increased (**Figure 4**). Minimal softening occurred while fruit were stored at 10°C. As temperatures increased from 12°C to 20°C the rate of softening gradually increased. The fruit held at 12°C and 14°C remained sprung until cold removal while fruit stored at 20°C reached the end of shelf life (oversoft stage) after 20 days.

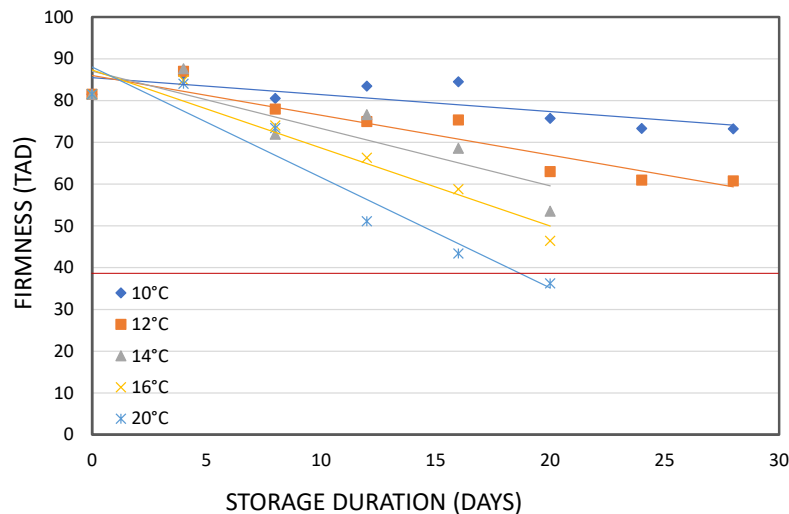


Figure 4: Firmness changes in 'Honey Gold' mangoes harvested from Katherine orchard during storage at various temperatures. The red line indicated fruit firmness cutoff when they are oversoft.

Shelf life

Fruit picked from Katherine orchard had an average dry matter (DM) of 18.5% at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 21.2 days from harvest to ESL (**Table 6**). Fruit with the longest postharvest life of 34 days were those stored at 10°C and 12°C for 28 days prior to transfer to 20°C. In general, total fruit life was progressively extended by longer durations at cooler storage temperatures. There was no chilling injury fruit from this trial.

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 7**. Fruit RSL was related to storage temperature and time. In general, RSL decreased with longer storage time. Storage at 10°C and 12°C were typically associated with the longest RSL. The percentage of fruit reaching ESL due to oversoft was 93%. Other reasons attributing to ESL include under skin browning (4%) and body rot (2%).

Table 6. Average postharvest life (days) since harvest for 'Honey Gold' mango fruit picked from Katherine, NT and stored at different temperatures to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C						
	4	8	12	16	20	24	28
10	19.1	22.3	25.0	28.1	29.1	34.2	34.6
12	20.5	24.5	22.0	27.5	28.0	31.4	34.3
14	21.3	21.9	23.2	27.3	27.8		
16	20.5	21.9	22.6	25.3	24.0		
20	19.4	21.5	18.0	18.2	20.9		

Table 7. Heat map of average of remaining shelf life of 'Honey Gold' mango fruit picked from Katherine, NT and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (days) \ Temp (°C)	Average of residual shelf life at 20°C (days) after storage							
	0	5	8	12	16	20	23	28
10	21.2	16.1	14.3	12	12.1	9.1	10.2	6.6
12		17.5	16.5	9	11.5	8	7.4	6.3
14		18.3	13.9	10.2	11.3	7.8		
16		17.5	13.9	9.6	9.3	4		
20		16.4	13.5	5	2.2	0.9		

Effect of ethylene treatment on fruit shelf life

As shown in **Table 8**, the HG fruit treated with ethylene reached firm soft stage after 3.8 days at 20°C which is 1.7 days faster than non-ethylene treated fruit. Although effect of ethylene on fruit shelf life varied, on average the shelf life of ethylene treated fruit was 3 days shorter than untreated fruit.

Table 8. Effect of ethylene treatment on the shelf life of HG fruit picked from Katherine orchard

Storage temperature (°C)	Storage duration (day)	Days to firmsoft at 20°C		Remaining shelf life (day)		Difference in shelf life (day)
		No C ₂ H ₄	C ₂ H ₄	No C ₂ H ₄	C ₂ H ₄	
10	5	6.5	5.3	12.8	10.7	2.1
	8	7.6	3.7	12.7	6.2	6.5
12	5	5.1	4.1	10.3	8.4	1.9
	8	4.3	3.8	9.9	7.4	2.5
14	5	5.2	4.1	11.0	9.1	1.9
16	5	4.8	4.0	11.3	9.3	2.0
20	0	9.3	4.1	15.6	9.3	6.3
	8	1.8	1.6	7.3	6.4	0.9
Ave		5.6	3.8	11.4	8.4	3.0

Shelf-life models

'Honey Gold' time x temperature trials harvested from Katherine, NT obtained great quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) showed a strong linear regression ($R^2=0.92$ ², **Figure 5**).

In predicting shelf life, we have considered DM as another independent variable (**Figure 6**). We found that there was a strong relationship between DM, TTU and fruit shelf life ($R^2=0.92$). It means that if fruit with lower DM and exposed to the same TTU, they will have a longer shelf life compared to those having higher DM.

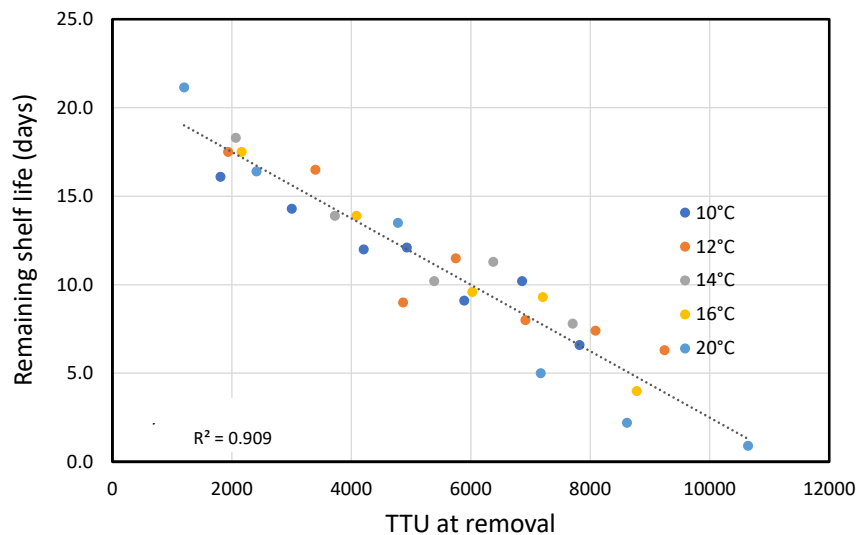


Figure 5. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from Katherine, NT.

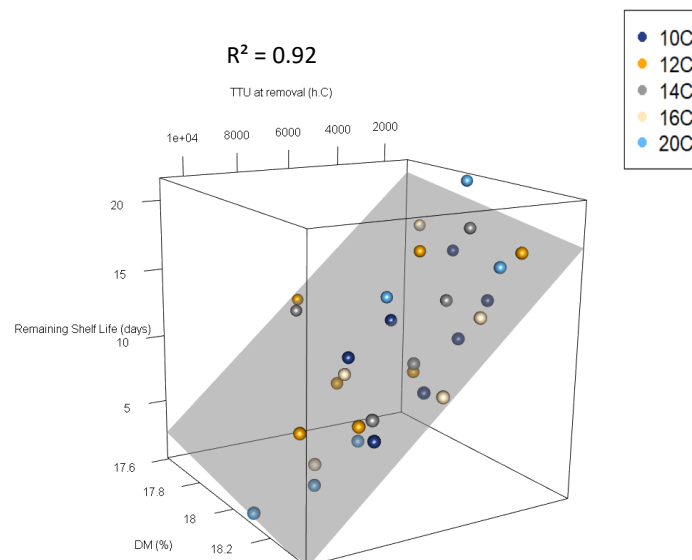


Figure 3. Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures, fruit dry matter (DM) and remaining shelf life (tray averages) in 'Honey Gold' mangoes from Katherine, NT.

² R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.



4. Summary and recommendations

The results from these trials indicated that 'Honey Gold' fruit harvested from Darwin orchard had a big issue with body rot, resulting in shorter fruit shelf life as compared with Katherine fruit. Treating fruit with ethylene shortened fruit shelf life (1.3-3 days). There was no chilling injury fruit found at either 10 °C or 12°C after 28 days. There was a strong relationship between TTU and remaining shelf life which suggests model can be used to predict fruit shelf life under varied supply chain conditions.

Further trials will be needed to confirm current findings and explore what causes body rot for Darwin fruit.

5. Acknowledgments

We thank growers for supplying fruit for trials and for their technical advice and support. We acknowledge Sohail Mazhar, Alan Niscioli, Salman Quddus and Saeeda Taghadimo-Saberi from the Northern Territory Department of Industry Trade and Tourism plus Lawrence Smith from the Queensland Department of Agriculture and Fisheries for assistance in managing trials and data collection.

Appendix 53

‘Honey Gold’ mango simulation trials report 2022/23b

Predicting the shelf life of 'Honey Gold' mango fruit

A 2022/23 season summary report

Hung Duong, Lawrence Smith, Pip Bryant and Andrew Macnish

Department of Agriculture and Fisheries

1. Introduction

The Serviced Supply Chains II (AM21000) project is a new RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2022/23 mango season with 'Honey Gold' from farm A near Townville. The main objectives of the trials were to generate preliminary data sets to develop fruit shelf life prediction models for 'Honey Gold' mango under varied supply chain conditions and to explore chilling temperature threshold.

2. Materials and methods

Commercially mature (e.g. dry matter $\approx 18\%$) 'Honey Gold' mango fruit were sourced for trial during the 2022/23 season. Fruit were harvested from farm A near Townville, Northern Queensland. Fruit were destemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby pack shed within 24 hours of harvest. The fruit were treated with a fungicide, sorted by size and quality, and packed into cardboard tray. After that the fruit were transported to Brisbane the same day by air freight, then transported by car at 22°C to a laboratory near Nambour, a distance of about 100 km.

Upon arrival at the laboratory, near-infrared spectroscopy (NIR) was measured on all trial and dry matter (DM) fruit as an index of DM content. NIR was measured using a Felix F-750 Quality Meter, based on a general mango dry matter model (generated by CQU). NIR predicted dry matter was measured on 2 sides of each fruit, near the cheek centre. The fruit were grouped into DM categories that differed by 0.5% DM eg 14.6 – 15 etc. These categorised fruit were then assigned randomly and evenly to treatment trays (ten fruit per tray). This is to make sure that every tray contains a normal distribution of the DMs in the population supplied. The trays were placed to storage treatments (**Table 1**). Relative humidity (RH) was maintained at 85-90% during cold treatment.

The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL). After removal from different storage temperatures, fruit was kept at 20°C plus 65% RH until they reached ESL. Fruit quality (weight loss, skin color, firmness) was recorded at intake and cold removal. Fruit firmness and skin defects (stem-end rot, body rot, under-skin browning, and chilling injury) were checked every 2 days. The fruit was considered to reach ESL when it was either oversoft (<38 TAD or firmness $<4\text{N}$), developed rots, or was rated 'extremely poor' in visual appeal.

Table 1. Time x temperature matrix used to simulate supply chain handling of 'Honey Gold' mango fruit.

Temp. (°C)	Removal time (days) to ongoing 20°C storage								
	0	4	8	12	16	20	24	28	32
8		X	X	X	X	X	X	X	X
10		X	X	X	X	X	X	X	X
12		X	X	X	X	X	X	X	
14		X	X	X	X	X			
16		X	X	X	X	X			
20	X,X	X	X	X	X	X			

X trays (10 fruit/tray) were removed from the cold storage and held at 20°C plus 65% RH

Blue shaded area was for time x temp matrix

Green area was for chilling injury examination

3. Results

Weight loss, skin colour and fruit firmness

Fruit stored at 16°C and lower temperature lost 2.8% its weight by the end of cold storage whereas fruit held at 20°C lost 9.6% after 20 days (data not shown). Skin colour of HG mangoes reached colour stage between 5 and 6 after 16 days at 14°C, 16°C and 20°C (data not shown). Changes in firmness associated with ripening occurred more rapidly as storage temperatures increased (**Figure 1**). Firmness of fruit held at 8°C remained rubbery after 32 days while those kept at 10°C and 12°C were at sprung. As temperatures increased from 14°C to 20°C, the rate of softening gradually increased. For example, fruit stored at 14°C and 16°C reached firm soft after 20 days whilst those kept at 20°C reached the end of shelf life (oversoft stage) after 20 days.

Shelf life

Fruit picked from Bowen orchard had an average dry matter (DM) of 18% at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 20 days from harvest to ESL (**Table 2**). Fruit with the longest postharvest life of 43.1 days were those stored at 10°C for 32 days prior to transfer to 20°C. In general, total fruit life was progressively extended by longer durations at cooler storage temperatures, for except 8°C storage. Moderate severity of chilling injury (CI) was found on fruit stored at 8°C for 24 days with 40% incidence. CI became more severe after 32 days at 8°C. No CI was found on the fruit kept at 10°C or 12°C for either 28 or 32 days.

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 3**. Fruit RSL was related to storage temperature and time. In general, RSL decreased with longer storage time. Storage at 10°C was typically associated with the greatest RSL. The percentage of fruit reaching ESL due to oversoft was 96.5%. Other reasons attributing to ESL include chilling injury (1.8%) and stem end rot (1.5%).

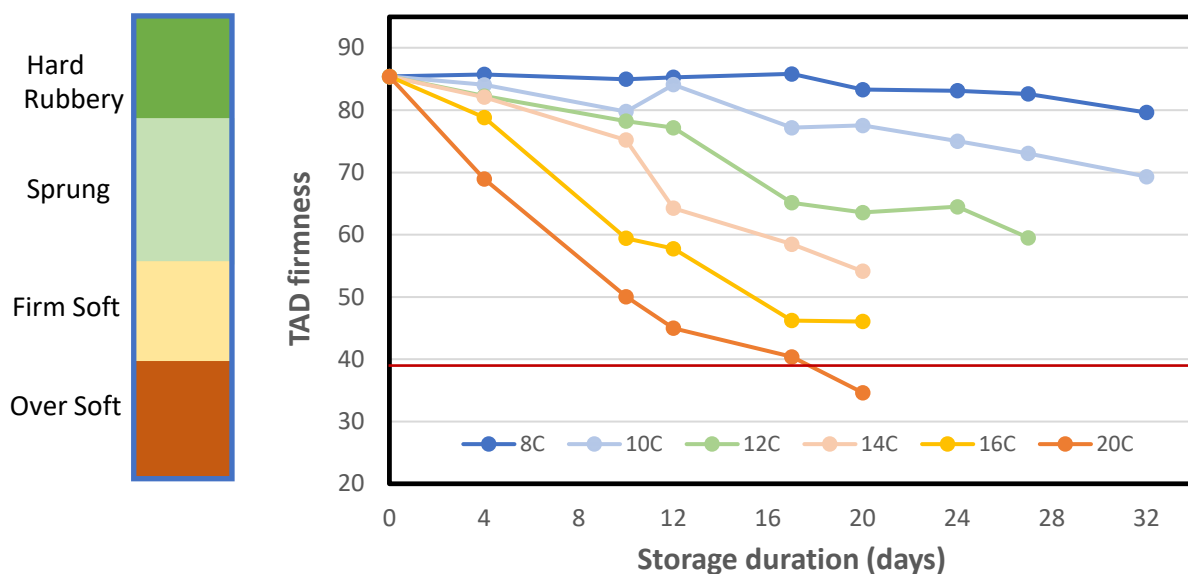


Figure 1: Firmness changes in 'Honey Gold' mangoes harvested from farm A during storage at various temperatures. The red line indicated fruit firmness cutoff when they are oversoft.

Table 2. Average postharvest life (days) since harvest for 'Honey Gold' mango fruit picked from farm A and stored at different temperatures to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C							
	4	10	12	17	20	24	27	32
8	20.2	24.1	26.7	30.1	31.9	36	41.6	40.7
10	19.6	23.6	25.7	29.2	30.1	35.8	36.9	43.1
12	18.8	23.8	25.5	28.1	30.6	33.9	36.6	
14	21.2	22.2	23.2	26.5	27.4			
16	18.6	20.1	19.6	20.8	24.2			
20	19.7	19.9	18.3	19.7	20			

Table 4. Heat map of average of remaining shelf life of 'Honey Gold' mango fruit picked from farm A and held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (days) / Temp (°C)		Average of residual shelf life at 20°C (days) after storage								
		0	4	10	12	17	20	24	27	32
8	20		16.2	14.1	14.7	13.1	11.9	12	14.6	8.7
10			15.6	13.6	13.7	12.2	10.1	11.8	9.9	11.1
12			14.8	13.8	13.5	11.1	10.6	9.9	9.6	
14			17.2	12.2	11.2	9.5	7.4			
16			14.6	10.1	7.6	3.8	4.2			
20			15.7	9.9	6.3	2.7	0			

Shelf-life models

'Honey Gold' time x temperature trials harvested from farm A, NQ captured great quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) showed an impressive linear regression ($R^{21}=0.92$, Figure 2). Such strong relationships will

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

be instrumental in guiding the development of models to predict the response of fruit from different districts under variable supply chain conditions.

In predicting shelf life, we have considered DM as another independent variable (**Figure 3**). We found that there was a strong relationship between DM, TTU and fruit shelf life. It means that if fruit with lower DM and exposed to the same TTU, they will have a longer shelf life compared to those having higher DM.

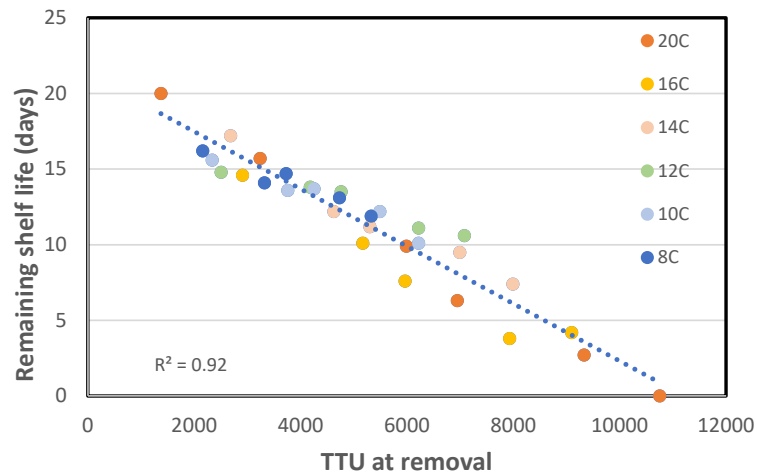


Figure 2. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from farm A.

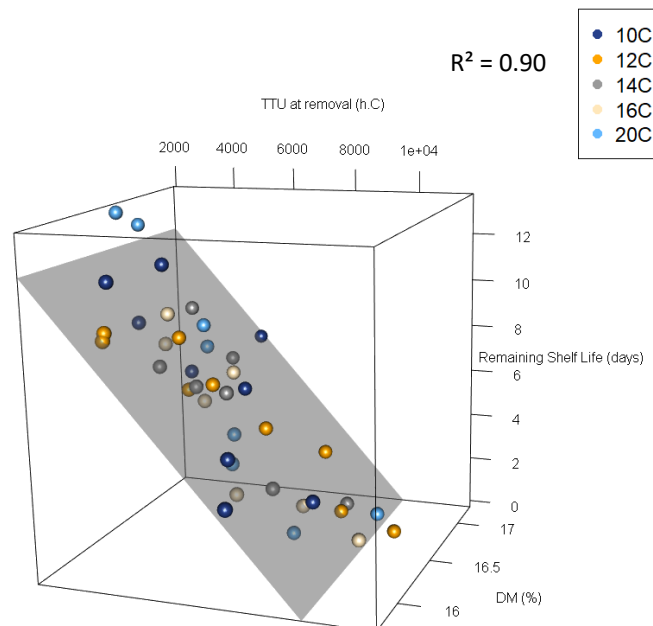


Figure 3. Relationship between temperature time unit (TTUs) from harvest and during storage at various temperatures, fruit dry matter (DM) and remaining shelf life (tray averages) in 'Honey Gold' mangoes from farm A, NQ.



4. Summary and recommendations

The results from current study indicated that 'Honey Gold' fruit harvested from farm A had a very good quality with minimal skin defects (stem-end rot and body rot). Fruit with the longest postharvest life of 43.1 days were those stored at 10°C for 32 days prior to transfer to 20°C. CI was found on the fruit stored at 8°C for 24 days, but no CI fruit was observed at either 10 °C or 12°C after 28 or 32 days. There was a strong relationship between TTU and remaining shelf life which suggests model can be used to predict fruit shelf life under varied supply chain conditions.

Further trials will be needed to confirm current findings, especially chilling injury threshold temperature

5. Acknowledgments

We thank grower for supplying fruit for trial and for their technical advice and support. We acknowledge John Archer and Minh Nguyen from the Queensland Department of Agriculture and Fisheries for assistance in managing trials and data collection.

Appendix 54

‘Honey Gold’ mango simulation trials report 2022/23c



Predicting the shelf life of 'Honey Gold' mango fruit

A 2022/23 season summary report

Hung Duong, John Archer, Minh Nguyen, and Andrew Macnish, Department of Primary Industries

Summary

Forty six trays of count 12 mature-green 'Honey Gold' fruit from farm A near Mareeba, NQ were sampled from the packhouse in January 2023. The fruit were transported to the DAF laboratory in Nambour within 72 hours of harvest. Fruit were stored at a range of temperatures (8, 10, 12, 14, 16, 20°C) and times (0, 4, 8, 12, 16, 20, 24, 28, 32 days) to simulate potential domestic and export supply chain conditions. Following storage, fruit were allowed to ripen at 20°C. The end of shelf life was recorded when fruit became oversoft or lost visual appeal due to skin defects. Key observations included:

- Fruit had an average dry matter content of 15.9% (range: 13.9 to 18.5%) at harvest.
- Total postharvest life from harvest to end of shelf life was progressively extended by longer durations at cooler storage temperatures of 8, 10 and 12°C.
- No chilling injury developed on fruit at 8, 10 or 12°C after 32 days of cold storage.
- Fruit maintained at 8 and 10°C remained relatively firm during storage, while those at 12 and 14°C displayed moderate rates of softening.
- Fruit held between 8 and 14°C consistently exhibited at least 8 days of residual shelf life at 20°C.
- Fruit softening and the loss of residual shelf life occurred more rapidly as storage temperatures increased, particularly at 16 and 20°C.
- The end of shelf life was associated with fruit that were oversoft (73%) or with rots (26%).
- Ethylene treatment accelerated uniform ripening by 2.9 days relative to non-treated fruit.
- Fruit shelf life was very closely related to cumulative storage temperature x time units.
- A model was developed to predict fruit shelf life under varied supply chain conditions.

Further trials will be needed to confirm these findings and include consideration of other production and harvest factors. The predictive models may support a move away from 'first-in, first-out' marketing towards delivering more consistent fruit quality to consumers.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2022/23 mango season with 'Honey Gold' fruit from Mareeba, North Qld. The main objectives of the trial were to generate data sets to develop preliminary fruit shelf life prediction models for 'Honey Gold' mango under varied supply chain conditions and to explore chilling temperature thresholds.

2. Materials and methods

Commercially mature (e.g. >13.9% dry matter content) 'Honey Gold' mango fruit were harvested from the farm A near Mareeba in north Queensland on 2 January 2023. Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby packhouse within 24 hours of harvest. On the morning of 4 January 2023, the fruit were run across a commercial pack line, dipped in fungicide at the prescribed rate, sorted by size and quality, and packed into cardboard trays. Forty-six trays of count 12 fruit from batch 1 Item No 4965144/737271/76546 were sampled from the end of the pack line. The sample trays were transported to Cairns in an air-conditioned (22°C) car and then to Brisbane by air freight within 12 hours of packing. The trays were then brought to the DAF laboratory near Nambour, a distance of about 100 km, in a car at 22°C.

On 6 January, the dry matter (DM) content of individual fruit was determined using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general mango DM model generated by Central Queensland University. NIR spectra were recorded on 2 sides of each fruit, near the cheek centre. The fruit were grouped into different categories based on their DM. The categorised fruit were then assigned evenly to treatment trays with ten replicate fruit per tray. This ensured that every tray contained a normal distribution of DM in the population supplied. The trays were transferred to storage treatments within 96 hours of harvest (**Table 1**). Relative humidity (RH) was maintained at 85-90% during cold storage.

The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL) using a HOBO data logger. After removal from different storage temperatures, fruit were kept at 20°C plus 65% RH until they reached ESL. Fruit quality (weight loss, skin color, firmness) was recorded at laboratory intake and removal from storage. Fruit firmness and skin defects (stem-end rot, body rot, under-skin browning, and chilling injury) were checked every 2 days. The fruit was considered to reach ESL when it was either oversoft (firmness of <38 Shore units or <4 N), developed rots, or was rated 'extremely poor' in visual appeal.

Table 1. Time x temperature matrix used to simulate supply chain handling of ‘Honey Gold’ mango fruit.

Temp. (°C)	Removal time (days) to ongoing 20°C storage								
	0	4	7	12	17	19	24	28	32
8		X	X	X	X	X	X	X	X
10		X,X	X,X	X	X	X	X	X	X
12		X,X	X,X	X	X	X	X	X	X
14		X,X	X,X	X	X	X			
16		X,X	X,X	X	X	X			
20	X,X,X	X,X	X,X	X	X	X			

X trays (10 fruit/tray) were removed from the cold storage and held at 20°C plus 65% RH

X trays were removed from the cold storage and treated with 100 pm ethylene at 18°C for 2 days, then held at 20°C

Blue shaded area was for time x temp matrix

Green area was for chilling injury examination

3. Results

Weight loss, skin colour and fruit firmness

Fruit stored at 8°C, 10°C, 12°C, 14°C, 16°C and 20°C lost 1.7%, 1.8%, 2.3%, 2.3%, 2.6% and 10.2% weight after 19 days, respectively. Weight loss from fruit kept at 8°C, 10°C and 12°C increased to 4.0%, 3.2% and 4.9%, respectively, after 32 days of storage. Fruit reached skin colour stages 5 to 6 after 17 days at 16°C and 20°C (data not shown) whereas those stored at 12°C and 14°C displayed colour stage 3 to 4 at the end of cold storage. The skin colour of fruit kept at 8°C and 10°C changed little during storage. Changes in firmness associated with ripening occurred more rapidly as storage temperatures increased (**Figure 1**). Firmness of fruit held at 8°C remained rubbery after 32 days while those kept at 10°C, 12°C and 14°C were sprung by the end of cold storage. As temperatures increased from 16°C to 20°C, the rate of softening gradually increased. Fruit stored at 16°C and 20°C reached firm soft after 17 days.

Shelf life

Fruit had an average dry matter (DM) of 15.9% (range: 13.9 to 18.5%) at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 20.1 days from harvest to ESL (**Table 2**). In general, total fruit life was progressively extended by longer durations at cooler storage temperatures. Fruit with the longest postharvest life of 46.5 days were stored at 8°C for 32 days prior to transfer to 20°C. No chilling injury was found on the fruit kept at 8°C, 10°C or 12°C after 32 days of cold storage.

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 3**. Fruit RSL was related to storage temperature and time. In general, RSL decreased with longer storage time and at temperatures above 10 or 12°C. Storing fruit at 8°C and 10°C was typically associated with the greatest RSL. The percentage of fruit reaching ESL due to oversoft was 73%. Other reasons attributing to ESL include stem end rot (23%), body rot (3%) and shrivel (1%).

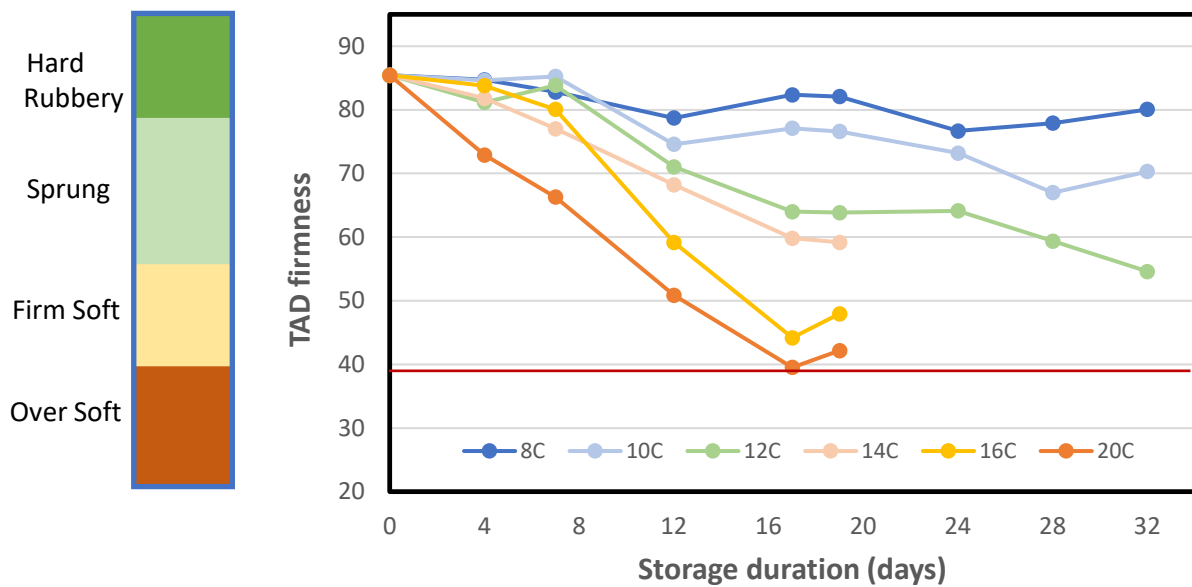


Figure 1: Changes in firmness of 'Honey Gold' mangoes during storage at various temperatures. The red horizontal line indicates the cutoff for when fruit are oversoft.

Table 2. Average postharvest life (days) since harvest for 'Honey Gold' mango fruit stored at different temperatures to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C							
	4	7	12	17	19	24	28	32
8	22.1	19.9	26.3	32.4	34.1	36.8	43.5	46.5
10	19.1	24.1	25.1	30.8	33.1	36.7	37.8	41.2
12	19.2	25.9	24.7	27.7	28.7	34.4	36.9	40.4
14	21.9	22.4	26.4	26.3	29.5			
16	19.1	22.7	23.6	21	24.5			
20	18.8	21.6	20.2	19.9	22.2			

Table 3. Heat map of average of remaining shelf life of 'Honey Gold' mango fruit when held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (days) \ Temp (°C)		Average of residual shelf life at 20°C (days) after storage								
		0	4	7	12	17	19	24	28	32
8	17.6		18.1	12.9	14.3	15.4	15.1	12.8	15.5	14.5
10			15.1	17.1	13.1	13.8	14.1	12.7	9.8	9.2
12			15.2	18.9	12.7	10.7	9.7	10.4	8.9	8.4
14			17.9	15.4	14.4	9.3	10.5			
16			15.1	15.7	11.6	4	5.5			
20			14.8	14.6	8.2	2.9	3.2			

Effect of ethylene treatment on fruit shelf life

As shown in **Table 5**, fruit treated with ethylene reached the firm soft stage after 4.4 days at 20°C which is 1.3 days faster than non-ethylene-treated fruit. As a result, the average shelf life of ethylene-treated fruit was 2.9 days shorter than those that were non-treated.

Table 5. Effect of ethylene treatment on the shelf life of ‘Honey Gold’ fruit following storage at different temperatures and durations.

Storage temperature (°C)	Storage duration (day)	Days to firmsoft at 20°C		Remaining shelf life (day)		Difference in shelf life (day)
		No C ₂ H ₄	C ₂ H ₄	No C ₂ H ₄	C ₂ H ₄	
10	4	5.7	4.8	15.1	14.9	0.2
	7	6.5	4.8	17.1	11.5	5.6
12	4	5.5	4.2	15.2	13.2	2.0
	7	6.4	5.3	18.9	14.0	4.9
14	4	5.6	4.3	17.9	13.3	4.6
	7	6.1	4.0	15.4	13.1	2.3
16	4	5.2	3.8	15.1	14.3	0.8
	7	5.9	5.0	15.7	11.8	3.9
20	0	6.9	5.8	17.6	16.3	1.3
	4	4.1	3.1	14.8	12.9	1.9
	7	4.9	3.8	14.6	10.4	4.2
Ave		5.7	4.4	16.1	13.2	2.9

Shelf-life models

The ‘Honey Gold’ time x temperature trial showed how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) produced a good linear regression ($R^{21}=0.8$, Figure 1).

In predicting shelf life, we considered DM over the range of 13.9% to 18.5% as another independent variable. We found that there was a strong relationship between DM, TTU and fruit shelf life (data not shown). It means that if fruit with lower DM were exposed to the same TTU, they will have a longer shelf life compared to those having higher DM.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

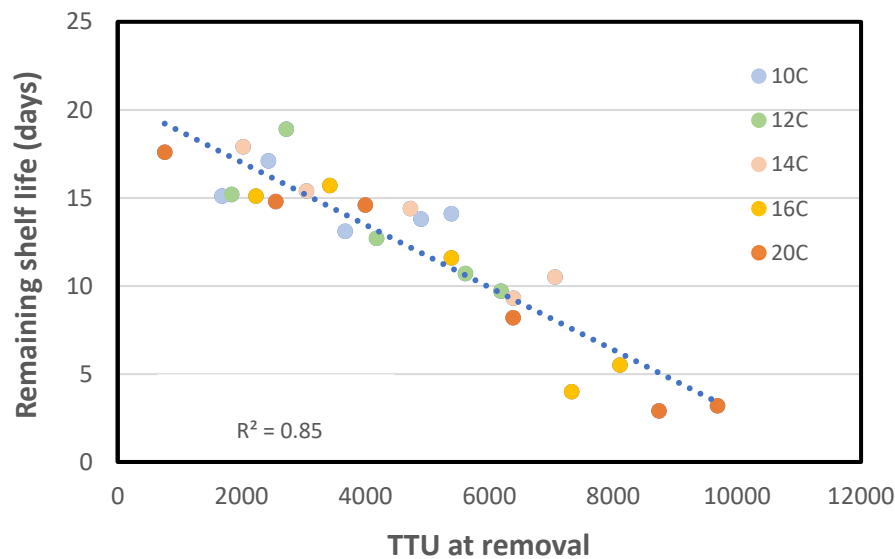


Figure 2. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from Mareeba.

4. Summaries and recommendations

The current study demonstrated that 'Honey Gold' fruit harvested from an orchard near Mareeba had an elevated incidence of stem-end rot (23%) as fruit ripened. Fruit with the longest postharvest life of 46.5 days were those stored at 8°C for 32 days prior to transfer to 20°C. This fruit had a 15-day residual shelf life at 20°C. No chilling injury symptoms were observed at 8°C, 10°C or 12°C after 32 days. Nonetheless, 'Honey Gold' mangoes are not currently recommended to be held at less than 12°C. There was a strong relationship between TTU and remaining shelf life which suggests a model can be used to predict fruit shelf life under varied supply chain conditions. Further trials will be needed to confirm current findings and the robustness of models to predict accurately across different fruit batches.

5. Acknowledgments

We thank grower for supplying packed fruit for the trial and for his technical advice and support. We acknowledge Lawrence Smith from the Queensland Department of Primary Industries for assistance in managing the trial and data collection.

Acknowledgment: The Serviced Supply Chains II project (AM21000) is funded by the Hort Innovation Frontiers Fund, Avocado and Strawberry research and development levy, and contributions from the Australian Government, with co-investment from the Department of Primary Industries, Queensland (DPI), Department of Energy, Environment and Climate Action, Victoria (DEECA), Department of Agriculture and Fisheries, Northern Territory (DAF), Department of Primary Industries and Regional Development, Western Australia (DPIRD), Pinata Farms Pty Ltd and Summerfruit Australia Ltd. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Appendix 55

‘Honey Gold’ mango simulation trials report 2022/23d



Predicting the shelf life of 'Honey Gold' mango fruit

A 2022/23 season summary report for Simpson Farms

Hung Duong and Andrew Macnish, Department of Agriculture and Fisheries

Summary

Forty trays of count 14 mature-green 'Honey Gold' fruit from farm A were sampled from the packhouse in January 2022. The fruit were transported to the DAF laboratory in Nambour within 48 hours of harvest. Fruit were stored at a range of temperatures (8, 10, 12, 14, 16, 20°C) and times (0, 4, 8, 12, 16, 20, 24, 28, 32 days) to simulate potential domestic and export supply chain conditions. Following storage, fruit were allowed to ripen at 20°C. The end of shelf life was recorded when fruit became oversoft or lost visual appeal due to skin defects. Key observations included:

- Fruit had an average dry matter content of 16.6% (range: 14.6 to 18.2%) at harvest.
- Total postharvest life from harvest to end of shelf life was progressively extended by longer durations at cooler storage temperatures, except at 8°C where chilling injury developed after 20 days.
- Storage at 10 and 12°C was optimal and associated with at least 6.3 days of residual shelf life at 20°C.
- Fruit softening and the loss of residual shelf life occurred more rapidly as storage temperatures increased, particularly at 14, 16 and 20°C.
- Treating fruit with ethylene gas accelerated uniform ripening by 2.7 days relative to non-treated fruit.
- Fruit shelf life was very closely related to cumulative storage temperature x time units.
- A model was developed to predict fruit shelf life under varied supply chain conditions.

Further trials will be needed to confirm these findings and include consideration of fruit harvest maturity and orchard block effects. The predictive models may support a move away from 'first-in, first-out' marketing towards delivering more consistent fruit quality to consumers.

1. Introduction

The Serviced Supply Chains II (AM21000) project is a RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2022/23 mango season with 'Honey Gold' fruit from Bundaberg. The main objectives of the trial were to generate data sets to develop preliminary fruit shelf life prediction models for 'Honey Gold' mango under varied supply chain conditions, to investigate the effect of ethylene treatment on fruit shelf life and to explore chilling temperature thresholds.

2. Materials and methods

Commercially mature (e.g. 14.6-18.5% dry matter content) 'Honey Gold' mango fruit were harvested from farm A near Childers in Central Queensland in February 2023. Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby packhouse within 24 hours of harvest. After that the fruit were run across a commercial pack line, dipped in fungicide at the prescribed rate, sorted by size and quality, and packed into cardboard trays. Forty trays of count 14 fruit were sampled from the end of the pack line. The trays were then brought to the DAF laboratory near Nambour, a distance of about 230 km, in a car at 22°C.

Upon arrival at the laboratory, near-infrared spectroscopy (NIR) was measured on all trial and DM fruit as an index of dry matter content. NIR was measured using a Felix F-750 Quality Meter, based on a general mango dry matter model (generated by CQU). NIR predicted dry matter was measured on 2 sides of each fruit, near the cheek centre. The fruit were grouped into DM categories that differed by 0.5% DM (e.g. 14.6 – 15.0). These categorised fruit were then assigned randomly and evenly to treatment trays (ten fruit per tray). This is to make sure that every tray contains a normal distribution of the DMs in the population supplied. The trays were placed to storage treatments (**Table 1**). Relative humidity (RH) was maintained at 85-90% during cold treatment.

Table 1. Time x temperature matrix used to simulate supply chain handling of 'Honey Gold' mango fruit.

Temp. (°C)	Removal time (days) to ongoing 20°C storage								
	0	4	8	12	16	20	24	28	32
8		X	X	X	X	X	X	X	X
10		X,X	X,X	X	X	X	X	X	X
12		X,X	X,X	X	X	X	X	X	X
14		X,X	X,X	X	X	X			
16		X,X	X,X	X	X	X			
20	X,X,X	X,X	X,X	X	X	X			

X trays (10 fruit/tray) were removed from the cold storage and held at 20°C plus 65% RH

X trays were removed from the cold storage and treated with 100 pm ethylene at 18°C for 2 days, then held at 20°C

Blue shaded area was for time x temp matrix

Green area was for chilling injury examination

The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL). After removal from different storage temperatures, fruit was kept at 20°C plus 65% RH until they reached ESL. Fruit quality (firmness) was recorded at intake and cold removal. Fruit firmness and skin defects (stem-end rot, body rot, under-skin browning, and chilling injury) were checked every 2 days. The fruit was considered to reach ESL when it was either oversoft (<38 TAD or firmness <4N), developed rots, or was rated 'extremely poor' in visual appeal.

3. Results

Fruit firmness

Changes in firmness associated with ripening occurred more rapidly as storage temperatures increased (**Figure 1**). Minimal softening occurred while fruit were stored at 8°C. As temperatures increased from 10°C to 20°C the rate of softening gradually increased. For example, fruit stored at 16°C and 20°C reached the end of shelf life (oversoft stage) after 16 and 20 days, respectively.

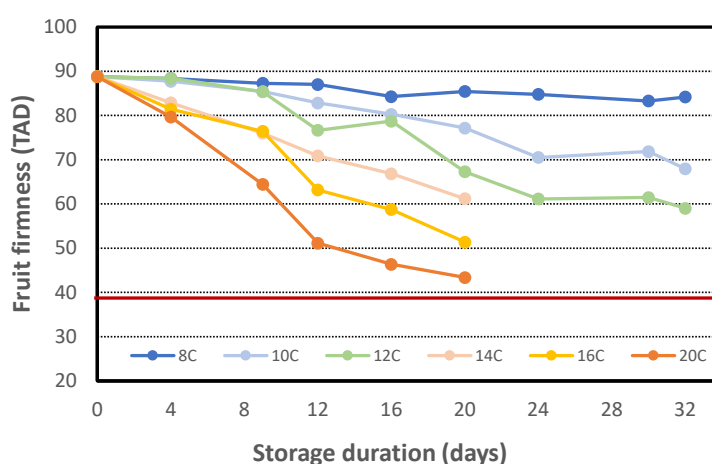


Figure 1: Changes in firmness of 'Honey Gold' mangoes during storage at various temperatures. The red horizontal line indicates the cutoff for when fruit are oversoft.

Shelf life

Fruit had an average dry matter (DM) of 16.6% at harvest. Fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 21.4 days from intake to ESL (**Table 2**). Fruit with the longest postharvest life of 38.3-40.4 days were those stored at 8°C, 10°C and 12°C for 32 days prior to transfer to 20°C. In general, total fruit life was progressively extended by longer durations at cooler storage temperatures. However, the fruit held at 8°C expressed chilling injury (CI) after 20 days of storage.

Table 2. Average postharvest life (days) since harvest for 'Honey Gold' mango fruit stored at different temperatures to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C							
	4	10	12	17	20	24	27	32
8	23.1	27	29.6	30	32.6	33.4	39.3	40.4
10	22.6	26.3	27	29.9	31	32.8	38.1	39.2
12	23.2	29.8	26.3	32.4	32	31.8	37	38.3
14	21.7	24.2	26	27.2	30.8			
16	20	22.8	23.8	24.3	27.4			
20	21	22.1	22.2	20.5	22.5			

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 3**. Fruit RSL was related to storage temperature and time. In general, RSL decreased with longer storage time and temperatures above 8°C. Fruit held at 10°C and 12°C did not develop CI and typically exhibited the greatest RSL after each storage period. The percentage of fruit reaching ESL due to oversoft and stem end rot was 54% and 33%, respectively. Other reasons attributing to ESL include body rot (11%), CI and shrivel (2%).

Table 3. Heat map of average of remaining shelf life of 'Honey Gold' mango fruit when held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage time (days) Temp (°C)	Average of residual shelf life at 20°C (days) after storage								
	0	4	9	12	17	20	24	27	32
8	20.3	19.1	18	17.6	14	12.6	9.4	9.3	8.4
10		18.6	17.3	15	13.9	11	8.8	8.1	7.2
12		19.2	20.8	14.3	16.4	12	7.8	7	6.3
14		17.7	15.2	14	11.2	10.8			
16		16	13.8	11.8	8.3	7.4			
20		17	13.1	10.2	4.5	2.5			

Effect of ethylene treatment on fruit shelf life

As shown in **Table 4**, fruit treated with ethylene after cold storage of 4 or 9 days reached firm soft stage after 3.4 days at 20°C which is 1.5 days faster than non-ethylene treated fruit. As a result, on average the shelf life of ethylene treated fruit was 2.7 days shorter than untreated fruit.

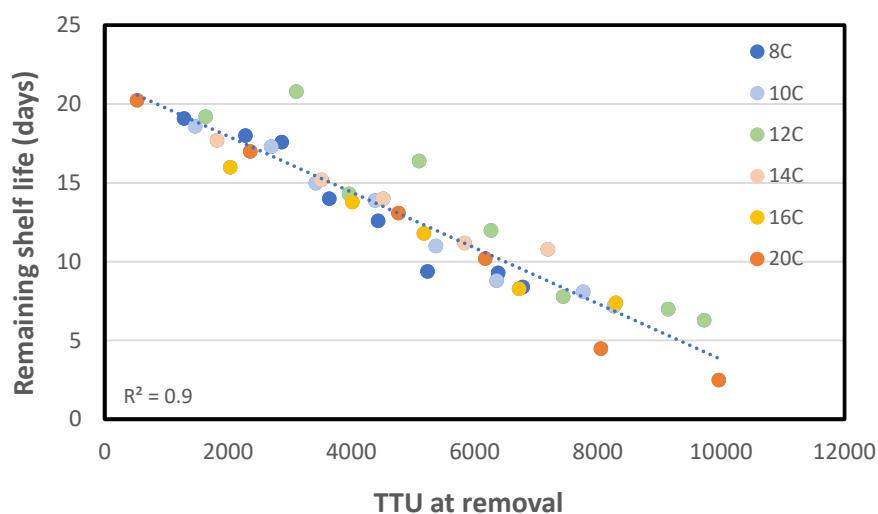
Table 4. Effect of ethylene (100 ppm, 18°C, 2 days) treatment on the shelf life of 'Honey Gold' fruit following storage at various temperatures for 0, 4 and 9 days.

Storage temperature (°C)	Storage duration (days)	Days to firmsoft at 20°C		Remaining shelf life (day)		Difference in shelf life (day)
		No C ₂ H ₄	C ₂ H ₄	No C ₂ H ₄	C ₂ H ₄	
10	4	8.6	7.0	18.6	14.9	3.7
	9	7.8	6.7	17.3	14.8	2.5
12	4	10.5	7.7	19.2	16.9	2.3
	9	8.8	6.1	20.8	16.0	4.8
14	4	8.4	6.8	17.7	14.7	3.0
	9	5.7	6.6	15.2	13.7	1.5
16	4	8.3	6.0	16.0	15.4	0.6
	9	6.3	5.4	13.8	12.7	1.1
20	0	10.6	8.9	20.3	16.3	4.0
	4	7.8	6.0	17.0	14.0	3.0
	9	2.9	2.4	13.1	9.4	3.7
AVE		7.8	6.3	17.2	14.4	2.7

Shelf-life models

'Honey Gold' time x temperature trials captured great quality data showing how storage conditions influence shelf life and fruit quality. The modelling of fruit shelf life using temperature x time units (TTUs) showed an impressive linear regression ($R^2=0.9$, **Figure 2**). Such strong relationships will be instrumental in guiding the development of models to predict the response of fruit from different districts under variable supply chain conditions.

Figure 2. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from Childers.



4. Summary and recommendations

The results from this trial indicated that 'Honey Gold' fruit had an elevated incidence of stem end rot as fruit ripened. Storage at 10 and 12°C was optimal and associated with at least 6.3 days of residual shelf life at 20°C even after storage for 32 days. Fruit developed chilling injury after storage at 8°C for 20 days. 'Honey Gold' mangoes are not currently recommended to be held at less than 12°C and further trials are required to confirm these findings. Treating fruit with ethylene after cold storage shortened the time for fruit to reach ripe by 2.7 days. There was a strong relationship between TTU and remaining shelf life which suggests model can be used to predict fruit shelf life under varied supply chain conditions. Further trials will be needed to confirm the robustness of models to predict accurately across different fruit batches and orchard blocks.

5. Acknowledgments

We thank growers for supplying fruit for trials and for their technical advice and support. We acknowledge Andy Mead, Lawrence Smith and Pip Bryant from the Queensland Department of Agriculture and Fisheries for assistance in managing trials and data collection.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

Appendix 56

‘Honey Gold’ mango simulation trials combined report 2023/24



Predicting the shelf life of 'Honey Gold' mango fruit

A 2023/24 season summary report

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Summary

Mature-green 'Honey Gold' mango fruit were sourced from orchards near Darwin and Katherine in the Northern Territory in November 2023 and from farm A and B near Childers in central Queensland in January 2024. The fruit were transported to the NT DITT and QLD DAF laboratories within 48 to 72 hours of harvest. The fruit quality and shelf life response to different domestic and export supply chain temperatures (e.g. 8, 10, 12, 14, 16, 20°C) and times (0, 4, 8, 12, 16, 20, 24, 28, 32 days) was quantified. Sub-samples of fruit were regularly removed from storage and held at 20°C and 65% RH to evaluate remaining shelf life. The influence of ethylene, irradiation and surface coating treatments on fruit quality was also assessed. Key observations included:

- Fruit had an average dry matter content of 14.9-18.7% at harvest.
- There was a strong relationship between cumulative time temperature units (TTU) during postharvest storage and the remaining shelf life of fruit from all orchards.
- In general, fruit from Darwin, Katherine and Childers stored best at 12°C. The fruit exhibited at least 5 to 8 days of shelf life at 20°C even after storage for 25, 28, 30 and 32 days.
- Holding fruit at 14, 16 and 20°C increased rates of softening and progressively reduced remaining shelf life by 3 to 9 days relative to those stored at 12°C.
- Fruit developed mild chilling injury when stored at 8°C for 8 days and at 10°C for 32 days, with moderate to severe symptoms developing after 20 to 32 days at 8°C. Katherine fruit were sensitive to developing under-skin browning when maintained at 10°C.
- Ethylene gas treatment accelerated uniform fruit ripening at 20°C by about 3 to 5 days, as compared with the non-treated controls. Holding ethylene-treated fruit at 12, 14 or 16°C for 7 days instead of the standard 20°C delayed rates of ripening and extended shelf life by 4 to 7 days.
- Coating green fruit with a proprietary solution extended shelf life by 3 days relative to non-coated controls but prevented development of a full yellow skin colour at ripe.
- Gamma irradiation of partially ripe (i.e. 10 to 50% yellow skin) fruit with 500 Gy did not significantly affect shelf life and was associated with reduced rots.
- Under-skin browning was higher in fruit transported by truck than those air-freighted at similar temperatures.

The trial results suggest that mathematical models could be developed and used to predict fruit shelf life under a range of supply chain conditions. Further trials will be needed to confirm and/or refine the coating and irradiation treatment effects.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and updated handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers trial work completed during the 2023/24 mango season with 'Honey Gold' fruit from the Northern Territory (NT) and central Queensland (Qld) production regions. The main objectives of the trial were to generate data sets to develop fruit shelf life prediction models for 'Honey Gold' mango under varied supply chain conditions, to investigate the effect of ethylene, surface coating and irradiation treatments on fruit shelf life, and to explore chilling temperature thresholds.

2. Materials and methods

Plant material

Commercially mature 'Honey Gold' mango fruit of $\geq 15\%$ dry matter (DM) content were harvested from the farm A near Darwin and Katherine in the NT on 23 and 29 November 2023, respectively (**Table 1**). An additional batch of fruit were harvested from the Katherine orchard on 3 December 2024 for an air vs road freight trial. 'Honey Gold' fruit were also harvested from farm A and B near Childers in Central Qld on 9 and 17 January 2024, respectively. The orchards were selected for their geographical distribution and different soil types.

Table 1. Details of trials, fruit harvesting locations, date and dry matter (DM) content.

Trial	Trial description	Orchard	Harvest date	DM (%)	
				Mean	Std dev
1	Time x temperature, ethylene	Darwin, NT	23/11/2023	16.0	1.1
2	Time x temperature, ethylene	Katherine, NT	29/11/2023	17.3	1.3
3	Air vs road freight, chilling	Katherine, NT	03/12/2023	18.7	1.1
4	Time x temperature, ethylene, irradiation, coating	Farm A, CQ	09/01/2024	14.9	0.9
5	Time x temperature, ethylene, irradiation, coating	Farm B, CQ	17/01/2024	15.3	0.7

Fruit processing

Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby packhouse within 24 hours of harvest. The fruit were run across a commercial pack line, dipped in fungicide at the prescribed rate, sorted by size and quality, and packed into cardboard trays. Trays with fruit of count 14 size were sampled from the end of the pack line. Darwin and Katherine fruit were transported to a laboratory near Darwin in an air-conditioned car at approximately 22–25°C within 1 and 5 hours, respectively. Childers fruit were brought to a laboratory near Nambour, a distance of about 230 km, in a car at 22°C.

On arrival at each laboratory, the DM content of individual fruit was determined using near-infrared (NIR) spectroscopy with a Felix F-750 Quality Meter, based on a general mango DM model generated by Central

Queensland University. NIR spectra were recorded on 2 sides of each fruit, near the cheek centre. The fruit were grouped into different categories based on their DM. The categorised fruit were then assigned evenly to treatment trays with ten replicate fruit per tray. This ensured that every tray contained a normal distribution of DM in the population supplied. A random selection of fruit were also assessed for DM content using the traditional oven-dried destructive method. Where necessary, a correction factor was applied to the NIR readings across the entire trial. Forty-two trays were transferred to different temperature x time storage treatments within 2-3 days of harvest (**Table 2**). Relative humidity (RH) was maintained at 85-90% during cold storage. After cold storage, the fruit were held at 20°C and 65% RH to monitor the shelf life. The remaining trays were used for coating, irradiation, and ethylene treatments.

Table 2. Time x temperature matrix used to simulate supply chain handling of 'Honey Gold' mango fruit.

Temp. (°C)	Removal time (days) to ongoing 20°C storage								
	0	4	8	12	16	20	24	28	32
8		X	X	X	X	X	X	X	X
10		X	X	X	X	X	X	X	X
12		X	X	X	X	X	X	X	X
14		X	X	X	X	X			
16		X	X	X	X	X			
20	XX	X	X	X	X	X			

Blue shaded area was for time x temp matrix

Green area was for chilling injury examination

Ethylene treatments

In trials 1 and 2 from Darwin and Katherine, respectively, an additional tray of fruit was stored at 10, 12, 14, 16 and 20°C for 4 and 8 days prior to removal and treatment with 100 ppm of ethylene at 18°C for 2 days in line with commercial practice. After ethylene treatment, the fruit were maintained at 20°C and 65% RH until the end of shelf life.

In trial 4 from Childers, 5 trays from West Farm were held at 20°C for 4 days prior to exposing to ethylene gas as described above. After ethylene treatment, the fruit were stored at 20, 16, 14 or 12°C for 7 days before transfer to 20°C for shelf life evaluation. In trial 5 from Childers, a sub-sample of 4 trays from Promised Land were held at 20°C and 12°C for 4 days and treated with ethylene, then stored at 20, 16, 14 and 12°C for 7 days prior to shelf life evaluation at 20°C (**Figure 1**). As a reference, a single tray from trials 4 and 5 was treated with ethylene at intake and kept at 20°C along with non-treated fruit.

Trial	Pre-ethylene Storage	Ethylene treatment	Post-ethylene storage	Final storage (retail simulation)
1,2	10, 12, 14, 16, 20°C for 0, 4 and 8 days	100 ppm, 18°C for 2 days	-	20°C until end of shelf life
3	20°C for 0 and 4 days	0 or 100 ppm, 20°C for 2 days	12, 14, 16, 20°C for 7 days	20°C until end of shelf life
4	12 and 20°C for 0 and 4 days	0 or 100 ppm, 20°C for 2 days	12, 14, 16, 20°C for 7 days	20°C until end of shelf life

Figure 1. Ethylene treatment details design for trials 1, 2, 4 and 5.

Irradiation treatments

The effects of gamma irradiation on 'Honey Gold' mangoes were determined using Childers fruit from trials 4 and 5. Following arrival at the Nambour laboratory, four trays of fruit were held at 20°C for 2-3 days to



obtain skin color score of 2 to 3 (i.e. 10 to 50% yellow). The fruit were transported in an air-conditioned car to Steritech Ltd., at Narangba Queensland for irradiation treatment. Briefly, the trays of fruit were placed on the top layer of a pallet consisting of other fresh produce scheduled for gamma irradiation treatment. The pallet entered the ambient temperature (i.e. 28°C) irradiation chamber via a conveyor and orbited the Cobalt-60 irradiation source for even dose distribution. After a defined period of 1 hour, the pallet exited the irradiation chamber at which point dosimeters were removed and read to record the irradiation dose received ($\approx 500\text{Gy}$). This dose was consistent with an export protocol. Once completed, the samples were brought back to the DAF laboratory. Two irradiated trays were stored at 20°C whereas other trays were kept at 12°C for 12 days.

Surface coating treatments

Four trays of Childers fruit from trials 4 and 5 were coated with a proprietary Akorn Technologies solution. Briefly, two fruit were put into a ziplock bag and a small amount of liquid was added to the bag. The bag was closed and the fruit was agitated. Once the fruit was fully covered with the solution, it was removed from the bag and gently wiped using a wet microfiber cloth to make sure there was uniform coat and no visible drops left on the fruit surface. Thereafter, the fruit were dried using a blow dryer at the warm setting for 30 seconds. Two trays were stored at 20°C and the other two trays were kept at 12°C for 12 days.

Two non-treated trays from the time x temperature matrix at 20°C and 12°C were used for comparison with coated and irradiated fruit. After cold removal, the fruit were held at 20°C to assess fruit quality.

Effect of transport mode on sensitivity to under skin browning at low temperature

A hundred and forty fruit harvested from Katherine for trial 3 were transported in an air-conditioned car to Darwin airport and then air-freighted to Brisbane airport. The fruit were taken to the DAF laboratory near Nambour on following day and held at 15-16°C. The fruit were from the same batch as a commercial consignment that was transported in a refrigerated truck at 16°C from Katherine to Brisbane, Queensland. Once road-transported fruit arrived at DAF laboratory, they were placed at 8, 10, 12°C for 32 days together with the air-freight fruit.

Fruit quality assessments

The air temperature adjacent to fruit was monitored from harvest to the end of shelf life (ESL) using a HOBO data logger. After removal from different storage temperatures, fruit were kept at 20°C plus 65% RH until they reached ESL. Fruit quality (weight loss, skin color, firmness) was recorded at laboratory intake and removal from storage. Fruit firmness and skin defects (stem-end rot, body rot, under-skin browning, and chilling injury) were checked every 2 days. The fruit was considered to reach ESL when it was either oversoft (firmness of <38 Shore units or <4 N), developed rots, or was rated 'extremely poor' in visual appeal.

3. Results

3.1 'Honey Gold' fruit from Darwin

Fruit firmness

As storage temperatures increased, the changes in firmness associated with ripening occurred more rapidly (see **Figure 2**). At 10°C, fruit softening was minimal. However, as temperatures rose to 20°C, the rate of softening increased progressively. For instance, fruit stored at 16°C and 20°C reached the over-soft stage, marking the end of shelf life, after 29 and 23 days, respectively. This stage is identified where the extrapolated fit lines for these temperatures intersect the firmness cut-off line (firmness < 38).

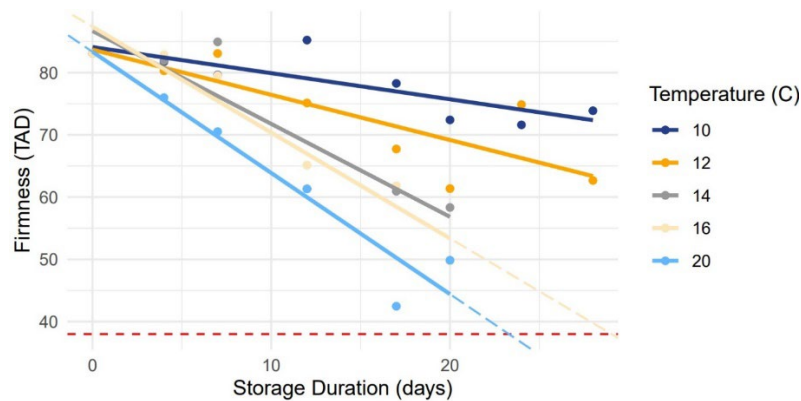


Figure 1. Firmness changes in ‘Honey Gold’ mangoes harvested from Darwin orchard during storage at various temperatures. The red line indicated fruit firmness cut off when they are over-soft.

Effect of ethylene treatment on fruit shelf life

As shown in **Table 3**, the HG fruit treated with ethylene reached the firm soft stage after 10.9 days at 20°C, which is approximately 5 days quicker than the fruit not treated with ethylene. This indicates that ethylene treatment accelerated the ripening process by about 4.8 days compared to non-treated fruit. Additionally, lower values of standard deviation (SD) for ethylene-treated fruits suggest that these fruits were more uniform in their ripening times. Lower SD values indicate less variability among the ripening times of individual fruits, demonstrating a more consistent ripening process.

Table 1. Effect of Ethylene treatment on the Remaining Shelf Life (RSL) of ‘Honey Gold’ fruit from Darwin orchard: presented as mean $\pm$ Standard Deviation (SD) in days. Remaining shelf life is measured from the point of cold treatment removal to the end of shelf life.

Storage Temperature (°C)	Storage Duration (day)	Days to firm soft at 20°C		Remaining shelf life at 20° (day)		Difference in Remaining shelf life (Days)
		Non-C ₂ H ₄	C ₂ H ₄	Non-C ₂ H ₄	C ₂ H ₄	
10	4	16.1 $\pm$ 4.9	10.0 $\pm$ 0.0	19.3 $\pm$ 3.6	14.5 $\pm$ 2.5	4.8
	7	16.0 $\pm$ 3.8	12.4 $\pm$ 1.0	16.8 $\pm$ 4.4	11.7 $\pm$ 2.5	5.1
12	4	15.6 $\pm$ 4.4	11.4 $\pm$ 2.6	19.9 $\pm$ 3.1	15.8 $\pm$ 4.2	4.1
	7	15.5 $\pm$ 2.7	12.8 $\pm$ 2.2	15.7 $\pm$ 3.8	12.3 $\pm$ 2.7	3.4
14	4	16.9 $\pm$ 3.7	12.1 $\pm$ 1.3	21.6 $\pm$ 4.4	15.0 $\pm$ 2.6	6.6
	7	18.2 $\pm$ 2.8	12.6 $\pm$ 1.0	19.6 $\pm$ 4.2	11.9 $\pm$ 2.3	7.7
16	4	17.4 $\pm$ 5.3	10.0 $\pm$ 0.0	22.1 $\pm$ 4.4	14.0 $\pm$ 1.5	8.1
	7	15.8 $\pm$ 3.3	10.8 $\pm$ 1.9	18.7 $\pm$ 4.7	11.4 $\pm$ 2.8	7.3
20	0	14.3 $\pm$ 4.0	6.0 $\pm$ 0.0	21.6 $\pm$ 4.3	18.1 $\pm$ 0.9	3.5
	4	13.8 $\pm$ 4.8	10.2 $\pm$ 0.6	16.7 $\pm$ 2.8	16.0 $\pm$ 2.3	0.7
	7	14.0 $\pm$ 2.7	11.4 $\pm$ 3.0	14.0 $\pm$ 3.7	12.4 $\pm$ 2.4	1.6
Average		15.8	10.9	18.7	13.9	4.8

Shelf life

Fruit harvested from the Darwin orchard had a 16.0% average dry matter (DM) content. When stored at 20°C in the lab, these fruits had an average postharvest lifespan of 22.4 days, as shown in **Table 4**. The longest lifespan, approximately 35-36 days, was observed in fruits stored at cooler temperatures of 10°C and 12°C for 28 days before being moved to 20°C. Generally, storing fruit at cooler temperatures for longer periods significantly extended their overall lifespan.

Table 2. Average postharvest life (PHL) in days for 'Honey Gold' mangoes harvested from Darwin, NT. PHL is the time from harvest to the end of shelf life, across various storage temperatures corresponding to different handling regimes. For higher temperatures (14°C, 16°C, and 20°C), storage times of 24 and 28 days were not tested.

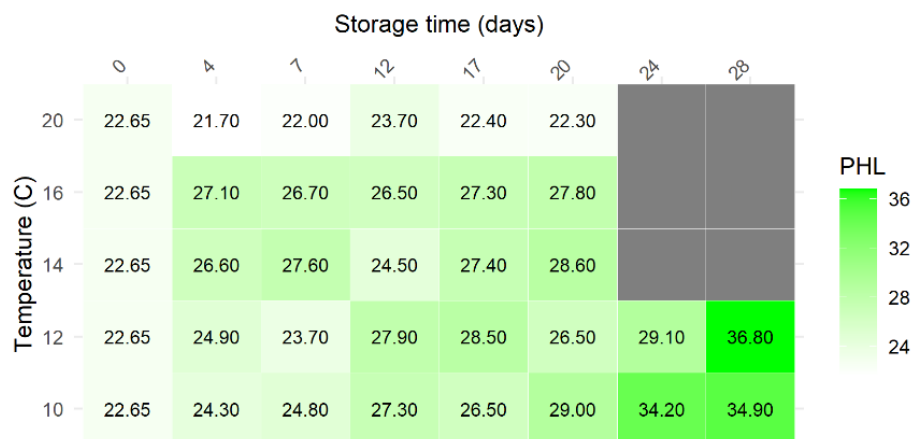
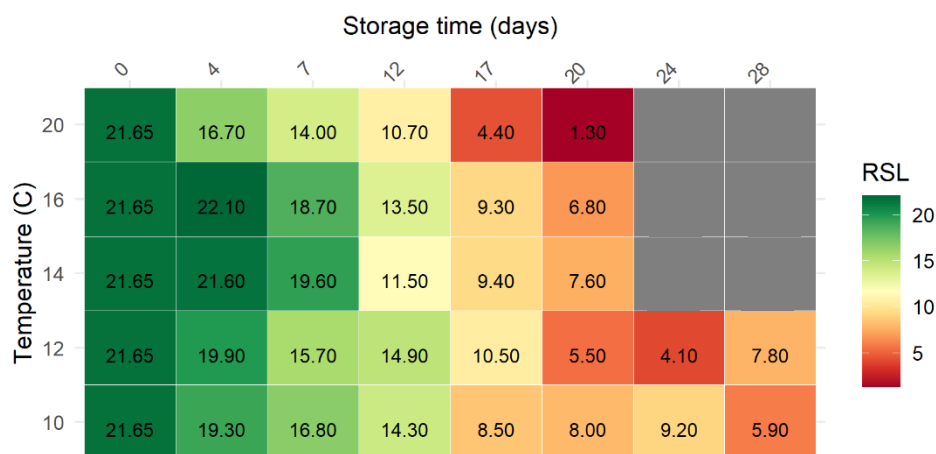


Table 5 shows the average remaining shelf life (RSL) of fruit stored at 20°C after different storage treatments. The RSL of the fruit depended on both the storage temperature and duration. Generally, the longer the storage time, the shorter the RSL. Storing fruit at 10°C resulted in the longest RSL.

Table 3. Heat map displaying the average remaining shelf life (RSL) in days for 'Honey Gold' mangoes from Darwin, NT, from the point of cold treatment removal to the end of shelf life. The fruits were held at 20°C after being stored at varying temperatures for different durations to simulate diverse handling regimes. Note: Storage times of 24 and 28 days at higher temperatures (14°C, 16°C, and 20°C) were not evaluated.



Reasons for end of shelf life in Darwin fruits

Figure 3 illustrates the reasons for fruits reaching their end of shelf life (ESL). The most common cause was 'over-soft' at 55.5%, followed by 'Stem End Rot (SER)' at 31% for fruits from Darwin, making it the second major reason. Other noted reasons were 'Body Rot (BR)' (6.9%), 'Resin Canal Disorder (RCD)' (3.6%), 'Under Skin Browning (USB)' at 2.1%—one of the least common causes, 'other reasons' (0.5%), and 'Soft nose' (0.5%).

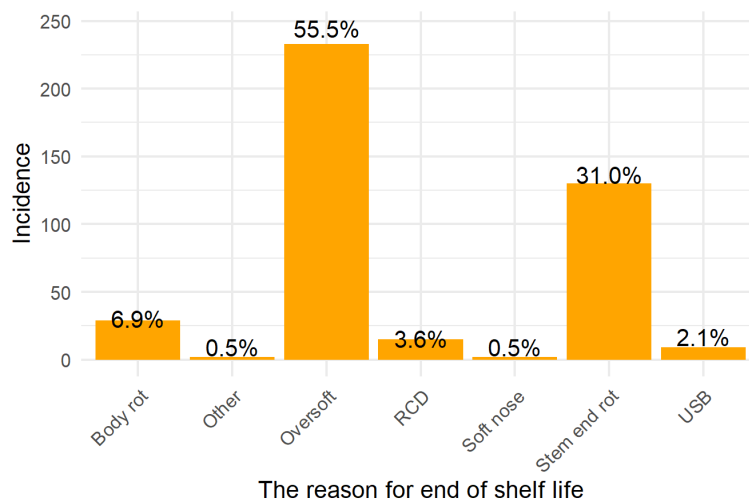


Figure 2. Occurrence of various reasons leading to the end of shelf life in 'Honey Gold' trial fruits sourced from Darwin.

Figure 4 illustrates the reasons for the end of shelf life, categorized by the temperature of the prior cold treatment, before the fruits were kept at 20°C. USB defects were observed only in fruits stored at 10°C. Over-softening was the predominant reason for reaching the end of shelf life in fruits stored at 14°C, 16°C, and 20°C. Additionally, the incidence of rot was higher in fruits that had been stored at the lower temperatures of 10°C and 12°C.

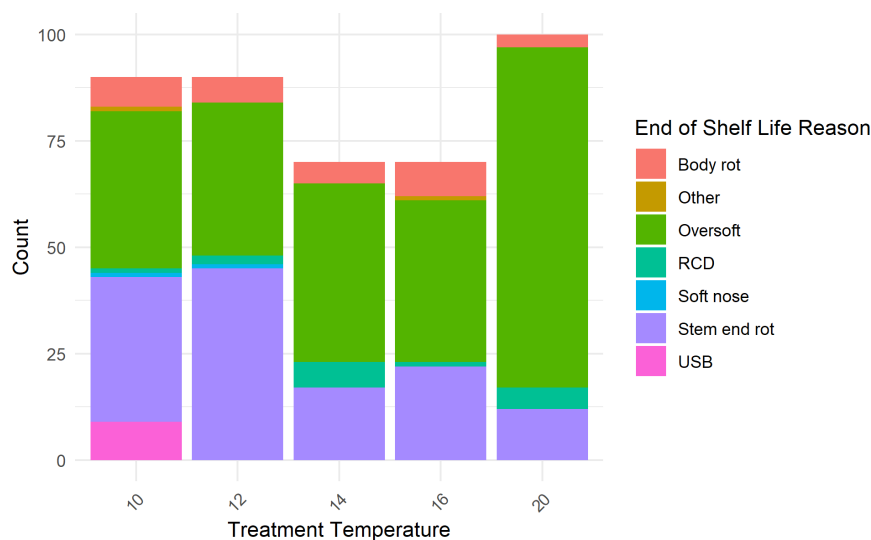


Figure 3. Occurrence of various reasons leading to the end of shelf life for in 'Honey Gold' trial fruits sourced from Darwin divided by their cold storage temperatures.

Some fruits from Darwin exhibited defects not critical enough to mark the end of their shelf life. For instance, Under Skin Browning (USB) was detected in 4% of the fruits, yet only 2.1% exhibited USB to a degree that compromised their shelf life. Chilling injury was present in 1.9% of fruits, though none were deemed severe enough to end shelf life. Body rot was noted in 29.3% of the fruits. However, the most significant issues were Stem End Rot (SER) and Resin Canal Disorder (RCD), affecting 67.9% and 35.2% of the fruits, respectively. **Figure 5** displays the incidence of defects for each temperature. It does not suggest that these defects developed during cold storage; rather, it indicates the defects observed at the end of the shelf life in fruits that had been stored at specific temperatures before being maintained at 20°C. Generally, the overall incidence of defects increases with higher temperatures. Notably, USB defects are more prevalent at the lower temperature of 10°C. The incidence of RCD is significantly higher than other defects across all temperatures, particularly at higher degrees. Meanwhile, the incidences of body rot and stem end rot remain relatively consistent across all temperatures.

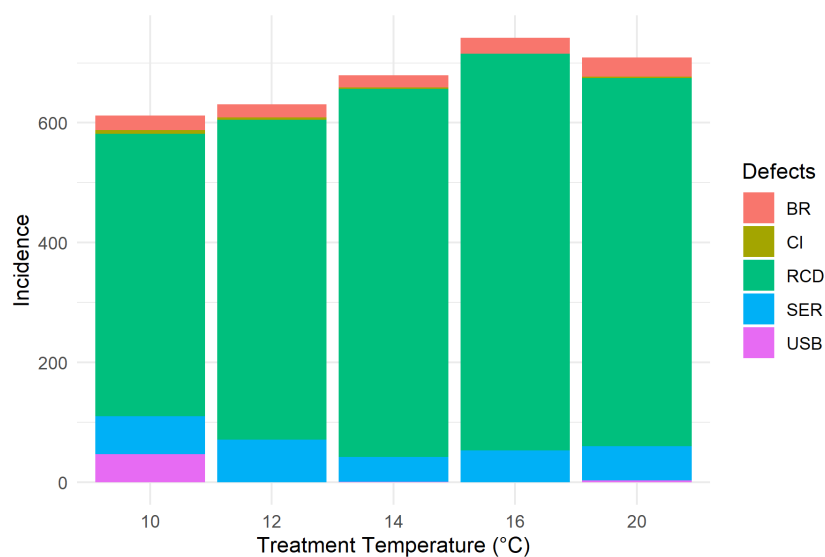


Figure 4. Incidence of defects for each temperature for 'Honey Gold' fruits sourced from Darwin. BR: Body Rot, CI: Chilling Injury, RCD: Resin Canal Disorder, SER: Stem End Rot and USB: Under Skin Browning.

Shelf-life models

The 'Honey Gold' time-temperature trials conducted in Darwin, NT, provided valuable data on how storage conditions affect shelf life and fruit quality. Modelling the shelf life using temperature-time units (TTUs) demonstrated a strong linear relationship ($R^{21} = 0.85$, shown in **Figure 6a**). This relationship slightly improved when considering only fruits not treated with ethylene ($R^2 = 0.87$, as shown in **Figure 6b**). These robust correlations are crucial for developing predictive models for fruit response under varying supply chain conditions across different districts. In our shelf life predictions, we also considered dry matter (DM) as an independent variable (**Figure 7**), discovering a negative relationship between DM and shelf life. Specifically, fruits with lower DM tend to have a longer shelf life compared to those with higher DM.

¹ R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

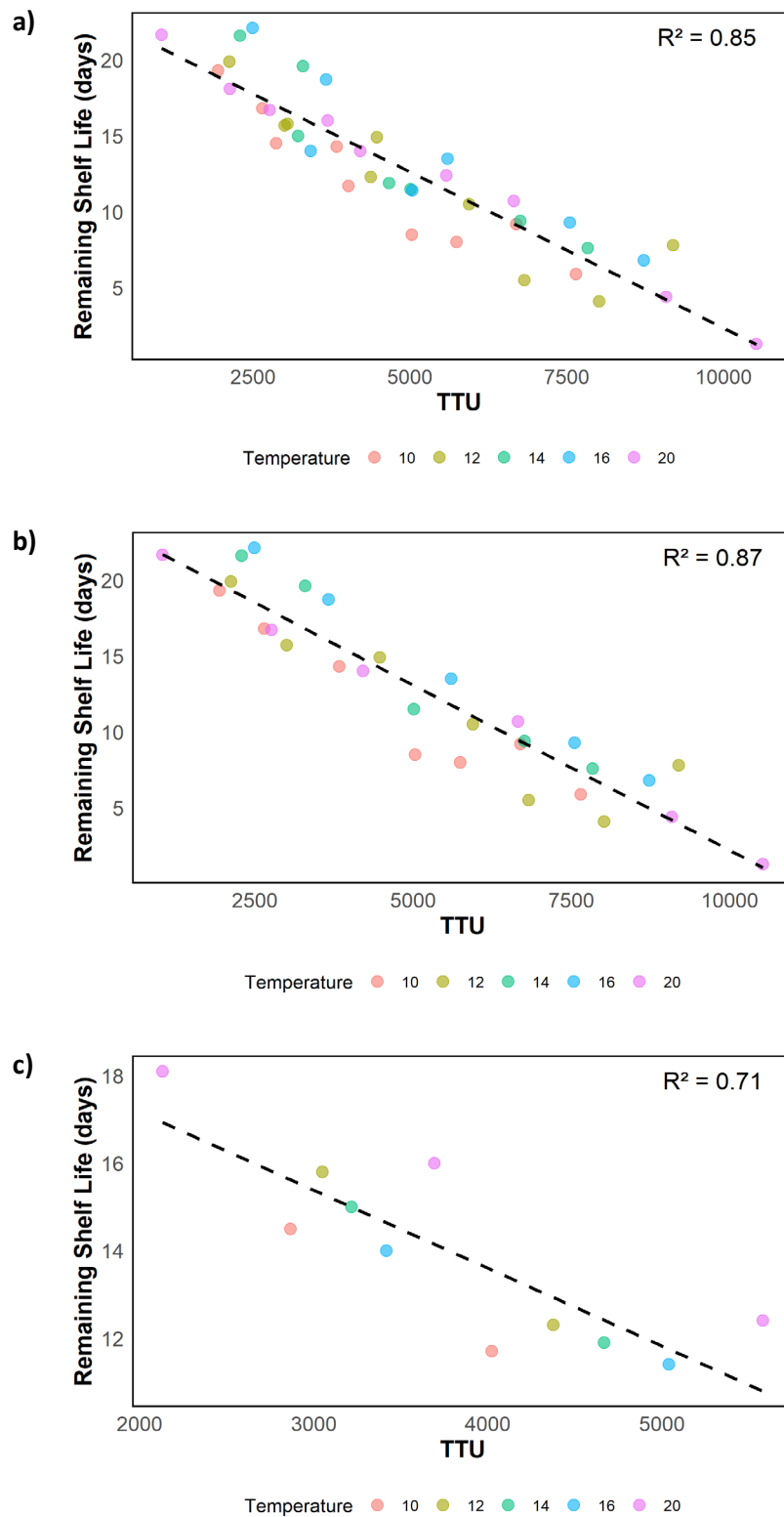


Figure 6. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from Darwin for a) all fruits including ethylene treated fruits; b) only non-treated fruits and c) only ethylene-treated fruits.

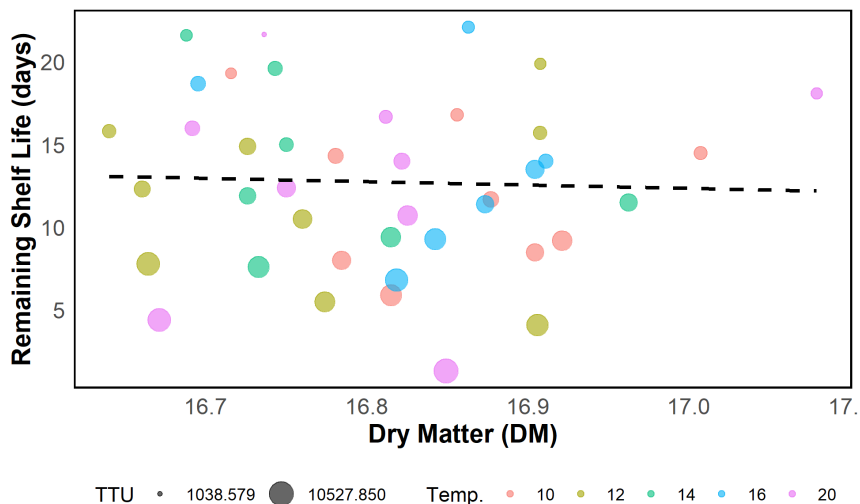


Figure 7. The relationship between fruit dry matter (DM) content, time temperature unit (TTU) and the remaining shelf life (based on tray averages) of 'Honey Gold' mangoes from Darwin, NT, across different storage temperatures. The size of the points indicates TTU; larger data points represent higher TTU values.

3.2 'Honey Gold' fruit from Katherine

Fruit firmness

Fruit from the Katherine orchard showed a trend where ripening, and consequently softening, accelerated with higher storage temperatures, as illustrated in **Figure 8**. At 10°C, the fruit experienced minimal softening. However, as temperatures rose from 12°C to 20°C, the rate of softening gradually increased. Fruits stored at 12°C and 14°C stayed firm until removed from the cold, except for those at 14°C for 20 days. In contrast, fruits stored at 20°C and 16°C reached their over-soft stage, which marks the end of shelf life, after an average of 18 and 25 days, respectively, where the lines intersect with a firmness value of 38.

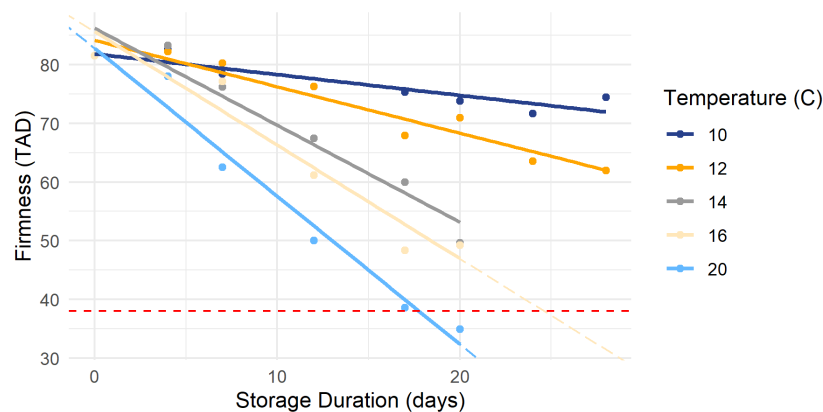


Figure 8. Firmness changes in 'Honey Gold' mangoes harvested from Katherine orchard during storage at various temperatures. The red line indicated fruit firmness cut off when they are over-soft.

Effect of ethylene treatment on fruit shelf life

As shown in **Table 6**, fruit treated with ethylene reached the firm soft stage after 10.5 days at 20°C, which is approximately 2.5 days quicker than the fruit not treated with ethylene. This indicates that ethylene treatment accelerated the ripening process by about 3.8 days compared to non-treated fruit. Additionally,



lower values of standard deviation (SD) for ethylene-treated fruits suggest that these fruits were more uniform in their ripening times. Lower SD values indicate less variability among the ripening times of individual fruits, demonstrating a more consistent ripening process.

Table 4. Effect of Ethylene treatment on the remaining shelf life of 'Honey Gold' fruit from Katherine: Presented as Mean $\pm$ Standard Deviation (SD) in Days. Remaining shelf life is measured from the point of cold treatment removal to the end of shelf life.

Storage Temperature (°C)	Storage Duration (day)	Days to firm soft at 20°C		Remaining shelf life at 20° (day)		Difference in Remaining shelf life (Days)
		Non-C2H4	C2H4	Non-C2H4	C2H4	
10	4	11.8 $\pm$ 1.8	10.1 $\pm$ 0.3	13.5 $\pm$ 2.7	10.8 $\pm$ 3.6	2.7
	7	13.1 $\pm$ 1.0	11.9 $\pm$ 0.7	11.1 $\pm$ 7.2	10.0 $\pm$ 2.2	1.1
12	4	14.2 $\pm$ 2.3	11.1 $\pm$ 1.6	18.8 $\pm$ 3.4	14.4 $\pm$ 5.0	4.4
	7	16.3 $\pm$ 3.4	12.5 $\pm$ 2.1	16.6 $\pm$ 4.7	12.2 $\pm$ 3.2	4.4
14	4	14.0 $\pm$ 3.4	9.4 $\pm$ 2.5	19.1 $\pm$ 6.6	12.9 $\pm$ 5.4	6.2
	7	12.7 $\pm$ 2.5	11.7 $\pm$ 0.8	11.4 $\pm$ 5.2	10.8 $\pm$ 2.0	0.6
16	4	13.0 $\pm$ 4.0	9.9 $\pm$ 2.1	16.7 $\pm$ 7.4	12.0 $\pm$ 3.7	4.7
	7	14.2 $\pm$ 3.6	12.3 $\pm$ 0.5	17.2 $\pm$ 5.9	10.8 $\pm$ 0.9	6.4
20	0	10.9 $\pm$ 3.6	7.0 $\pm$ 1.9	20.1 $\pm$ 4.0	13.3 $\pm$ 3.3	6.8
	4	12.0 $\pm$ 1.4	9.7 $\pm$ 1.3	16.3 $\pm$ 5.1	13.1 $\pm$ 2.3	3.2
	7	11.1 $\pm$ 3.5	10.0 $\pm$ 2.6	10.8 $\pm$ 5.4	9.1 $\pm$ 2.8	1.7
Average		13.0	10.5	15.6	11.8	3.8

Shelf life

Fruit harvested from the Katherine orchard had a 17.3% average dry matter (DM) content at harvest. When stored at 20°C in the lab, these fruits had an average postharvest lifespan of 22 days, according to **Table 7**. The fruits that experienced the longest postharvest life, approximately 37 days, were those kept at cooler temperatures of 10°C and 12°C for 28 days before being moved to 20°C. Overall, the total lifespan of the fruit increased with longer storage periods at lower temperatures.

Table 5. Average postharvest life (PHL) in days for 'Honey Gold' mangoes harvested from Katherine, NT. PHL is the time from harvest to the end of shelf life, across various storage temperatures corresponding to different handling regimes. For higher temperatures (14°C, 16°C, and 20°C), storage times of 24 and 28 days were not tested.

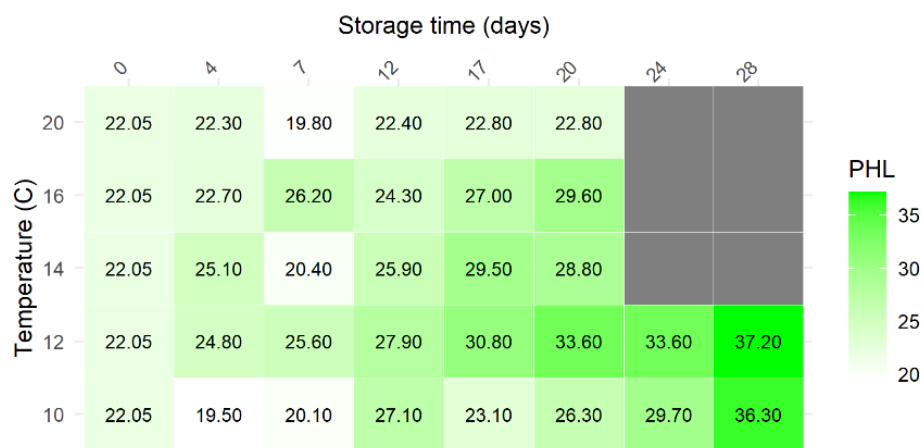
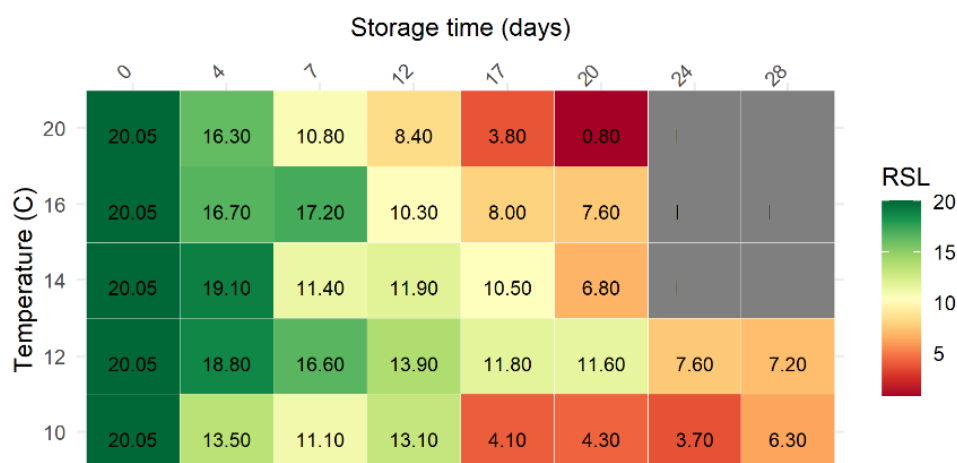


Table 8 shows the average remaining shelf life (RSL) of fruit stored at 20°C after being subjected to different storage treatments. The RSL was influenced by both the storage temperature and duration. Typically, the RSL shortened as the storage time increased. Fruits sourced from Katherine stored at 12°C had the longest RSL.

Table 6. Heat map displaying the average remaining shelf life (RSL) in days for 'Honey Gold' mangoes from Katherine, NT, from the point of cold treatment removal to shelf life end. The fruits were held at 20°C after being stored at varying temperatures for different durations to simulate diverse handling regimes. Note: Storage times of 24 and 28 days at higher temperatures (14°C, 16°C, and 20°C) were not evaluated.



Reasons for end of shelf life in Katherine fruits

Trial fruits from Katherine primarily reached the end of their shelf life due to becoming over-soft, as shown in **Figure 9**. The second most common cause was 'Under Skin Browning' (USB), with an incidence of 10.2%. Other reasons for reaching the end of shelf life in Katherine fruits, in descending order of frequency, included 'Stem End Rot' (9%), 'body rot' (5.5%) and 'chilling injury' (0.5%).

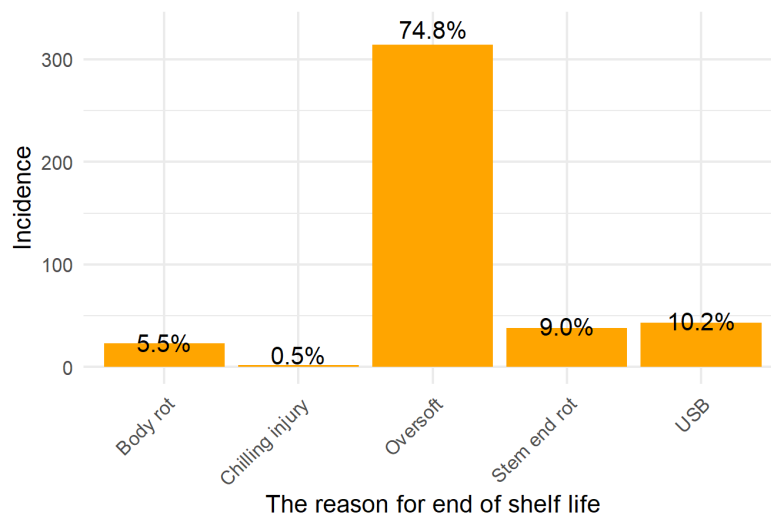


Figure 9. Occurrence of various reasons leading to the end of shelf life in 'Honey Gold' trial fruits sourced from Katherine.

Figure 10 illustrates the reasons for the end of shelf life, categorized by the temperature of the prior cold treatment, before the fruits were kept at 20°C for Katherine fruits. USB defects were observed considerably more as the reason for the end of shelf life in fruits that had been stored at 10°C. Over-softening was the predominant reason for reaching the end of shelf life in all storage temperatures. Additionally, rot as the reason for the end of shelf life was higher in fruits that had been stored at the temperatures of 12°C and 14°C.

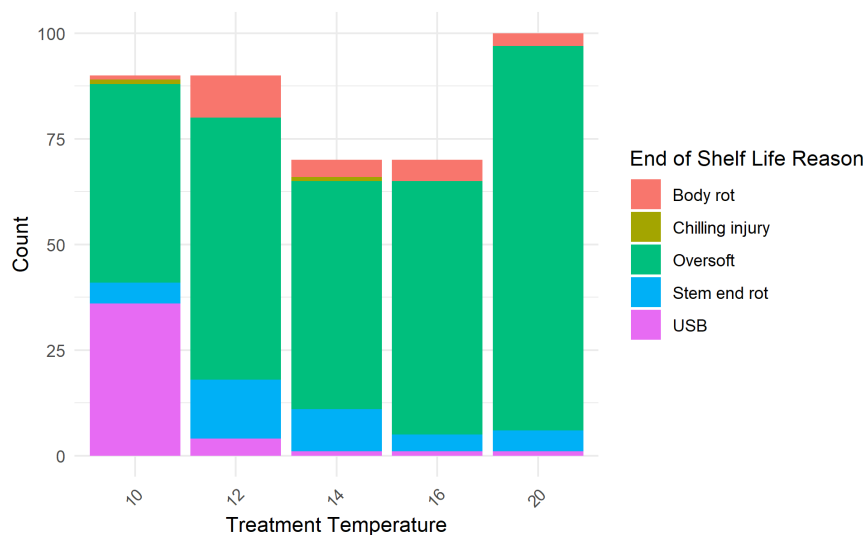


Figure 5. Occurrence of various reasons leading to the end of shelf life for in 'Honey Gold' trial fruits sourced from Katherine divided by their cold storage temperatures.

Some fruits from Katherine displayed defects that were not severe enough to be considered as causing the end of shelf life. For example, Under Skin Browning (USB) was found in 15% of the fruits, but only 10.2% had

USB severe enough to end their shelf life. Chilling injury appeared in 5.7% of fruits, with only 0.5% of these cases being serious enough to consider end shelf life. Resin Canal Disorder (RCD) was observed in 3.1% of the fruits. Notably, the most prevalent defects affecting fruits from Katherine were stem end rot and body rot, occurring in 29.3% and 19.3% of the fruits, respectively. **Figure 11** displays the incidence of defects for each temperature, indicating defects observed at the end of the shelf life in fruits previously stored at specific temperatures before being maintained at 20°C. It does not imply that these defects developed during cold storage. Generally, the overall incidence of defects decreases with higher temperatures, with the lowest incidence observed at 16°C. USB defects were more prevalent at lower temperatures. Majority of fruits stored at 10°C has USB at varying levels—some of which might still be acceptable to consumers. The incidence of RCD is almost uniformly high across all temperatures except for fruits kept at 10°C. However, this does not imply that RCD incidence is inherently low at this temperature; rather, most fruits at this temperature were removed from the trial due to USB while still quite firm, making it difficult to assess RCD. Meanwhile, the incidences of body rot and stem end rot remain relatively consistent across all temperatures.

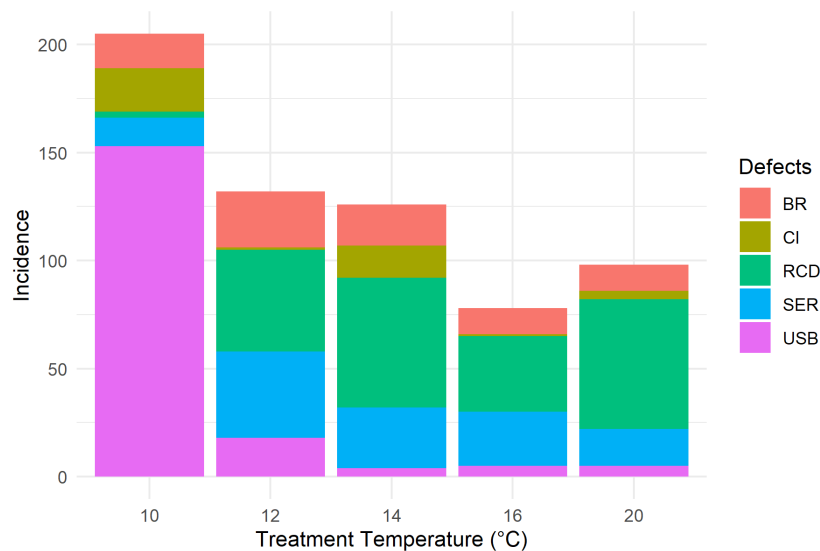


Figure 6. Incidence of defects for each temperature for 'Honey Gold' fruits sourced from Katherine. BR: Body Rot, CI: Chilling Injury, RCD: Resin Canal Disorder, SER: Stem End Rot and USB: Under Skin Browning.

Shelf-life models

The 'Honey Gold' time-temperature trials conducted with fruit harvested from Katherine, NT, yielded valuable data demonstrating the impact of storage conditions on shelf life and fruit quality. The model used to predict fruit shelf life, based on temperature x time units (TTUs), resulted in a satisfactory linear regression with an R^2 of 0.66 (**Figure 12a**). This correlation slightly improved to an R^2 of 0.69 when the analysis was limited to fruits not treated with ethylene (**Figure 12b**).

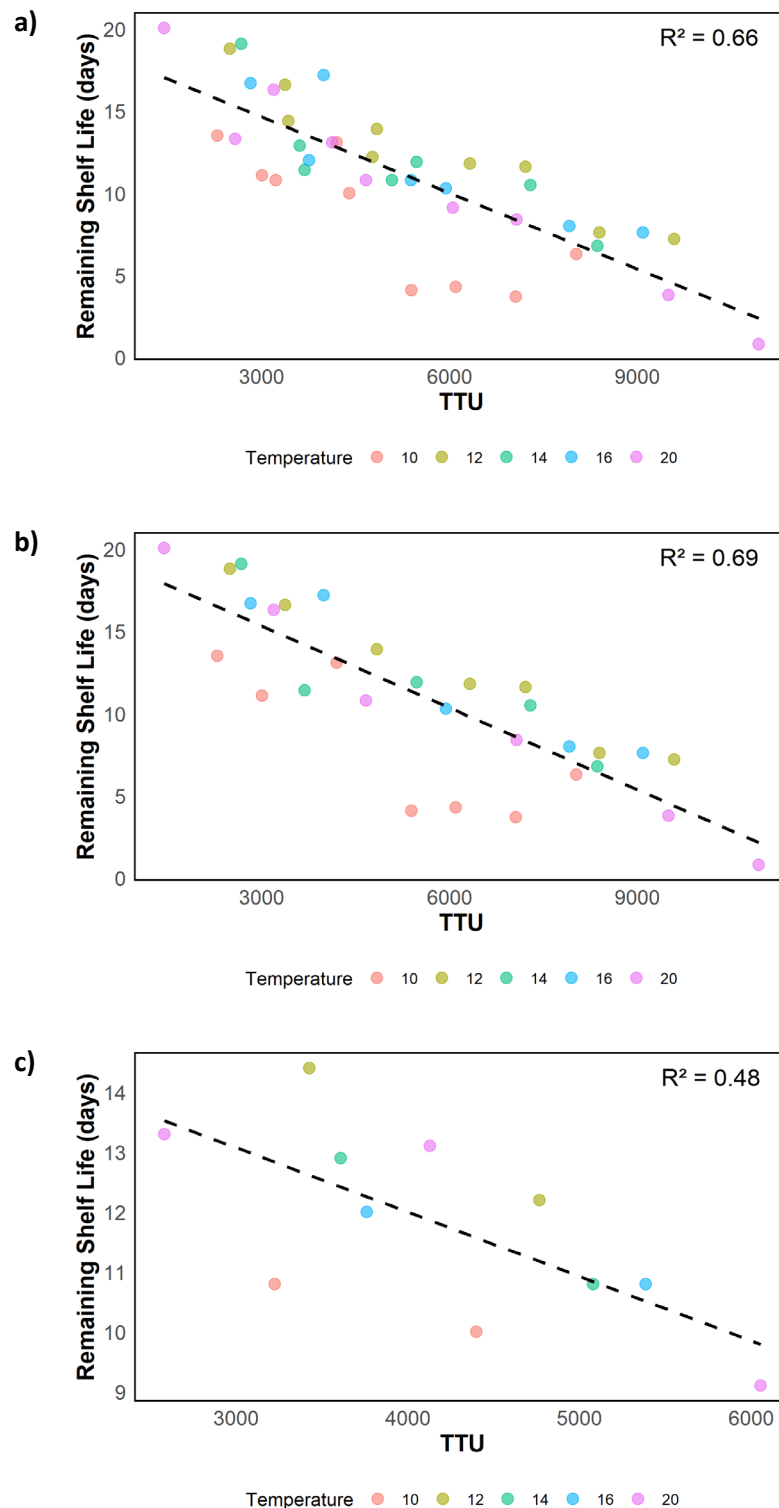


Figure 12. Relationship between temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in ‘Honey Gold’ mangoes harvested from Katherine for a) all fruits including ethylene treated fruits; b) only non-treated fruits and c) only ethylene-treated fruits.

The relationship between TTU and the remaining shelf life of fruits from Katherine was weaker than that observed in fruits from Darwin. This discrepancy is attributed to a higher incidence of under-skin browning (USB) in the Katherine fruits. Notably, almost 10% of the fruits from the Katherine farm, especially those stored at the low temperature of 10°C, reached the end of their shelf life prematurely and were immediately

removed from the trial after cold removal. This effect is evident in Figure 8, where the orange points representing 10°C are noticeably further from the trend line, thereby decreasing the correlation coefficient.

In predicting shelf life, we included dry matter (DM) as an additional independent variable (**Figure 13**), discovering a negative correlation between DM and fruit shelf life. This indicates that fruits with lower DM tend to have a longer shelf life than those with higher DM.

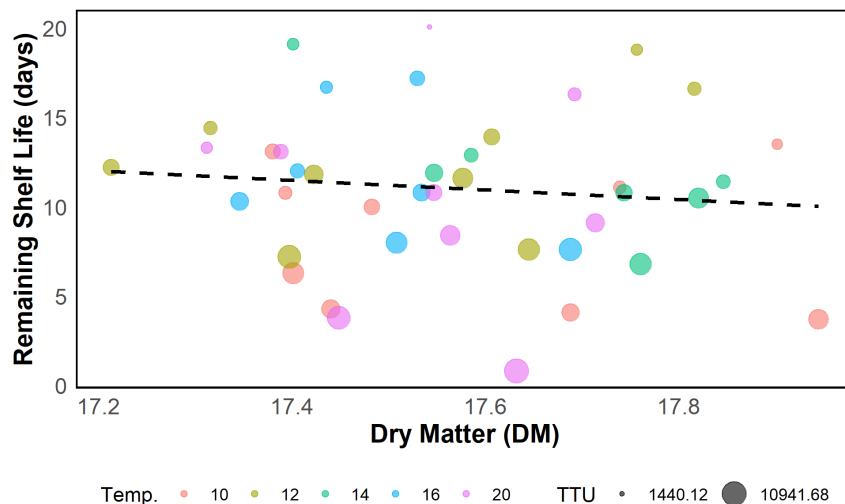


Figure 13. The relationship between fruit dry matter (DM) content, time temperature unit (TTU) and the remaining shelf life (based on tray averages) of 'Honey Gold' mangoes from Katherine, NT, across different storage temperatures. The size of the points indicates TTU; larger data points represent higher TTU values.

3.3 'Honey Gold' fruit from Childers

Dry matter (DM) content

Fruit harvested from the West Farm and Promised Land orchards had an average oven dried DM content of 14.9% and 15.3%, respectively. The relationship between NIR predicted DM and oven dried DM was relatively strong in these trials, averaging $R^2=0.72$ (data not shown).

Weight loss

Fruit weight loss at cold removal tended to increase with extended storage time. For all treatments at 16°C or lower, weight loss remained less than 4% for up to 32 days at 85-90% RH (data not shown). Weight loss occurred rapidly during subsequent shelf life at 20°C, due to the higher temperature and lower (i.e. 65%) RH. The fruit lost an average of 8% of their weight after 12 days at 20°C and 11% at 20 days.

Fruit firmness

Changes in fruit firmness and associated ripening were related to storage temperature and time (**Figure 14**). Minimal softening occurred while fruit were stored at 8°C. As temperatures increased from 10°C to 20°C, the rate of softening gradually increased. For example, fruit stored at 16°C and 20°C reached the stage of firm soft after 12 and 16 days, respectively. The fruit stored at 20°C reached over soft or ESL at 20 days. There was no appreciable difference in firmness changes for fruit from West Farm or Promised Land orchards.

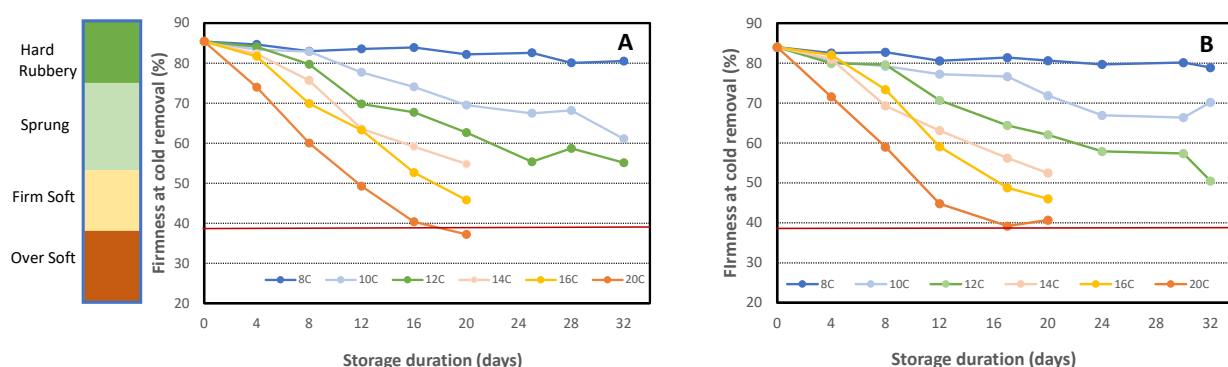


Figure 14. Changes in firmness of ‘Honey Gold’ mangoes harvested from West Farm (A) and Promised Land (B) orchards during storage at various temperatures. The red horizontal line indicates the cutoff for when fruit are over soft.

Shelf life

West Farm fruit stored continuously in the laboratory at 20°C displayed an average postharvest life of 19.8 days from harvest to ESL (**Table 9**). In general, total fruit life was progressively extended by longer durations at cooler storage temperatures. Fruit with the longest postharvest life of 35 days or more were those stored at 8°C, 10°C and 12°C for 25, 30 and 32 days prior to transfer to 20°C. While fruit held at 8°C exhibited the longest life and slowest rates of ripening, they also expressed chilling injury (CI) even after 4 days of storage with very minor severity. Similar results were seen for Promised Land fruit (data not shown)

Table 9. Average postharvest life (days) from harvest to end of shelf life for ‘Honey Gold’ mango fruit from West Farm that were stored at different temperatures and times to reflect various handling regimes.

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C							
	4	8	12	16	20	25	30	32
8	22.5	21.5	27.8	29.1	34	39.6	40.9	47.3
10	21.6	25.2	25.6	29.5	30.8	34.2	37	42.7
12	23.4	24.7	24.3	28.4	29.8	33	36.6	39.4
14	20.6	24.1	24.8	26.8	30.2			
16	23	22.6	24.7	24.6	24.8			
20	18.4	19.4	20.9	19.5	20.5			

The average remaining shelf life (RSL) of fruit at 20°C after removal from storage treatments is presented in **Table 10**. West Farm fruit RSL was related to storage temperature and time. In general, RSL decreased for fruit that experienced longer storage time and higher temperatures. The exception was for fruit held at 8 and 10°C for 32 days. These fruit developed minor (10°C) to severe (8°C) CI which interfered with ripening. Fruit stored 12°C did not develop CI and typically exhibited the greatest RSL after each storage period. A similar response was recorded for Promised Land fruit (data not shown).

Table 10. Heat map of average of remaining shelf life of ‘Honey Gold’ mango fruit harvested from West Farm held at 20°C after storage at different temperatures and duration (green → red: high → low).

Storage temperature (°C)	Storage time (days) prior to transfer to 20°C								
	0	4	8	12	16	20	25	30	32
8	19.8	18.5	13.5	15.8	13.1	14	14.6	10.9	15.3
10		17.6	17.2	13.6	13.5	10.8	9.2	7	10.7
12		19.4	16.7	12.3	12.4	9.8	8	6.6	7.4
14		16.6	16.1	12.8	10.8	10.2			
16		19	14.6	12.7	8.6	4.8			
20		14.4	11.4	8.9	3.5	0.5			

The percentage of fruit reaching ESL due to oversoft was 75% and 62% for fruit picked from the West Farm and Promised Land orchards, respectively. Fruit harvested from West Farm had a lower incidence of rots (23%) as compared to those sourced from Promised Land (36%). Other reasons attributing to ESL include CI and shrivel (2%).

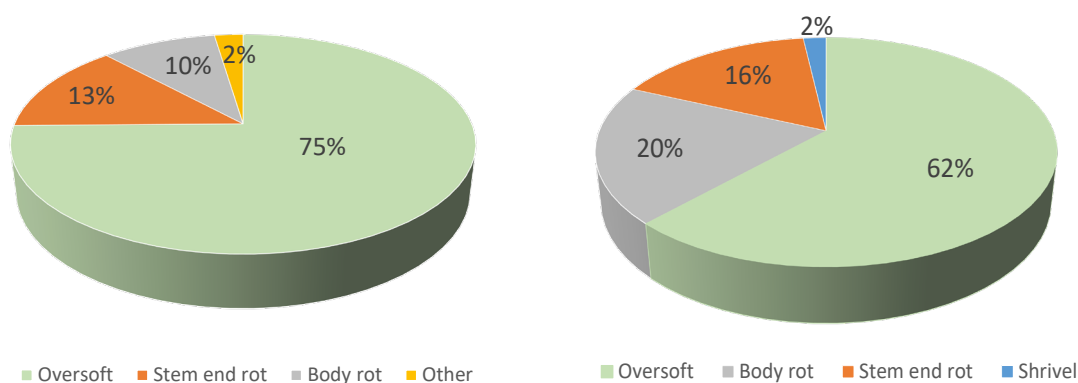


Figure 2. Reasons to reach ESL for the fruit harvested from farm A (left) and farm B (right).

Shelf life models

The ‘Honey Gold’ time x temperature trials captured great quality data showing how storage conditions influence shelf life and fruit quality. Modelling of fruit shelf life using temperature x time units (TTUs) showed an impressive linear regression ($R^2=0.89$, Figure. 15) relationship. Such strong relationships will be instrumental in guiding the development of models to predict the response of fruit from different districts under variable supply chain conditions. The precision of shelf model needs to be validated using temperature data from incoming domestic or overseas shipments.

² R squared value (R^2) range from 0 to 1, is a statistical measure that represents the proportion of the variance for a dependent variable (RSL in this case) that's explained by an independent variable (TTUs). A higher R^2 indicates a better fit for the model.

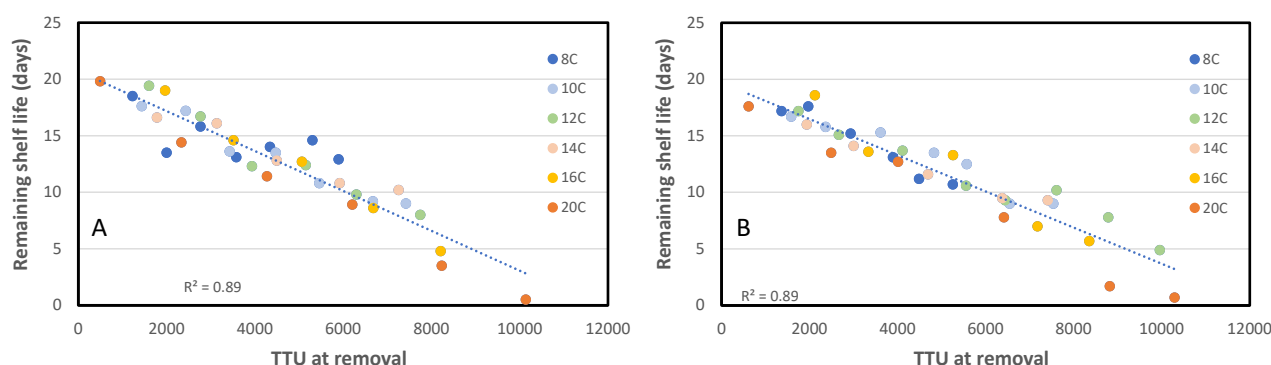


Figure 15. Relationship between cumulative temperature time units (TTUs) from harvest and during storage at various temperatures and remaining shelf life (tray averages) in 'Honey Gold' mangoes harvested from West Farm (A) and Promised Land (B) orchards.

Effect of ethylene treatment on fruit shelf life

As shown in **Table 11**, treating fruit with ethylene accelerated the development of yellow skin colour and loss of fruit firmness. For fruit that were immediately treated with ethylene after packing and held continuously at 20°C, ripening was advanced and shelf life was reduced by 3 days, as compared with non-treated fruit. For fruit that were subjected to simulated road transport at 20°C for 4 days prior to ethylene treatment, a similar reduction in shelf life was observed. However, storing the ethylene-treated fruit 16, 14, and 12°C for 7 days could delay the ripening process and extend the shelf life by 4 to 7 days over fruit that were always maintained at 20°C. A similar response was observed for fruit that were subjected to simulated road transport at 12°C for 4 days prior to ethylene treatment. Weight loss of the treated fruit was lower than non-treated controls at end of shelf life, reflecting the accelerated ripening induced by ethylene.

Table 11. Effect of ethylene treatment (100 ppm, 18°C, 2 days) and storage temperature prior to ethylene application on the shelf life of 'Honey Gold' fruit following storage at various temperatures for 7 days.

Pre-ethylene treatment		Ethylene treatment	Post-ethylene treatment		Colour score		Fruit firmness		Days from trial start to firmsoft	Shelf life (days)	Shelf life loss due to C2H4 (days)	Wt loss at ESL (%)
Storage temperature (°C)	Duration (days)		Storage temperature (°C)	Duration (days)	At C ₂ H ₄ removal	At cold removal	At C ₂ H ₄ removal	At cold removal				
20	0	No	20	0	1.6	N/A	77.8	N/A	8.5	18.5	-3	10.5
		Yes	20	0	3	N/A	63.1	N/A	6.5	15.5		8.5
20	4	No	20	7	3.2	5.4	60.9	43.0	8.3	17.4	-2.7	10.4
		Yes	20	7	3	5.6	60.1	39.9	7.5	14.7		8.4
		No	16	7	2.1	3.4	69.8	55.6	12.6	23.6	-5	9.7
		Yes	16	7	2.7	5.5	61.3	44.9	13	18.6		7.1
		No	14	7	2.2	3.9	64.7	54.5	13.1	24.8	-3.2	9.0
		Yes	14	7	2.6	4.7	60.7	45.2	11.6	21.6		8.3
		No	12	7	2.4	3	67.6	60.2	15.4	25.4	-4.2	9.9
		Yes	12	7	2.7	3.6	57.9	45.2	11.6	21.2		8.1
12	4	No	20	7	1.6	4.7	73.1	46.7	11.1	19.5	-0.2	9.9
		Yes	20	7	1.4	5.6	69.9	41.6	9.4	19.3		8.2
		No	16	7	1.4	4	75.5	53.8	14.6	24.3	-0.7	8.3
		Yes	16	7	1.5	4.3	69.9	46.5	13.1	23.6		8.3
		No	14	7	1.5	2.6	77.9	60.1	16.2	26	-5	9.7
		Yes	14	7	1.9	4.2	67.9	46.7	13.4	21		6.5
		No	12	7	1.8	2.3	74.4	59.3	16	24.4	-1.1	8.8
		Yes	12	7	1.6	3.7	68.4	49.1	13.3	23.3		8.1

Effect of coating on fruit quality

Coating green fruit from West Farm and Promised Land with an Akorn Technologies solution extended shelf life by about 3 days following simulated transport at 12 or 20°C for 12 days, relative to non-coated controls (**Table 12**). The coating treatment reduced fruit weight loss and inhibited skin colour development. There was no consistent effect of the coating on fruit rots. The coating treatment prevented fruit from developing full yellow skin colour at ripe and was associated with a sticky plastic-like film residue on the fruit surface. The treatment formulation or dose will need to be optimised to be practical for 'Honey Gold' mangoes.

Table 12. Effect of coating on fruit shelf life and quality after storage at 12 and 20°C for 12 days

Location	Storage temperature (°C)	Coating	Shelf life (days)	Wt loss at ESL (%)	Color at ESL	% Body rot	% SER
West Farm	20	No	19.8	11.7	6.0	15	10
		Yes	21.1	8.2	4.5	10	20
	12	No	24.3	9.6	5.7	5	35
		Yes	27.6	8.3	5.3	5	10
Promised Land	20	No	17.6	10.9	5.9	15	15
		Yes	20.6	8.9	4.5	20	15
	12	No	25.7	10.1	5.8	55	5
		Yes	28.9	8.9	4.8	20	20

Effect of irradiation on fruit quality

Gamma irradiation of 'Honey Gold' mango fruit at colour stage 2 to 3 with 500 Gy did not significantly affect shelf life or weight loss (**Table 13**), except for one treatment from West Farm that was stored at 12°C. Irradiation treatment was associated with a reduction in fruit rots compared to the controls.

Table 13. Effect of irradiation on fruit shelf life and quality after storage at 12 and 20°C for 12 days

Location	Storage temperature (°C)	Irradiation	Shelf life (days)	Wt loss at ESL (%)	% Body rot	% SER
West Farm	20	No	19.80	11.67	15	10
		Yes	19.55	11.73	0	5
	12	No	28.65	11.01	20	10
		Yes	25.95	9.40	5	5
Promised Land	20	No	17.6	10.9	15	15
		Yes	18.6	11.1	10	5
	12	No	26.4	10.2	35	20
		Yes	26.5	10.7	10	5

Effect of transport mode on chilling injury and USB

When held at 20°C, 30% of fruit transported by truck suffered from USB. Chilling injury developed after 20 days at 8°C regardless mode of transport (**Table 14**). Fruit carried by air plane had less incidence of USB when kept at 10 and 12°C.

Table 14. Effect of transport mode on fruit sensitivity to USB at low temperature

Storage temperature (°C)	Duration (days)	Mode of transport	Chilling injury		USB	
			Incidence (%)	Severity (1-5)	Incidence (%)	Severity (1-5)
20	12	Air freight	0	0	0	0
		Truck	0	0	30	0.8
8	12	Air freight	0	0	20	0.6
		Truck	0	0	30	0.9
	20	Air freight	0	0	20	0.5
		Truck	20	0.6	30	0.5
	24	Air freight	40	0.6	20	0.9
		Truck	40	0.8	30	1
	28	Air freight	60	1.9	0	0
		Truck	80	2.7	30	0.4
	32	Air freight	80	3.5	20	0.5
		Truck	80	3.9	10	0.2
10	20	Air freight	0	0	0	0
		Truck	0	0	20	0.4
	24	Air freight	10	0.1	0	0
		Truck	10	0.2	10	0.2
	28	Air freight	0	0	0	0
		Truck	30	0.7	20	0.7
	32	Air freight	20	0.2	0	0
		Truck	40	0.5	10	0.4
12	20	Air freight			0	0
		Truck			50	1.2
	24	Air freight	10	0.4	0	0
		Truck	0	0	30	0.8
	28	Air freight	30	0.5	0	0
		Truck	50	1.1	10	0.6

4. Summary and recommendations

There was a strong relationship between temperature time units (TTU) and remaining shelf life (RSL), especially in Darwin and Childers fruit, indicating that mathematical models could effectively predict shelf life under various supply chain conditions. The high incidence of Under Skin Browning (USB) in Katherine fruit stored at 10°C and their removal from the trial while they were quite firm resulted in a lower correlation coefficient for the model fitted on Katherine fruits. Removing data related to 10°C from the dataset will considerably increase the predictive power of the model.

Ethylene treatment accelerated uniform ripening in Darwin, Katherine and Childers fruit by an average of 4.8, 3.8 and 3.0 days, respectively, as compared to non-gassed mangoes. Holding ethylene-treated fruit at 12, 14 or 16°C for 7 days instead of the standard 20°C delayed the induced ripening and extended shelf life by 4 to 7 days. This approach may be useful to manage rates of fruit ripening depending on market conditions.

Storing fruit at cooler temperatures for longer periods significantly extended their postharvest life. Darwin and Katherine fruits exhibited the maximum postharvest life when stored at 10 and 12°C, respectively. Over-



softening, rots (Darwin) and USB (Katherine at 10°C) were the main reasons for fruit reaching the end of their shelf life. Childers fruit stored best at 12°C and exhibited at least 7 to 8 days of shelf life at 20°C even after storage for 25, 30 and 32 days. Short-term exposure to 10°C was also effective at delaying fruit ripening. Holding fruit at 14, 16 and 20°C progressively reduced remaining shelf life by 3 to 9 days relative to storage at 12°C. Fruit developed mild chilling injury when stored at 8°C for 8 days and moderate and severe symptoms were evident after 20 and 32 days, respectively.

Coating green fruit with a proprietary solution extended shelf life by 3 days relative to non-coated controls but prevented development of a full yellow skin colour at ripe. The treatment formulation or dose will need to be optimised to be practical for 'Honey Gold' mangoes.

Gamma irradiation of partially ripe (i.e. 10 to 50% yellow skin) 'Honey Gold' mango fruit with 500 Gy did not significantly affect shelf life and was associated with reduced rots. Further trials with irradiation at different doses, including those suited to domestic market protocols, will be necessary to incorporate this treatment variable into the shelf life models.

5. Acknowledgments

We thank all growers for supplying fruit for trials and for their technical advice and support. We acknowledge Alan Niscioli, Soraya Nour, Induni Vijaya Kumar, Jashanpreet Kaur, Chelsea Moore, Upendra Shekhawat, Sohail Mazhar, Peter Bergin and Cliff Hansen from the Northern Territory Department of Industry, Tourism and Trade plus Andy Mead, from the Queensland Department of Agriculture and Fisheries for technical advice and support in managing trials and data collection.

Appendix 57

‘Honey Gold’ mango postharvest treatments report 2024/25



The effect of several postharvest treatments on quality of 'Honey Gold' mango fruit

A 2024/25 season summary report

Hung Duong, Pip Bryant, Lawrence Smith and Andrew Macnish

Department of Primary Industries

Summary

Mature-green 'Honey Gold' mango fruit were sourced from farm A near Bowen in northern Queensland on 3rd and 15th December 2024 and from farm B near Childers in central Queensland on 21st, 29th January and 4th February 2025, respectively. The fruit were transported to the Department of Primary Industries (DPI) laboratory in Nambour via air or road transport. The influence of relative humidity (RH), controlled atmosphere (CA) storage, ethylene, irradiation, 1-MCP and surface coating on mango quality was investigated. Key observations included:

- Fruit had an average DM content of 16.3-18% at harvest.
Fruit held at 20°C and 90% RH had a shorter shelf life of 2.6 days compared to those stored at 20°C and 65% RH.
- Fruit stored at 12°C under CA had reduced weight loss, maintained firmness and increased postharvest shelf life by between 1.4 to 4.4 days compared to those kept without CA.
- There was a significant difference in incidence of body rot and stem-end rot between the two growing regions.
- CA storage slightly reduced the incidence of body rot and stem-end rot.
- There was no difference in eating quality between CA and non-CA stored fruit.
- Effect of ethylene treatment on fruit shelf life depended on fruit source and delay time. Treating Euri Gold fruit with ethylene one day after harvest resulted in a shorter shelf life (1.7 days).
- Ethylene treatment had little or no effect on the shelf life of Simpson fruit when treated one day after harvest or after 4 days holding at 20°C.
- Irradiation at 150 Gy had no effect on fruit shelf life, but increasing the dose to 400 Gy reduced fruit shelf life (2 days) when fruit were kept at 12°C before treatment and then held at 20°C post-treatment.
- Coating had no influence on fruit quality and defects.
- 1-MCP treatment improved fruit shelf life (2.5 days) only when fruit were held at 20°C after application.



1. Introduction

The Serviced Supply Chains II (AM21000) project is a RD&E investment into assessing and managing current supply chain risks for delivering more consistent quality fresh produce. It will provide decision support for aspiring, emerging and established horticulture exporters to maximise product value, reduce claims and expand trade volume. The objectives of the project are to:

1. Develop predictive shelf life models for a range of fresh horticultural produce
2. Apply the models to develop decision aid tools and update handling guidelines
3. Establish an information portal that facilitates access to the decision aid tools

The current report covers all trial work completed during the 2024/25 mango season with 'Honey Gold' fruit from the Bowen (NQ) and Bundaberg (CQ) production regions. The main objectives of the trials were to investigate the effect of RH, CA storage, ethylene, surface coating and irradiation treatments on postharvest quality of Honey Gold mango.

2. Materials and methods

Commercially mature ($\approx 17.3\%$ dry matter (DM) content) 'Honey Gold' mangoes were harvested from orchards at farm A near Bowen in NQ on 3rd and 15th December 2024 and from farm B near Childers in CQ on 21st, 29th January and 4th February 2025, respectively. Fruit were de-stemmed in a proprietary mango wash solution to prevent sapburn injury. They were placed into field bins and transferred to a nearby packhouse within 24 hours of harvest. The fruit were run across a commercial pack line, dipped in fungicide at the prescribed rate, sorted by size and quality, and packed into cardboard trays. Trays with fruit of count 12 or 14 size were sampled from the end of the pack line. The fruit harvested from the Bowen farm were transported to Townsville in an air-conditioned (25°C) car and then to Brisbane by air freight within 12 hours of packing. They were then transported to the Department of Primary Industries (DPI) laboratory in Nambour, a distance of about 100 km, in a car at 24.5°C. The fruit picked from Simpson farm were brought to the DPI laboratory in Nambour, a distance of about 230 km, in a car at 22°C.

On arrival at laboratory, the DM content of individual fruit was determined using near-infrared spectroscopy (NIR) with a Felix F-750 Quality Meter, based on a general mango DM model generated by Central Queensland University. NIR spectra were recorded on 2 sides of each fruit, near the cheek centre. The fruit were grouped into different categories based on their DM. The categorised fruit were then assigned evenly to treatment trays with eight replicate fruit per tray. This ensured that every tray contained a normal distribution of DM from the population supplied. A random selection of fruit were also assessed for DM content using the traditional oven-dried destructive method. Where necessary, a correction factor was applied to the NIR readings across the entire trial.

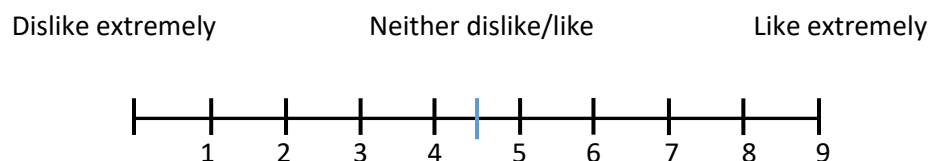
Effect of relative humidity (RH) on shelf life

Two trials were conducted for each farm. Three trays were kept at 20°C plus 65% RH whilst another three trays were kept at 90% RH. The fruit shelf life was monitored every two days.

Controlled atmosphere (CA) storage

One trial was carried out for each growing region. Twenty-four trays of mangoes were used for each CA storage trial. The fruit were stored at 12°C for 21, 28, 35 and 42 days. Half of the trays were exposed to CA conditions of 2% O₂ and 5% CO₂ within 400 L chambers and the remaining fruit were stored in a similar chamber under non-CA conditions. A sample of three trays was stored at 20°C and 65% RH as a control. After cold storage, the fruit were held at 20°C and 65% RH to evaluate postharvest shelf life. Once the fruit reached the end of shelf life (fruit firmness <38 shore unit), they were cut into pieces and eating quality (flavour, sweetness and texture) was checked by a small untrained sensory panel of 3-4 people using a 1-9 hedonic

scales (Gambaro et al. (2021), where 0 = dislike extremely and 9 = like extremely. In this trial, the effect of RH on fruit shelf life when held at 20°C was investigated.



Ethylene treatments

Forty-eight trays of HG mangoes were utilized for ethylene trials per farm. On the arrival day into the lab, twelve trays were treated with 100 ppm ethylene at 18°C for 2 days in line with commercial practice and twelve trays were held at 18°C for 2 days without ethylene treatment (**Table 1**). The remaining fruit were held at 20°C and 90% RH for 4 days prior to exposing to ethylene gas. After ethylene treatment, the fruit were either stored at 12°C for 12 days then held at 20°C, or transferred directly to 16, 20, or 24°C and 65% RH to monitor fruit quality.

Table 1. Pre and post treatment temperature and duration for ethylene treatment of Honey Gold fruit.

Pre-treatment temperature (°C)	Pre-treatment duration (days)	Ethylene treatment	Post-treatment temperature (°C)	Post-treatment duration (days)	On-going assessment temperature (°C)
20	0	Yes	12	12	20
		No	12	12	20
		Yes			16
		No			16
		Yes			20
		No			20
		Yes			24
		No			24
	4	Yes	12	12	20
		No	12	12	20
		Yes			16
		No			16
		Yes			20
		No			20
		Yes			24
		No			24

Irradiation treatments

Irradiation trials were carried out on fruit from each farm. Upon arrival at the Nambour laboratory, twelve trays of fruit were stored at 12°C for 4-5 days whilst another twelve trays were held at 20°C for 4-5 days to obtain skin color score of 2 to 3 (i.e. 10 to 50% yellow). The aim of these trials was to explore if the maturity



of fruit and irradiation doses affected fruit quality. After the holding period at 12 and 20°C, the fruit were all transported in an air-conditioned car to Steritech Ltd., at Narangba Queensland for irradiation treatment. Three doses of 0 (control), 150 Gy (required for domestic supply chain quarantine) and 400 Gy (for export quarantine) were used. Briefly, the trays of fruit were placed on the top layer of a pallet consisting of other fresh produce scheduled for gamma irradiation treatment. The pallet entered the ambient temperature (i.e. 28°C) irradiation chamber via a conveyor and orbited the Cobalt-60 irradiation source for even dose distribution. After a defined period of 30 min to one hour, the pallet exited the irradiation chamber at which point dosimeters were removed and read to record the irradiation dose received. The doses were consistent with domestic and export protocols. Control fruit were left at the same temperature without irradiation exposure. Once completed, the samples were brought back to the Nambour laboratory. Half of the control and irradiated trays were stored at 20°C and the remainder were kept at 12°C for 13 days before being moved 20°C.

Surface coating treatments

Coating treatments were tested on fruit picked from Simpson Farms. Three trays of fruit were coated with a proprietary Akorn Technologies solution. Briefly, two fruit were put into a ziplock bag and a small amount of coating solution was added to the bag. The bag was closed and the fruit were agitated. Once the fruit was fully covered with the solution, it was removed from the bag and gently wiped using a damp microfiber cloth to make sure there was uniform coat and no visible drops left on the fruit surface. Thereafter, the fruit were dried using a blow dryer at the warm setting for 30 seconds. The fruit were kept at 20°C and 65% RH to evaluate the quality. Three un-treated trays held at 20°C were used for comparison to the coated fruit.

1-MCP treatment

1-MCP is a gaseous compound that binds to ethylene receptors in plant organs, thereby inhibiting the action of ethylene, a hormone that promotes fruit ripening and senescence. By blocking ethylene receptors, 1-MCP delays ripening and maintains the quality of fresh produce. 1-MCP was sourced from Agrofresh Ltd, Australia. The trial was repeated twice using fruit harvested from Euri Gold and Simpson farms. At intake, the fruit were treated with 1-MCP at concentration of calculated 800 part per billion (ppb) inside 200 L sealed chambers at 18°C for 1 day. After 1-MCP treatment, half of the fruit were kept at 20°C and the other half were stored at 12°C for 28 days. For Euri Gold fruit, 1-MCP treatment was reapplied after 10 days to the 20°C-stored fruit and after 14 days to the 12°C-stored fruit. Only fruit stored at 12°C were retreated with 1-MCP after 14 days for Simpson fruit. After cold storage with 1-MCP treatment, the fruit were held at 20°C and 65% RH to assess fruit quality.

3. Results

Effect of RH

Holding mangoes at 20°C and 90% RH resulted in a reduction of 2.7 days shelf life as compared to those kept at 20°C and 65% RH (**Table 2**). Majority of fruit reached end of shelf life due to softness. High RH did not affect skin defects like body rot and stem-end rot (data not shown).

Table 2. Effect of high and low RH on ‘Honey Gold’ mango shelf life when stored at 20°C.

Farms	Trial	Relative humidity (%)	Shelf life (day)	Difference (days)
Euri	1	65	19.7	
		90	16.5	-3.2
	2	65	18.9	
		90	17.2	-1.7
Simpson	3	65	23.5	
		90	20.6	-2.9
	4	65	19.9	
		90	17.0	-2.9

Effect of controlled atmosphere (CA) storage on fruit quality and shelf life

As can be seen from **Table 3**, CA treatment at 12°C reduced fruit weight loss, maintained firmness during cold storage and increased postharvest life compared to those stored in air (non-CA), regardless of removal time. CA also inhibited fruit ripening as reflected by more green skin colour (**Image 1**). However, it seems that both growing region (farm) and CA storage contributed to the fruit shelf life. For example, the fruit sourced from Simpson farm and stored under CA extended shelf life by 4.4 days compared to non-CA fruit. (**Table 3**). There was a significant variation in rots between the two farms. Very low incidence of rots was observed on fruit harvested from Euri Gold. A small portion of Simpson fruit stored under the air environment expressed symptom of stem-end rot (SER) after 35 days at 12°C (**Image 1**) whereas no fruit kept under CA showed symptom of SER. CA fruit still developed SER when held at 20°C, but it did occur more slowly than air-stored fruit. Nearly 50% of fruit from Simpson farm suffered from stem-end rot when stored in air for 35 days or more which resulted in shortened shelf life compared to Euri Gold fruit stored in air. CA storage only slightly reduced the incidence of stem-end rot in fruit assessed at end of shelf life (**Table 4**).

There was no difference in eating quality between CA and non-CA stored fruit. The average sensory score was 5.2, which is above acceptability.

Table 3. Weight loss, firmness at cold removal and shelf life of ‘Honey Gold’ mangoes harvested from two farms and stored under controlled atmosphere and air after 21, 28, 35 and 42 days.

Farms	Storage duration (days)	Weight loss (%)		Firmness (shore)		Postharvest Shelf life (days)		Shelf life after removal (days)		Extended shelf life by CA (days)
		CA	Air	CA	Air	CA	Air	CA	Air	
Euri	21	2.4	3.0	71.6	61.8	35.0	32.4	14.0	11.4	2.5
	28	3.2	4.0	66.0	59.7	39.7	38.7	11.7	10.7	1.0
	35	3.9	5.4	61.9	56.3	45.1	44.2	10.1	9.2	1.0
	42	4.8	6.0	54.7	51.3	51.0	49.7	9.0	7.7	1.3
Simpson	21	2.6	3.5	76.9	63.7	35.5	32.0	14.5	11.0	3.5
	28	3.8	4.6	65.3	57.6	40.8	35.8	12.8	7.8	5.0
	35	3.9	5.4	63.2	57.1	45.3	40.8	10.3	5.8	4.6
	42	4.6	5.9	58.9	52.5	50.5	46.1	8.5	4.1	4.5

Air



CA



Image 1. Visual quality (colour and stem-end rot) of HG fruit stored at 12°C under air (left) and CA storage (right) after 35 days and one day at 20°C

Table 4. Incidence of body rot and stem-end rot assessed at the end of storage from ‘Honey Gold’ mangoes sourced from two farms and stored under controlled atmosphere and air at 12°C for up to 42 days and held at 20°C until fruit reached the end of shelf life.

Farms	Incidence of body rot (%)		Incidence of stem-end rot (%)	
	CA	Air	CA	Air
Farm A	1.2	1.8	8.3	11.9
Farm B	20.2	15.5	43.5	48.8

Effect of ethylene treatment on shelf life

As shown in **Table 5**, the HG fruit treated with ethylene had a shorter shelf life than non-treated fruit. However, the loss of shelf life due to ethylene varied depending on pre-treatment duration and fruit source. Euri Gold fruit treated with ethylene lost about 3.4 days of shelf life as compared to non-treated fruit. Holding fruit at 20°C for 4 days before ethylene treatment did not affect the fruit shelf life. In contrast, the effect of ethylene on Simpson fruit was minimal. When ethylene was applied soon after harvest (e.g 1 day) shelf life was shortened by 1.7 days. Fruit kept at 20°C for 4 days before ethylene was applied displayed little treatment effect, especially those held at 24°C post-ethylene. Ethylene treatment did not affect fruit quality issues such as body rot and stem-end rot. It is noted that HG fruit held at 24°C expressed shiny and greasy skin.

Table 5. Effect of ethylene treatment on fruit postharvest shelf life. Fruit were either treated with 100 ppm ethylene at 18°C for 2 days one day after harvest or held at 20°C for 4 days prior to ethylene treatment.

Pre-treatment duration (days) at 20°C	Post-treatment temperature (°C)	Shelf life (days)					
		Farm A			Farm B		
		No C ₂ H ₄	C ₂ H ₄	Reduced SL due to C ₂ H ₄	No C ₂ H ₄	C ₂ H ₄	Reduced SL due to C ₂ H ₄
0	12*	27.5	25.2	-2.3	26.9	25.4	-1.5
	16	28.5	21.6	-7.0	25.5	23.9	-1.6
	20	18.9	15.5	-3.4	19.3	17.0	-2.3
	24	16.4	13.4	-3.0	15.4	13.8	-1.6
4	12*	28.0	25.5	-2.5	27.3	25.5	-1.8
	16	25.1	21.6	-3.5	25.9	25.3	-0.6
	20	21.0	17.4	-3.6	19.3	18.5	-0.8
	24	16.3	14.5	-1.8	16.1	15.9	-0.2

* After ethylene treatment, fruit were stored at 12°C for 12 days and then held at 20°C for ongoing assessment

Effect of irradiation on fruit quality

Irradiating fruit with 150 Gy dose did not affect shelf life (**Table 6**), however increasing the irradiation dose from 150 Gy to 400 Gy did reduce fruit shelf life in some cases. For instance, fruit held at 12°C for 4-5 days then treated with 400 Gr, lost about 2 days when post-treatment was at 20°C. Irradiation had no effect on body and stem-end rot, but it increased the likelihood of shrivel when holding fruit at 20°C (**Image 2**).

Table 6. Effect of pre-treatment temperature, irradiation doses and post-treatment temperature on 'Honey Gold' fruit shelf life.

Farms	Pre-treatment temperature (°C)	Pre-treatment duration (days)	Post-treatment duration (°C)	Fruit shelf life (days)		
				0 Gy	150 Gy	400 Gy
Farm A	20	5	12	22.8	22.0	20.9
			20	21.4	20.5	19.2
	12	5	12	29.4	29.1	28.3
			20	28.0	27.3	26.4
Farm B	20	5	12	20.0	19.6	20.5
			20	18.8	18.7	18.5
	12	5	12	29.4	29.1	29.5
			20	27.7	27.5	25.7

150 Gy



400 Gy



Image 2. Visual quality of 'Honey Gold' fruit observed at the end of shelf life after being treated with 150 Gy (left) and 400 Gy (right).

Coating trial

Coating did not improve the fruit shelf life. Coated fruit had a similar shelf life of 20.8 days vs 20.5 days for un-coated fruit. There was no effect of coating on body and stem-end rot incidence.

1-MCP trial

Treating Honey Gold fruit with 1-MCP at a concentration of 800 ppb for 24 hours did increase fruit shelf life by 2.2-2.7 days when post-treated fruit were held at 20°C. There was no effect of 1-MCP on fruit shelf life if the fruit were kept at 12°C for 28 days and then held at 20°C, although two applications were performed.



Table 5. Effect of 1-MCP treatment at concentration of 800 part per billion and storage temperature on 'Honey Gold' fruit shelf life

Storage temperature (°C)	1-MCP treatment	Shelf life (days)			
		Farm A	Increased SL	Farm B	Increased SL
20	No	19.6		18.7	
	Yes	21.8	2.2	21.4	2.7
12	No	38.6		37	
	Yes	39.5	0.9	36.5	-0.5

Appendix 58

Modelling shelf life of mango report



Modelling Shelf Life of Mango

Summary report

Saeedeh Taghadomi Saberi, Boyd Tarlinton, Yiru Chen, Neil White and Andrew Macnish

Department of Primary Industries

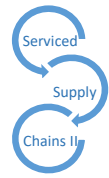
Summary

This report summarises the development and validation of predictive models to predict the residual shelf life¹ (RSL) and chilling injury of Honey Gold (HG), R2E2 and Kensington Pride (KP) mangoes using time × temperature (TxT) and time–temperature unit (TTU) approaches. Models were built using simulation trials across four seasons (2021–22 to 2024–25) for HG and R2E2 and KP trials (2018–19 to 2020–21) from SSC (AM15002) and validated using monitored commercial consignments (78 domestic and 2 international) tracked from key production regions in Queensland and the Northern Territory. Mixed-effects modelling was used to account for drivers of shelf life (e.g., temperature, transport/storage duration, fruit maturity) while capturing systematic variation between regions and seasons. Overall, the work demonstrates that integrating temperature history supports practical estimation of shelf-life distributions within consignments to inform handling, ripening and marketing decisions.

Key findings

- Temperature exposure and time in transit/storage reduce shelf life: higher temperatures and longer durations consistently shortened predicted shelf life in TxT models.
- Fruit maturity indicators matter: dry matter and firmness on arrival were informative predictors of remaining shelf life, supporting the use of simple intake measurements alongside temperature history.
- Humidity during retail storage can extend shelf life: for Honey Gold, higher relative humidity (RH) during retail holding was associated with longer shelf life.
- Region and season drive meaningful variability: models included region and harvest year as random effects to reflect consistent differences in postharvest performance across growing areas and seasons.

¹ The RSL is calculated as the time remaining until the product is unmarketable when stored at 20°C. This temperature was chosen as being representative of the retail environment.



- TTU supports scenario-based decision-making: TTU models enable prediction under multi-stage handling scenarios (changing temperatures over time) and performed well in internal validation, indicating value when conditions vary through the supply chain.
- Models were tested beyond controlled trials: external validation used monitored commercial consignments (including ethylene-treated and untreated fruit), providing an independent assessment under operational conditions.

Appendix 59

‘Red Rhapsody’ strawberry simulation trials report 2023



Predicting fruit quality and shelf life for 'Red Rhapsody' strawberry

A 2023 season summary report

Hung Duong, Lawry Smith, Pip Bryant, Jodie Campbell, Andrew Macnish

Summary

'Red Rhapsody' strawberries were sourced from farm A near Beerwah in south-east Queensland in August 2023. The fruit were transported to the DAF laboratory in Nambour within 5-6 hours of picking. The fruit quality and shelf life response to different domestic supply chain temperatures (5, 10, 15, 20°C) and handling duration (0, 1, 2, 3, 4, 5 days) was quantified. Sub-samples of fruit were regularly removed from storage and held at 5°C and about 90% RH to evaluate remaining shelf life. Key observations included:

- There was a good relationship between cumulative time temperature units (TTU) during postharvest storage and the remaining shelf life of fruit.
- Weight loss of fruit increased with an increase in storage temperature and time. Fruit lost about 2% at the removal time when held at 90% RH.
- When constantly held at 5°C from harvest, fruit exhibited a shelf life of 5.9 days.
- Remaining shelf life of fruit at 5°C was significantly reduced when they were stored at high temperature and longer time. Fruit held at 10°C lost 1 day of shelf life for every day of additional storage, relative to those always maintained at 5°C.
- Shelf life was mainly limited by the loss of fruit surface gloss and presence of wet bruises.

The trial results suggest that a mathematical model could be developed and used to predict fruit shelf life under a range of supply chain conditions. Further trials will be needed to confirm the accuracy of predictive model.



1. Introduction

The Serviced Supply Chains II project is developing decision support for growers and exporters to manage current supply chain risks and deliver more consistent quality fresh produce. Key project activities include:

1. Monitoring and the surveyor network – monitoring and improving supply chain and product performance
2. Modelling and simulations – developing decision aid tools based on shelf life modelling
3. Capacity building and communications – extending project learnings and tools to the broader industry

The current report covers a time by temperature simulation trial completed during the 2023 'Red Rhapsody' strawberry season from farm A. The main objective of the trial was to quantify the fruit quality and shelf life response of fruit to various supply chain conditions. Data generated from the trial will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Plant Material

'Red Rhapsody' strawberry fruit were harvested at commercial maturity (i.e. red colour on >75% of fruit surface) in August (Winter) from farm A located near Beerwah in south-east Queensland. 'Red Rhapsody' is a popular Australian cultivar for domestic and export markets. The fruit were picked at early in the morning and transferred to a nearby pack shed and graded for quality and size. A single layer of about 10-12 fruit was placed into a 250 g capacity plastic vented punnet. Two layers of eight punnets were packed into a cardboard tray. Eight trays with a combined 128 punnets were randomly selected and transported by car at 20°C to the laboratory near Nambour, about 40-50 km away. A temperature logger was placed into strawberry tray at the time of picking to track temperature from harvest to laboratory arrival.

Storage temperature x time treatments

On arrival at the laboratory, the berries were checked to remove those with visual defects such as cut/punctures, bruise and immaturity etc. After that the punnets were randomly assigned to treatment trays, each consisting of 4 punnets. The treatment trays were then placed into different temperatures at about 90% relative humidity (RH) to reflect road transport and storage condition as shown in **Table 1**. At the end of each treatment storage duration, berries were shifted to 5°C and 90% RH for ongoing assessment. The room air temperature and RH were measured using HOBO and RTDs dataloggers. The time and date of treatment commencement and removal were recorded.

Table 1. Storage temperature (°C) x time (days) matrix for 'Red Rhapsody' strawberry fruit. Following storage, the fruit were transferred to 5°C to assess remaining shelf life.

Storage temperature (°C)	Storage duration (days) prior to transfer to 5°C					
	0	1	2	3	4	5
5	X	X	X	X	X	X
10	X	X	X	X	X	X
15	X	X	X	X	X	
20	X	X	X	X		

X are punnets for time x temperature matrix.

Fruit assessment

Fruit quality

Once strawberries were held at 5°C, they were daily assessed for quality until the end of shelf life. Fruit quality was assessed based on four main attributes (Loss of gloss, wet bruise, wilted calyx and mould) using a 3-score scale; where 1 = within allowance; 2 = at limit of allowance and 3 = exceeding allowance. The shelf life was determined when a berry showed any symbols with score of 3 as presented in **Image 1**. The date and primary reason for each fruit reaching end of shelf life were recorded. Fruit were removed from punnets at the end of shelf life. Weight of whole punnet was measured at intake and at removal to calculate fruit weight loss.

Image 1. Symptoms of strawberries showing exceeding allowance (score 3).

Loss of gloss



Dull, matt surface with flat ridges, pronounced seeds

Wet bruise



Any presence of wet bruise

Mould



Any visible mould

Bruised tip/wilted calyx



Wilted/yellow/brown calyx

3. Results

Weight loss

Changes in fruit weight loss is presented in **Table 2**. As can be seen that weight loss of berries was affected by storage temperature and duration. Weight loss increased with an increase in storage temperature and time. There was a time when weight loss of fruit held at 20°C was lower than those held at 15°C and this possibly reflects a difference in RH between the cold rooms. In general, weight loss of fruit at the end of storage treatment was around 2% or less.

Table 2. Changes in weight loss of 'Red Rhapsody' strawberries stored under different storage temperatures over a period of 6 days (n=4).

Storage time (days) Temp (°C)	Average of weight loss at storage removal (%)					
	0	1	2	3	4	5
5	N/A					
10		0.47	0.66	1.13	1.34	1.24
15		0.56	0.87	1.98	1.57	
20		0.85	0.71	1.62		

Total soluble solid (TSS) and titratable acidity (TA)

Total soluble solid content of strawberries when measured at intake was 7.0 °Brix. TA of Winter berries measured at intake was 0.9% while that of Spring ones had 0.73%. TA of the fruit at harvest/intake was 0.80 (data not shown).

Shelf life

Average shelf life of strawberries stored at 5°C was 5.9 days (**Table 3**). In general, the fruit stored at higher temperatures exhibited progressively less shelf life. Extending the storage duration at each temperature also reduced remaining shelf life. Holding fruit at 10°C resulted in a cumulative loss of 1 day shelf life for every day of storage, relative to fruit maintained at 5°C. These findings have implications for strawberries that are transported in mixed loads at temperatures of about 10°C. Significant shelf life is being sacrificed when strawberries are handled above 5°C. This result also suggests that strawberries need to be cooled and stored at low temperature as quick as possible after harvest to ensure the maximum the shelf life. The main reasons for the end of shelf life were due to loss of surface gloss and presence of wet bruises.

Table 3. Average shelf life of 'Red Rhapsody' strawberries at 5°C following storage at different temperatures and times that represent domestic supply chain handling scenarios.

Temp (°C) \ Storage time (days)	Average of residual shelf life at 5°C (days) after storage					
	0	1	2	3	4	5
5	5.9					
10		4.8	3.8	2.4	1.2	0.8
15		5.1	3.5	2.5	1.2	
20		4.3	0.9	0.8		

Shelf life model

The strawberry time x temperature trial captured good quality data showing how storage conditions affect shelf life and fruit quality (**Fig. 1**). In general, shelf life data obtained from all temperatures and duration fitted well against a simple linear regression ($R^2 = 0.88$). This finding suggests that a linear model could be used to predict the remaining shelf life of strawberries under variable supply chain conditions.

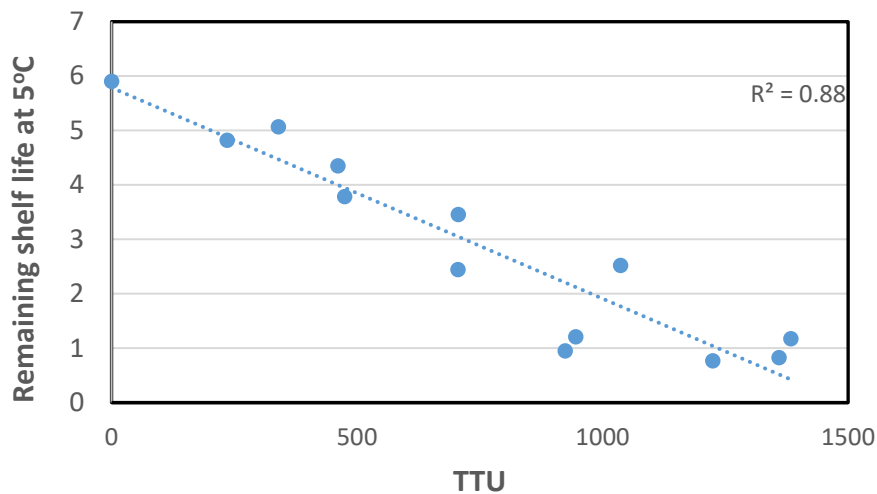


Figure 1. Relationship between remaining shelf life of ‘Red Rhapsody’ strawberries at 5°C following storage at 5, 10, 15 and 20°C. The time x temperature unit (TTU) was calculated based on heat unit from harvest to the end of storage treatment.

4. Summary and next steps

The preliminary time x temperature trial results show the potential of using a linear regression model to predict the remaining shelf life of ‘Red Rhapsody’ strawberries. However, more trials with fruit from the same variety, area, season will be needed to confirm the results. Other factors influencing fruit quality and shelf life such as relative humidity, irradiation, methyl bromide treatment, delayed cooling and weather conditions before harvesting are also recommended to investigate.

Appendix 60

‘Red Rhapsody’ strawberry simulation trials report 2024a



Predicting fruit quality and shelf life for 'Red Rhapsody' strawberry

A 2024 season summary report

Hung Duong, Lawry Smith, Pip Bryant, Jodie Campbell, Andrew Macnish

Queensland Department of Agriculture and Fisheries

Summary

'Red Rhapsody' strawberries were sourced from farm A at Beerwah in the south-east Queensland on 26 June and 29 August 2024. The fruit were transported to DAF laboratory in Nambour within 5-6 hours of picking. The fruit quality and shelf life response to different domestic supply chain temperatures (e.g. 1, 4, 10, 15, 20°C), relative humidity (65, 90%) and duration (0, 1, 2, 3, 5, 7 days) was quantified. Sub-samples of fruit were regularly removed from storage and held at 4°C and 65% RH to evaluate remaining shelf life. Key observations included:

- There was a good relationship between cumulative time temperature units (TTU) during postharvest storage and the remaining shelf life of fruit from both harvests.
- Fruit picked in June had a total soluble solid (TSS) content of 9.2 °Brix whereas those harvested in August had a TSS of 6.25 °Brix. Brix remained unchanged during the storage period at 10°C or below, but it slightly reduced once fruit kept at 15°C and 20°C after 5 days of storage.
- Titratable acidity (TA) of fruit harvested in June and August and measured at intake was 0.9% and 0.73%, respectively. TA did not change over the storage period.
- Weight loss of fruit increased with an increase in storage temperature and time, and with a decrease in RH. Fruit lost about 2% at the removal time when held at 90% RH regardless of temperature. When kept at 4°C and low RH (e.g. 66%), fruit lost its weight five times higher than those stored at same temperature and 90% RH.
- When held at 1°C or 4°C plus 90% RH, fruit harvested in August had 2 or 3 days longer shelf life than those picked in June.
- Remaining shelf life of fruit at 4°C and 65% RH significantly reduced when they were stored at high temperature and longer time. Fruit held at 20°C for 1 and 3 days lost 50% and 83% its shelf life, respectively as compared to those stored at 1°C. Similarly, berries stored at 10°C for 1 and 3 days lost 36% and 46% shelf life, respectively as compared to those kept at 1°C.
- There was not much difference in remaining shelf life between two harvests
- Main reasons for the end of shelf life were due to loss of gloss and wet bruise.
- Fruit picked in August had 5% of mould.

The trial results suggest that shelf life model could be developed and used to predict fruit shelf life under a range of supply chain conditions. Further trials will be needed to confirm the accuracy of predictive model.



1. Introduction

The Serviced Supply Chains II project is developing decision support for growers and exporters to manage current supply chain risks and deliver more consistent quality fresh produce. Key project activities include:

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2. Modelling and simulations – developing decision aid tools based on shelf life modelling
3. Capacity building and communications – extending project learnings and tools to the broader industry

The current report covers time by temperature simulation trials completed during the 2024 “Red Rhapsody” strawberry season with farm A. The main objective of the trials was to quantify the fruit quality and shelf life response of “Red Rhapsody” strawberry to various supply chain condition. In addition, the effect of harvesting season on fruit quality and shelf life was investigated. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Plant Material

‘Red Rhapsody’ strawberry fruit were harvested at commercial maturity (i.e. red colour on >75% of fruit surface) in June (Winter) and August (Spring) from farm A located at Beerwah in south-east Queensland. ‘Red Rhapsody’ is a popular Australian cultivar for domestic and export markets. The fruit were picked at early in the morning and transferred to a nearby pack shed and graded for quality and size. A single layer of about 10-12 fruit was placed into a 250 g capacity plastic vented punnet. Two layers of eight punnets were packed into a cardboard tray. Eight trays with a combined 128 punnets were randomly selected and transported by car at 20°C to the laboratory near Nambour, about 40-50 km away. A temperature logger was placed into strawberry tray at the time of picking to track temperature from harvest to laboratory arrival.

Storage temperature x time treatments

On arrival at the laboratory, the berries were checked to remove those with visual defects such as cut/punctures, bruise and immaturity etc. After that the punnets were randomly assigned to treatment trays, each consisting of 4 punnets. The treatment trays were then placed into different temperatures to reflect road transport and storage condition as shown in **Table 1**. At the end of each treatment storage duration, berries were shifted to 4°C and 60-65% relative humidity (RH) for ongoing assessment. Additional treatments were also tested to evaluate the fruit maximum shelf life at constant temperature and RH. The room air temperature and RH were measured using HOBO and RTDs dataloggers. The time and date of treatment commencement and removal were recorded.

Table 1. Storage temperature (°C) plus relative humidity (RH) x time (days) matrix for 'Red Rhapsody' strawberry fruit. Following storage, the fruit were transferred to 4°C plus 60-65% RH to assess remaining shelf life.

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 60% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	85-90	X	X	X	X	XX	X
4	85-90	X		X		XX	
10	85-90	X	X	X	X	XX	X
15	85-90		X	X	X	XX	
20	85-90		X	X	X		
Fruit	4 60-65	XX				X	

assessment

X are trays for time x temperature matrix and X are trays for measuring Brix and Acidity

Fruit quality

Once strawberries were held at 4°C plus 65% RH, they were daily assessed for quality until the end of shelf life. Fruit quality was assessed based on four main attributes (Loss of gloss, wet bruise, wilted calyx and mould) using a 3-score scale; where 1 = within allowance; 2 = at limit of allowance and 3 = exceeding allowance. The shelf life was determined when a berry showed any symbols with score of 3 as presented in **Image 1**. The date and primary reason for each fruit reaching end of shelf life were recorded. Fruit were removed from punnets at the end of shelf life. Weight of whole punnet was measured at intake and at removal to calculate fruit weight loss.

Image 1. Symptoms of strawberries showing exceeding allowance (score 3).

Loss of gloss



Dull, matt surface with flat ridges, pronounced seeds

Wet bruise



Any presence of wet bruise

Mould



Any visible mould

Bruised tip/wilted calyx



Wilted/yellow/brown calyx

Fruit total soluble solids (TSS) and titratable acidity (TA)

Four punnets of berries were used to assess for TSS and TA at the intake and 5 days after storage. Six berries per punnet were deployed and each was cut in quarter. The juice was captured by squeezing berries through a cheesecloth. TSS was determined with two Ataga refractometers and TA of matching samples was measured by titration.

3. Results

Weight loss

Changes in fruit weight loss is presented in **Figure 1**. As can be seen that weight loss of berries was affected by storage temperature, RH and duration. Weight loss increased with an increase in storage temperature and time when holding at the same RH. There was a time when weight loss of fruit held at 10°C was lower than those held at 4°C and 90% RH because fruit kept at 10°C had higher RH (95%). In general, weight loss of fruit at the end of storage treatment was around 2% or less. Fruit stored at 4°C and low RH (82% in Winter fruit and 66% in Spring fruit) lost its weight between 2.5 and 5 times higher than those kept at 4°C plus 90-92% RH. This result suggests that it is crucial to hold strawberries at as low temperature as possible and high RH (90%) to prolong the shelf life. On average, berries lost 2.6% weight by the end of the shelf life.

Total soluble solid (TSS) and titratable acidity (TA)

Total soluble solid content of strawberries picked in Winter and measured at intake was 9.2 °Brix whereas those harvested in Spring had 6.25 °Brix. TSS of fruit did not change over a storage period of 5 days when held at 10°C or below. °Brix reduced slightly once the fruit were kept at 15°C and 20°C for 5 days (**Figure 2**). TA of Winter berries measured at intake was 0.9% while that of Spring ones had 0.73%. TA of the fruit remained unchanged over the storage period (data not shown).

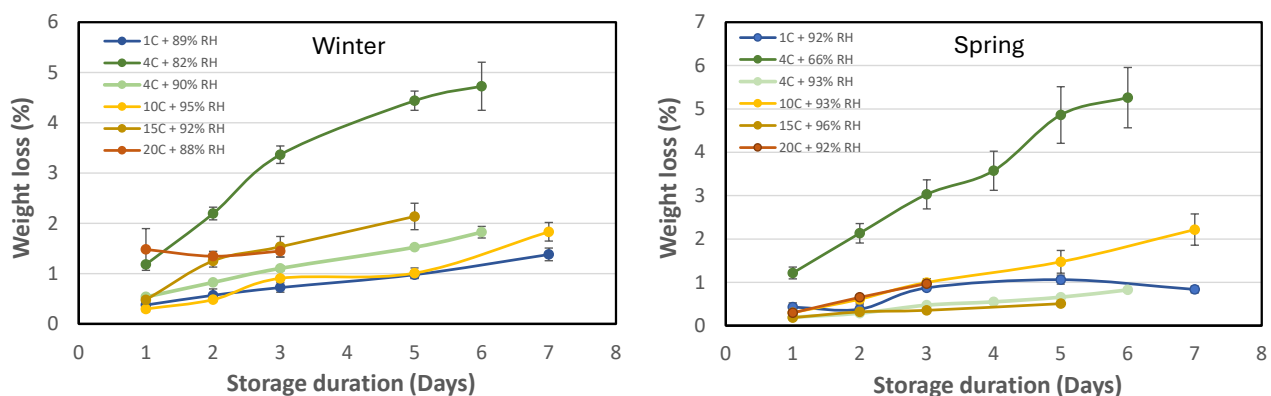


Figure 1. Changes in weight loss of berries harvested in Winter and Spring and stored under different storage temperatures and relative humidity over a period of 7 days (n=4).

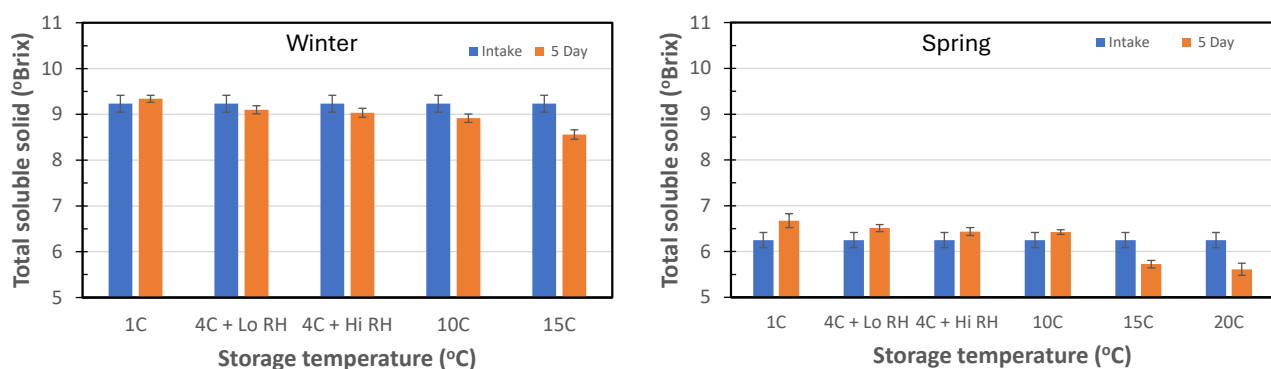


Figure 2. Measurements of total soluble solid content from berries harvested in Winter and Spring at intake and 5 days after storage at different storage temperatures and relative humidity (n=4).

Shelf life

Averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 82% RH for Winter fruit and 66% RH for Spring fruit after storage at different temperatures and duration is presented in **Table 2**. In general, the fruit stored at lower temperatures and higher RH had a longer shelf life than those kept at higher temperatures and lower RH. Spring strawberries held at 1°C plus 92% had 13.4 days whilst those picked in Winter and stored at the same condition had a 11.2-day shelf life, which is 2.2 days shorter. Fruit stored at 4°C and 90-93% RH had a little shorter shelf life compared to those stored at 1°C. In addition, holding fruit at 4°C plus low RH (82% in Winter vs 66% in Spring) shortened shelf life between 1-4 days in comparison with those stored at same temperature and 90% and 93% RH.

Remaining shelf life of berries at 4°C and low RH reduced with an increase in storage temperature and duration. For example, fruit held at 20°C for 2 or 3 days before shifting to 4°C had about 3-5 days shorter which was nearly 50-83% loss as compared those kept at 1°C. Similarly, berries stored at 10°C for 1 and 3 days lost 36% and 46% shelf life, respectively as compared to those kept at 1°C. This result suggest that strawberries need to be cooled and stored at low temperature as quick as possible after harvest to have the maximum the shelf life.

The percentage of fruit reaching the end of shelf life (ESL) due to loss of gloss was 73.5% and 55.5% for fruit picked in Winter and Spring, respectively. Second reason for ESL was wet bruise (25.1% in Winter and 49.1% in Spring). The incidence of fruit with mould was 5.1% for those picked after rain in Spring.

Table 2. Heat map of averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 82% RH for Winter fruit and 66% RH for Spring fruit after storage at different temperatures and duration (green → red: high → low).

Winter

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 82% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	89	11.2	7.3	6.5	5.4	4.4	3.5
4	90	9.1		6.3		4.2	
10	95	10.7	6.1	5.8	5.8	3.8	2.2
15	92		5.4	4.7	4.3	1.7	
20	88		5.3	3.3	2.9		
4	82	7.8					

Spring

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 66% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	92	13.4	10.7	7.8	9.3	9.3	6.4
4	93	12.6		5.1		6.7	
10	93	7.5	6.8	6.8	5.0	2.6	0.5
15	96		6.6	3.4	3.6	0.8	
20	92		5.4	2.7	1.6		
4	66	8.5					

Shelf life model

Strawberry time x temperature trials captured good quality data showing how storage conditions affect shelf life and fruit quality. In general, shelf life data obtained from all temperatures and duration fitted quite well with regression line ($R^2 = 0.68 - 0.88$), except for those picked in Winter and stored at 1°C. This finding suggests that the model could be used to predict the remaining shelf life of strawberries under variable supply chain conditions.

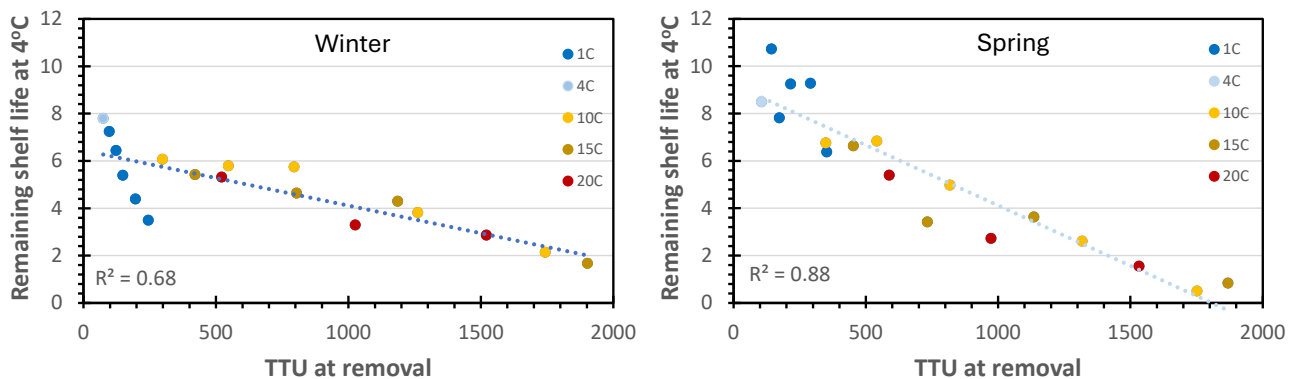


Figure 3. Relationship between remaining shelf life of strawberries harvested in Winter and Spring, and stored at 4°C and time x temperature unit (TTU) calculated based on heat unit from harvest to the end of storage treatment.

4. Summary and next steps

These time x temperature trial results showed the potential of using model to predict the remaining shelf life of strawberries. However, more trials with fruit from the same variety, area, season will be needed to confirm the results. Other factors influencing fruit quality and shelf life such as irradiation, methyl bromide treatment, delay cooling and weather condition before harvesting are also recommended to investigate.

Appendix 61

‘Red Rhapsody’ strawberry simulation trials report 2024b



Predicting fruit quality and shelf life for 'Red Rhapsody' strawberry

A 2024 season summary report

Hung Duong, Lawry Smith, Pip Bryant, Jodie Campbell, Andy Mead, Andrew Macnish

Queensland Department of Agriculture and Fisheries

Summary

'Red Rhapsody' strawberries were sourced from Farm A in Bundaberg, Central Queensland on 23 July and 5 September 2024. The fruit were transported to DAF laboratory in Nambour within 8-10 hours of picking. The fruit quality and shelf life response to different domestic supply chain temperatures (e.g. 1, 4, 10, 15, 20°C), relative humidity (65, 90%) and duration (0, 1, 2, 3, 5, 7 days) was quantified. Sub-samples of fruit were regularly removed from storage and held at 4°C and 65% RH to evaluate remaining shelf life. Key observations included:

- There was a strong relationship between cumulative time temperature units (TTU) during postharvest storage and the remaining shelf life of fruit from both harvests.
- Fruit picked in July had a total soluble solid (TSS) content of 8.6 °Brix whereas those harvested in September had a TSS of 6.14 °Brix. Brix remained unchanged during the storage period at 10°C or below, but it slightly reduced once fruit kept at 15°C after 5 days of storage.
- Titratable acidity (TA) of fruit harvested in July and September and measured at intake was 0.8% and 0.67%, respectively. TA did not change over the storage period.
- Weight loss of fruit increased with an increase in storage temperature and time, and with a decrease in RH. Fruit lost about 1.5% at the removal time when held at 90% RH regardless of temperature. When kept at 4°C and low RH (e.g 69%), fruit lost its weight five times higher than those stored at same temperature and 90% RH.
- When held at constant storage condition, fruit harvested in July had about 2-9 days longer shelf life than those picked in Sep.
- Remaining shelf life of fruit at 4°C and 61-69% RH significantly reduced when they were stored at high temperature and longer time. Fruit held at 20°C for 1 and 3 days lost 29% and 87% its shelf life, respectively as compared to those stored at 1°C. Similarly, berries stored at 15°C for 2 and 3 days lost 42% and 65% shelf life, respectively as compared to those kept at 1°C.
- On average, shelf life of Winter fruit was between 2.2-4.7 days longer than those picked in Spring
- Main reasons for the end of shelf life were due to loss of gloss and wet bruise.
- Fruit picked in July and September had 5.8% and 11.7% suffering from mould, respectively.

The trial results suggest that shelf life model could be developed and used to predict fruit shelf life under a range of supply chain conditions. Further trials will be needed to confirm the accuracy of predictive model.



1. Introduction

The Serviced Supply Chains II project is developing decision support for growers and exporters to manage current supply chain risks and deliver more consistent quality fresh produce. Key project activities include:

1. Monitoring and the surveyor network – monitoring and improving supply chain and product performance
2. Modelling and simulations – developing decision aid tools based on shelf life modelling
3. Capacity building and communications – extending project learnings and tools to the broader industry

The current report covers time by temperature simulation trials completed during the 2024 'Red Rhapsody' strawberry season with farm B. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Red Rhapsody' strawberry to various supply chain condition. In addition, the effect of harvesting season on fruit quality and shelf life was investigated. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Plant Material

'Red Rhapsody' strawberry fruit were harvested at commercial maturity (i.e. red colour on >75% of fruit surface) on 23 July (Winter) and on 5 September (Spring) from farm B located near Bundaberg in Central Queensland. 'Red Rhapsody' is a popular Australian cultivar for domestic and export markets. The fruit were picked at early in the morning and transferred to a nearby pack shed and graded for quality and size. A single layer of about 10-12 fruit was placed into a 250 g capacity plastic vented punnet. Two layers of eight punnets were packed into a cardboard tray. Eight trays with a combined 128 punnets were randomly selected and placed in mini esky running at 11-13°C, then transported by car to the laboratory near Nambour, about 270 km away. A temperature logger was placed into strawberry tray at the time of picking to track temperature from harvest to laboratory arrival.

Storage temperature x time treatments

On arrival at the laboratory, the berries were checked to remove those with visual defects such as cut/punctures, bruise and immaturity etc. After that the punnets were randomly assigned to treatment trays, each consisting of 4 punnets. The treatment trays were then placed into different temperatures to reflect road transport and storage condition as shown in **Table 1**. At the end of each treatment storage duration, berries were shifted to 4°C and 60-65% relative humidity (RH) for ongoing assessment. Additional treatments were also tested to evaluate the fruit maximum shelf life at constant temperature and RH. The room air temperature and RH were measured using HOBO and RTDs dataloggers. The time and date of treatment commencement and removal were recorded.

Table 1. Storage temperature (°C) plus relative humidity (RH) x time (days) matrix for 'Red Rhapsody' strawberry fruit. Following storage, the fruit were transferred to 4°C plus 60-65% RH to assess remaining shelf life.

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 60% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	85-90	X	X	X	X	XX	X
4	85-90	X		X		XX	
10	85-90	X	X	X	X	XX	X
15	85-90		X	X	X	XX	
20	85-90		X	X	X		
4	60-65	XX				X	

X are trays for time x temperature matrix and X are trays for measuring Brix and Acidity

Fruit assessment

Fruit quality

Once strawberries were held at 4°C plus 65% RH, they were daily assessed for quality until the end of shelf life. Fruit quality was assessed based on four main attributes (Loss of gloss, wet bruise, wilted calyx and mould) using a 3-score scale; where 1 = within allowance; 2 = at limit of allowance and 3 = exceeding allowance. The shelf life was determined when a berry showed any symbols with score of 3 as presented in **Image 1**. The date and primary reason for each fruit reaching end of shelf life were recorded. Fruit were removed from punnets at the end of shelf life. Weight of whole punnet was measured at intake and at removal to calculate fruit weight loss.

Image 1. Symptoms of strawberries showing exceeding allowance (score 3).

Loss of gloss



Dull, matt surface with flat ridges, pronounced seeds

Wet bruise



Any presence of wet bruise

Mould



Any visible mould

Bruised tip/wilted calyx



Wilted/yellow/brown calyx

Fruit total soluble solids (TSS) and titratable acidity (TA)

Four punnets of berries were used to assess for TSS and TA at the intake and 5 days after storage. Six berries per punnet were deployed and each was cut in quarter. The juice was captured by squeezing berries through a cheesecloth. TSS was determined with two Ataga refractometers and TA of matching samples was measured by titration.

3. Results

Weight loss

Changes in fruit weight loss is presented in **Figure 1**. As can be seen that weight loss of berries was affected by storage temperature, RH and duration. Weight loss increased with an increase in storage temperature and time when holding at the same RH. There was a time when weight loss of fruit held at 10°C was lower than those held at 4°C and 90% RH because fruit kept at 10°C had higher RH (95%). In general, weight loss of fruit at the end of storage treatment was around 1.5% or less. Fruit stored at 4°C and low RH (69% in Spring fruit and 61% in Winter fruit) lost its weight between 4 and 7 times higher than those kept at 4°C plus 90-92% RH. This result suggests that it is crucial to hold strawberries at as low temperature as possible and high RH (90%) to prolong the shelf life. On average, berries lost 2.5-3.2% weight by the end of shelf life.

Total soluble solid (TSS) and titratable acidity (TA)

TSS content of strawberries picked in Winter and measured at intake was 8.6 °Brix whereas those harvested in Spring had 6.15 °Brix. TSS of fruit did not change over a storage period of 5 days when held at 10°C or below. °Brix reduced slightly once the fruit were kept at 15°C for 5 days (**Figure 2**). TA of Winter berries measured at intake was 0.8% while it was 0.67% for Spring fruit. Fruit TA did not change during storage.

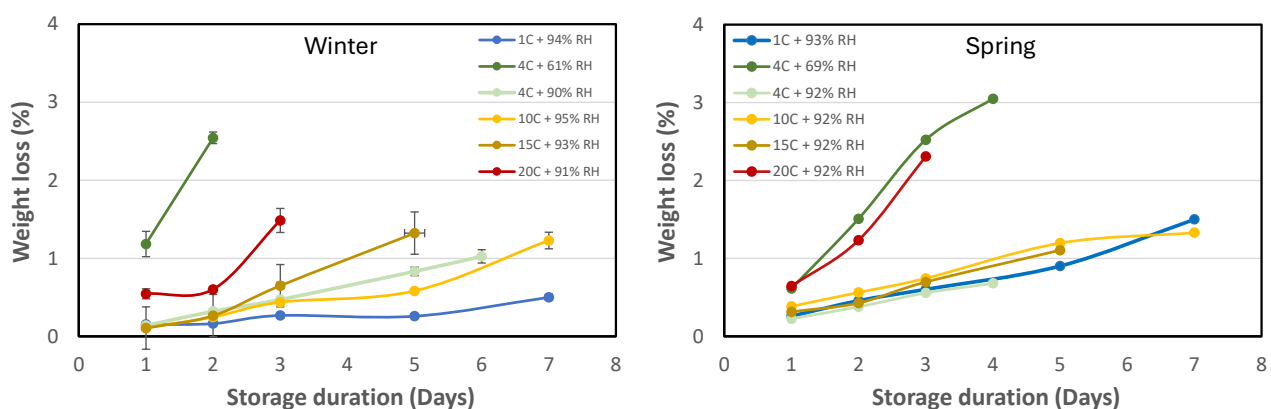


Figure 1. Changes in weight loss of berries harvested in Winter and Spring and stored under different storage temperatures and relative humidity over a period of 7 days (n=4).

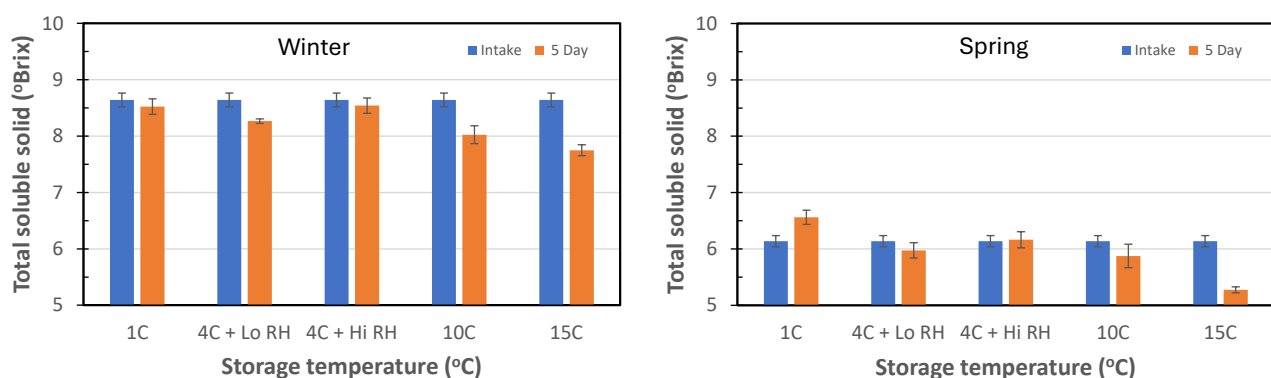


Figure 2. Measurements of total soluble solid content from berries harvested in Winter and Spring at intake and 5 days after storage at different storage temperatures and relative humidity (n=4).



Shelf life

Averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 61% RH for Winter fruit and 69% RH for Spring fruit after storage at different temperatures and duration is presented in **Table 2**. In general, the fruit stored at lower temperatures and higher RH had a longer shelf life than those kept at higher temperatures and lower RH. Spring strawberries held at 1°C plus 94% had 23.8 days whilst those picked in Winter and stored at the same condition had a 14.6 day shelf life, which is 9.2 days shorter. Fruit stored at 4°C and 90-92% RH had shorter shelf life compared to those stored at 1°C. In addition, holding fruit at 4°C plus low RH (61% in Winter vs 69% in Spring) shortened shelf life between 4.1-5.2 days in comparison with those stored at same temperature and 90% and 93% RH.

Remaining shelf life of berries at 4°C and low RH reduced with an increase in storage temperature and duration. For example, fruit held at 20°C for 2 or 3 days before shifting to 4°C had about 4-5 days shorter which was nearly 65-87% loss as compared those kept at 1°C. Similarly, berries stored at 15°C for 2 and 3 days lost 43% and 66% shelf life, respectively as compared to those kept at 1°C. Averaged remaining shelf life of Spring fruit was 2.2-4.7 days shorter than those picked in Winter. This result suggest that strawberries need to be cooled and stored at low temperature as quick as possible after harvest to have the maximum the shelf life.

The percentage of fruit reaching the end of shelf life (ESL) due to loss of gloss was 78.1% and 62.5% for fruit picked in Winter and Spring, respectively. Second reason for ESL was wet bruise (18.4% in Winter and 43.7% in Spring). The incidence of fruit with mould was 5.8% and 11.7% for Winter and Spring fruit, respectively.

Table 2. Heat map of averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 82% RH for Winter fruit and 66% RH for Spring fruit after storage at different temperatures and duration (green → red: high → low).

Winter

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 61% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	94	23.8	9.0	11.1	9.6	8.5	7.5
4	90	13.6		8.4		6.5	
10	95	10.0	10.6	8.3	8.2	6.4	3.3
15	93		9.7	7.5	5.2	4.6	
20	91		8.6	6.3	3.6		
4	61	9.5					

Spring

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 69% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	93	14.6	5.6	7.5	6.0	4.8	5.0
4	92	12.5		5.8		5.2	
10	92	6.7	5.3	6.3	4.8	2.0	0.9
15	92		5.2	4.3	2.1	0.4	
20	91		3.9	2.6	0.8		
4	69	7.3					

Shelf life model

In general, shelf life data obtained from all temperatures and duration (TTU) fitted well with regression line ($R^2 = 0.83 - 0.9$). This suggests that the model could be used to predict remaining shelf life.

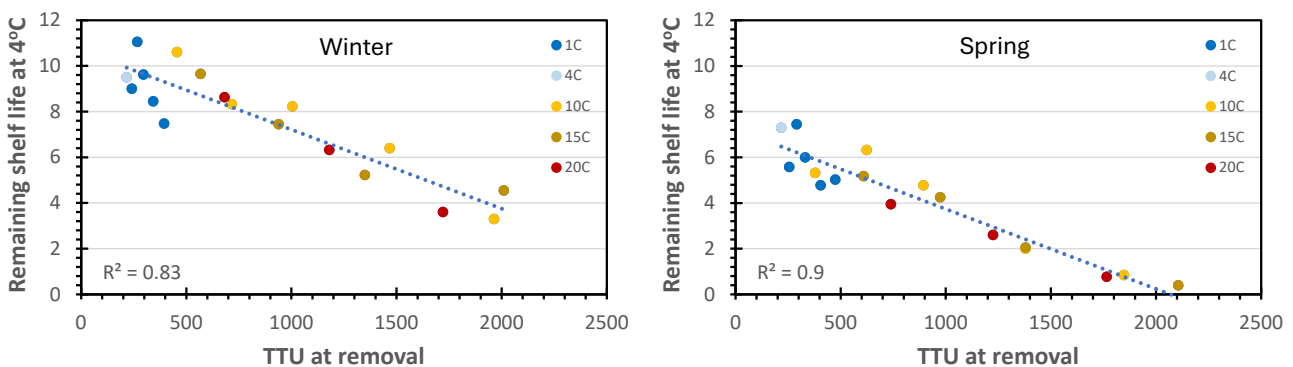


Figure 3. Relationship between remaining shelf life of strawberries harvested in Winter and Spring, and stored at 4°C and time x temperature unit (TTU) calculated based on heat unit from harvest to the end of storage treatment.



4. Summary and next steps

These time x temperature trial results showed the potential of using model to predict the remaining shelf life of strawberries. However, more trials with fruit from the same variety, area, season will be needed to confirm the results. Other factors influencing fruit quality and shelf life such as irradiation, methyl bromide treatment, delay cooling and weather condition before harvesting are also recommended to investigate.

Appendix 62

‘Red Rhapsody’ strawberry simulation trials report 2024c



Predicting fruit quality and shelf life for 'Red Rhapsody' strawberry

A 2024 season summary report

Hung Duong, Lawry Smith, Pip Bryant, Jodie Campbell, Andrew Macnish

Queensland Department of Agriculture and Fisheries

Summary

'Red Rhapsody' strawberries were sourced from farm C at Caboolture in the south-east Queensland on 25 June and 29 August 2024. The fruit were transported to DAF laboratory in Nambour within 5-6 hours of picking. The fruit quality and shelf life response to different domestic supply chain temperatures (e.g. 1, 4, 10, 15, 20°C), relative humidity (65, 90%) and duration (0, 1, 2, 3, 5, 7 days) was quantified. Sub-samples of fruit were regularly removed from storage and held at 4°C and 65% RH to evaluate remaining shelf life. Key observations included:

- There was a good relationship between cumulative time temperature units (TTU) during postharvest storage and the remaining shelf life of fruit from both harvests.
- Fruit picked in June had a total soluble solid (TSS) content of 9.2 °Brix whereas those harvested in August had a TSS of 5.85 °Brix. Brix remained unchanged during the storage period at 10°C or below, but it slightly reduced once fruit kept at 15°C and 20°C after 5 days of storage.
- Titratable acidity (TA) of fruit harvested in June and August and measured at intake was 0.74% and 0.55%, respectively. TA did not change over the storage period.
- Weight loss of fruit increased with an increase in storage temperature and time, and with a decrease in RH. Fruit lost about 3% or below at the removal time when held at 90% RH regardless of temperature. When kept at 4°C and low RH (e.g 80% and 66%), fruit lost its weight 3-8 times higher than those stored at same temperature and 90% and 93% RH, respectively.
- When held at 1°C plus 90% RH, fruit harvested in August had 6 days longer shelf life than those picked in June.
- Remaining shelf life of fruit at 4°C and 80% and 66% RH significantly reduced when they were stored at high temperature and longer time. Fruit held at 20°C for 2 and 3 days lost between 28% and 43% shelf life in June fruit, and 50%-92% its shelf life in August fruit, respectively as compared to those stored at 1°C. Similarly, berries stored at 15°C for 2 and 3 days lost 20% and 53% shelf life, respectively as compared to those kept at 1°C.
- Averaged remaining shelf life of Spring fruit was 1.5-4.1 days shorter than those picked in Winter
- Main reasons for the end of shelf life were due to loss of gloss and wet bruise.
- Fruit picked in August had 6.1% of mould.

The trial results suggest that shelf life model could be developed and used to predict fruit shelf life under a range of supply chain conditions. Further trials will be needed to confirm the accuracy of predictive model.



1. Introduction

The Serviced Supply Chains II project is developing decision support for growers and exporters to manage current supply chain risks and deliver more consistent quality fresh produce. Key project activities include:

1. Monitoring and the surveyor network – monitoring and improving supply chain and product performance
2. Modelling and simulations – developing decision aid tools based on shelf life modelling
3. Capacity building and communications – extending project learnings and tools to the broader industry

The current report covers time by temperature simulation trials completed during the 2024 'Red Rhapsody' strawberry season with farm C. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Red Rhapsody' strawberry to various supply chain condition. In addition, the effect of harvesting season on fruit quality and shelf life was investigated. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Plant Material

'Red Rhapsody' strawberry fruit were harvested at commercial maturity (i.e. red colour on >75% of fruit surface) on 25 June (Winter) and on 29 August (Spring) from farm C located near Caboolture in south-east Queensland. 'Red Rhapsody' is a popular Australian cultivar for domestic and export markets. The fruit were picked at early in the morning and transferred to a nearby pack shed and graded for quality and size. Double layers of about 12-15 fruit were placed into a 350 g capacity plastic vented punnet. A single layer of ten punnets were packed into a cardboard tray. Fruit picked on 25 June were stored at 2.5°C overnight at the pack shed. Nice trays for fruit picked in June and twelve trays for fruit harvest in August were randomly selected at 11 am and transported by car at 20°C to the laboratory near Nambour, about 70 km away. A temperature logger was placed into strawberry tray at the time of picking to track temperature from harvest to laboratory arrival.

Storage temperature x time treatments

On arrival at the laboratory, the berries were checked to remove those with visual defects such as cut/punctures, bruise and immaturity etc. The fruit were repacked into a single layer plastic punnet, each consisting of 10 berries. This repacking makes it easier for daily quality assessment. After that the punnets were randomly assigned to treatment trays, each consisting of 4 punnets. The treatment trays were then placed into different temperatures to reflect road transport and storage condition as shown in **Table 1**. At the end of each treatment storage duration, berries were shifted to 4°C and 60-65% relative humidity (RH) for ongoing assessment. Additional treatments were also tested to evaluate the fruit maximum shelf life at constant temperature and RH. The room air temperature and RH were measured using HOBO and RTDs dataloggers. The time and date of treatment commencement and removal were recorded.

Table 1. Storage temperature (°C) plus relative humidity (RH) x time (days) matrix for 'Red Rhapsody' strawberry fruit. Following storage, the fruit were transferred to 4°C plus 60-65% RH to assess remaining shelf life.

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 60% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	85-90	X	X	X	X	XX	X
4	85-90	X		X		XX	
10	85-90	X	X	X	X	XX	X
15	85-90		X	X	X	XX	
20	85-90		X	X	X		
Fruit	4 60-65	XX				X	

assessment

X are trays for time x temperature matrix and X are trays for measuring Brix and Acidity

Fruit quality

Once strawberries were held at 4°C plus 65% RH, they were daily assessed for quality until the end of shelf life. Fruit quality was assessed based on four main attributes (Loss of gloss, wet bruise, wilted calyx and mould) using a 3-score scale; where 1 = within allowance; 2 = at limit of allowance and 3 = exceeding allowance. The shelf life was determined when a berry showed any symbols with score of 3 as presented in **Image 1**. The date and primary reason for each fruit reaching end of shelf life were recorded. Fruit were removed from punnets at the end of shelf life. Weight of whole punnet was measured at intake and at removal to calculate fruit weight loss.

Image 1. Symptoms of strawberries showing exceeding allowance (score 3).

Loss of gloss



Dull, matt surface with flat ridges, pronounced seeds

Wet bruise



Any presence of wet bruise

Mould



Any visible mould

Bruised tip/wilted calyx



Wilted/yellow/brown calyx

Fruit total soluble solids (TSS) and titratable acidity (TA)

Four punnets of berries were used to assess for TSS and TA at the intake and 5 days after storage. Six berries per punnet were deployed and each was cut in quarter. The juice was captured by squeezing berries through a cheesecloth. TSS was determined with two Ataga refractometers and TA of matching samples was measured by titration.

3. Results

Weight loss

Changes in fruit weight loss is presented in **Figure 1**. As can be seen that weight loss of berries was affected by storage temperature, RH and duration. Weight loss increased with an increase in storage temperature and time when holding at the same RH. Weight loss of fruit picked in Winter and held at 10°C plus 95% was lower than those held at 4°C and 90% RH. Similarly, the fruit harvested in Spring and stored at 15°C plus 96% RH lost only 0.9% its weight, which was much lower compared to those held at 10°C and 92% RH. In general, weight loss of fruit at the end of storage treatment was 3% or less. Fruit stored at 4°C and low RH (80% in Winter fruit and 66% in Spring fruit) lost its weight between 3 and 8 times higher than those kept at 4°C plus 90-93% RH. This result suggests that it is crucial to hold strawberries at as low temperature as possible and high RH (90%) to prolong the shelf life. On average, berries lost 3.2% weight by the end of shelf life.

Total soluble solid (TSS) and titratable acidity (TA)

TSS content of strawberries picked in Winter and measured at intake was 9.2 °Brix whereas those harvested in Spring had 5.85 °Brix. TSS did not change over a storage period of 5 days when held at 10°C or below in Winter fruit and at 15°C or below in Spring fruit. °Brix reduced slightly once the fruit were kept at 10°C, 15°C in Winter fruit and 20°C in Spring fruit after 5 days (**Figure 2**). TA of Winter berries measured at intake was 0.74% while it was 0.55% for Spring fruit. TA remained unchanged over the storage period (data not shown).

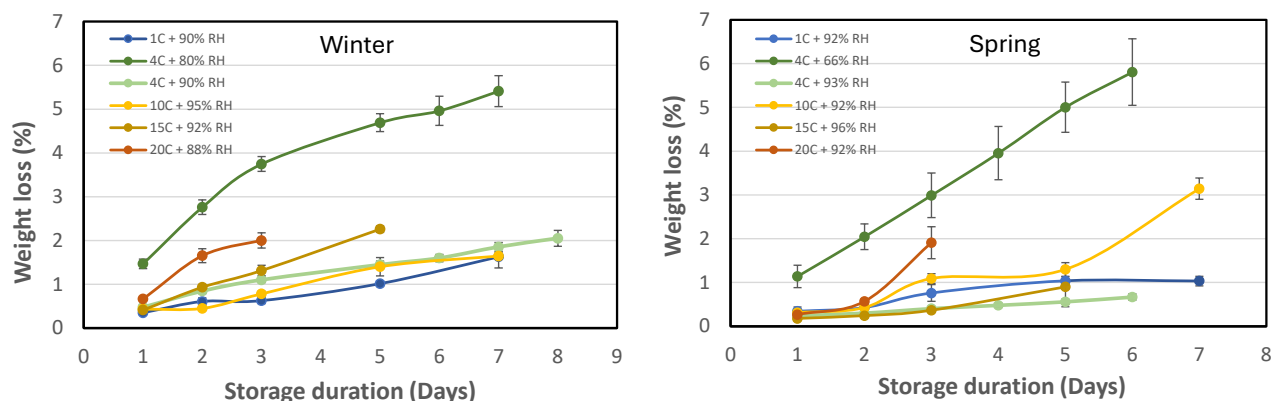


Figure 1. Changes in weight loss of berries harvested in Winter and Spring and stored under different storage temperatures and relative humidity over a period of 7 days (n=4).

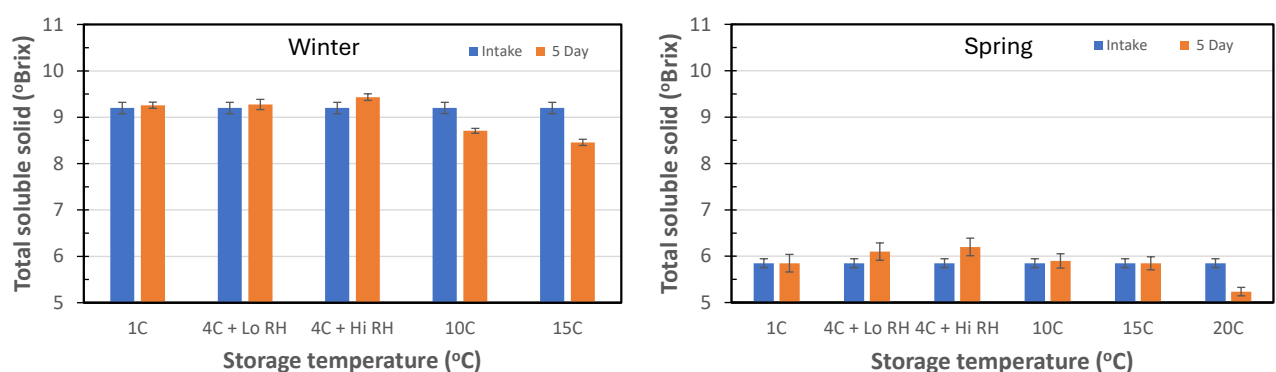


Figure 2. Measurements of total soluble solid content from berries harvested in Winter and Spring at intake and 5 days after storage at different storage temperatures and relative humidity (n=4).



Shelf life

The shelf life of strawberries stored at constant temperature and RH, and those held at 4°C and 80% RH for Winter fruit and 66% RH for Spring fruit following storage at different temperatures and duration is presented in **Table 2**. In general, the fruit stored at lower temperatures and higher RH had a longer shelf life than those kept at higher temperatures and lower RH. Spring strawberries held at 1°C plus 92% had 18.1 days whilst those picked in Winter and stored at the same condition had 12.1 days of shelf life, which is 6 days shorter. Fruit stored at 4°C and 89-93% RH had around 11 days of shelf life that was 3-4 days longer than those kept at same temperature and at low RH (80% in Winter vs 66% in Spring).

Remaining shelf life of fruit at 4°C and low RH reduced with an increase in storage temperature and duration. For example, Winter fruit held at 20°C for 2 or 3 days before shifting to 4°C had about 2.6-3.5 days shorter than those kept at 1°C at the same time whereas Spring fruit lost 3.5-7 days shelf life as compared to those stored at 1°C. This is equivalent to 28-92% loss of shelf life. Similarly, berries stored at 15°C for 2 and 3 days lost between 20% and 53% shelf life, respectively as compared to those kept at 1°C. Averaged remaining shelf life of Spring fruit was 1.5-4.1 days shorter than those picked in Winter. This result suggest that strawberries need to be cooled and stored at low temperature as quick as possible after harvest to have the maximum the shelf life.

The percentage of fruit reaching the end of shelf life (ESL) due to loss of gloss was 97% and 56% for fruit picked in Winter and Spring, respectively. Second reason for ESL was wet bruise (3.8% in Winter and 51.7% in Spring). The incidence of fruit with mould was 6.1% for those picked after rain in Spring.

Table 2. Heat map of averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 82% RH for Winter fruit and 66% RH for Spring fruit after storage at different temperatures and duration (green → red: high → low).

Winter

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 80% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	89	12.1	8.3	8.5	8.2	6.5	4.5
4	90	10.6		7.8		5.2	
10	95	12.2	7.7	7.8	7.6	5.0	3.5
15	92		6.4	6.7	5.7	3.3	
20	88		7.6	6.1	4.7		
4	80	8.2					

Spring

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 55% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	92	18.1	9.5	7.1	7.6	8.0	6.3
4	93	11.4		5.5		6.0	
10	92	6.7	7.2	7.0	5.7	1.3	0.6
15	96		6.8	3.7	3.5	0.9	
20	92		6.1	3.6	0.6		
4	66	7.2					

Shelf life model

In general, shelf life data obtained from all temperatures and duration fitted quite well with regression line ($R^2 = 0.66 - 0.91$), except for those picked in Winter and stored at 1°C. This finding suggests that the model could be used to predict the remaining shelf life of strawberries under variable supply chain conditions.

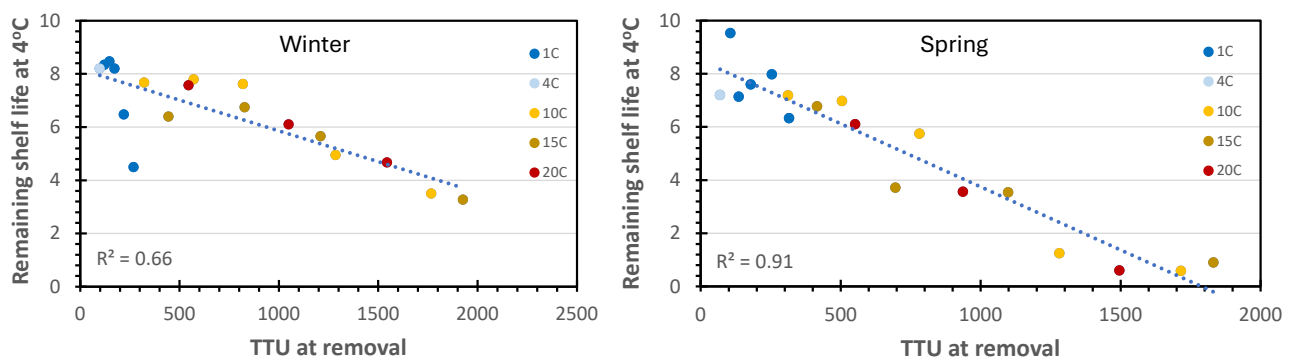


Figure 3. Relationship between remaining shelf life of strawberries harvested in Winter and Spring, and stored at 4°C and time x temperature unit (TTU) from harvest to the end of storage treatment.



4. Summary and next steps

These time x temperature trial results showed the potential of using model to predict the remaining shelf life of strawberries. However, more trials with fruit from the same variety, area, season will be needed to confirm the results. Other factors influencing fruit quality and shelf life such as irradiation, methyl bromide treatment, delay cooling and weather condition before harvesting are also recommended to investigate.

Appendix 63

‘Red Rhapsody’ strawberry simulation trials report 2025a



Predicting fruit quality and shelf life for 'Red Rhapsody' strawberry

A 2025 season summary report

Hung Duong, Lawry Smith, Pip Bryant, Andrew Macnish

Queensland Department of Primary Industries

Summary

'Red Rhapsody' strawberries were sourced from farm A in Beerwah, Southern Queensland, on 16 June and 16 July 2025. The fruit was transported to the Department of Primary Industry (DPI) laboratory in Nambour within 2-3 hours of picking. The study quantified the fruit quality and shelf-life response to various domestic supply chain conditions, including temperature (1°C, 4°C, 10°C, 15°C, 20°C), relative humidity (RH) (60%, 90%), and storage duration (0, 1, 2, 3, 5, 7 days). Sub-samples were periodically removed from storage and held at 4°C and 60% RH to evaluate remaining shelf life.

Key observations

- A moderate to strong relationship was observed between cumulative time–temperature units (TTU) during postharvest storage and the remaining shelf life of fruit from both harvests.
- Fruit harvested in June had a total soluble solids (TSS) content of 9.0 °Brix, whereas July-harvested fruit had a slightly lower TSS of 8.8 °Brix.
- Titratable acidity (TA) at intake was 0.77% for June fruit and 0.81% for July fruit.
- Weight loss increased with higher storage temperature, longer storage duration, and lower relative humidity (RH). Weight loss was minimal (<2%) in treatments combining high humidity with temperatures of 10°C or less. At 4°C and low RH (e.g. 63%), weight loss was 1.5- to 4-fold higher than at the same temperature under 90% RH.
- Remaining shelf life at 4°C and 63% RH decreased significantly with increasing pre-storage temperature and duration. Fruit held at 20°C for 2–3 days prior to transfer to 4°C exhibited a reduction of approximately 7–8 days (43–56%) compared with fruit maintained at 1°C. Similarly, fruit stored at 10°C for 2 days showed a 16–25% reduction in shelf life relative to those kept at 1 °C.
- Remaining shelf life at 4°C was similar between the two harvests.
- The primary causes of end of shelf life were loss of gloss and wet bruising.

These results indicate that a shelf life model can be developed to predict fruit shelf life under a range of supply chain conditions. However, further trials are required to validate the accuracy and robustness of the predictive model.



1. Introduction

The Serviced Supply Chains II project is developing decision support for growers and exporters to manage current supply chain risks and deliver more consistent quality fresh produce. Key project activities include:

1. Monitoring and the surveyor network – monitoring and improving supply chain and product performance
2. Modelling and simulations – developing decision aid tools based on shelf life modelling
3. Capacity building and communications – extending project learnings and tools to the broader industry

The current report covers time by temperature simulation trials completed during the 2025 'Red Rhapsody' strawberry season with Ashburn farm. The main objective of the trials was to quantify the fruit quality and shelf life response of 'Red Rhapsody' strawberry to various supply chain condition. In addition, the effect of harvesting season on fruit quality and shelf life was investigated. Data generated from the trials will assist in developing fruit quality and shelf life prediction models.

2. Materials and methods

Plant Material

'Red Rhapsody' strawberry fruit were harvested at commercial maturity (i.e. red colour on >75% of fruit surface) on 16th June and 16th July from farm A located at Beerwah in south-east Queensland. 'Red Rhapsody' is a popular Australian cultivar for domestic and export markets. The fruit were picked at early in the morning and transferred to a nearby pack shed and graded for quality and size. A single layer of about 10-12 fruit was placed into a 250 g capacity plastic vented punnet. Two layers of eight punnets were packed into a cardboard tray. Eight trays with a combined 128 punnets were randomly selected and transported by car at 20°C to the laboratory near Nambour, about 40-50 km away. A temperature logger was placed into strawberry tray at the time of picking to track temperature from harvest to laboratory arrival.

Storage temperature x time treatments

On arrival at the laboratory, the berries were checked to remove those with visual defects such as cut/punctures, bruise and immaturity etc. After that the punnets were randomly assigned to treatment trays, each consisting of 4 punnets. The treatment trays were then placed into different temperatures to reflect road transport and storage condition as shown in **Table 1**. At the end of each treatment storage duration, berries were shifted to 4°C and 60-65% relative humidity (RH) for ongoing assessment. Additional treatments were also tested to evaluate the fruit maximum shelf life at constant temperature and RH. The room air temperature and RH were measured using HOBO and RTDs dataloggers. The time and date of treatment commencement and removal were recorded.

Table 1. Storage temperature (°C) plus relative humidity (RH) x time (days) matrix for 'Red Rhapsody' strawberry fruit. Following storage, the fruit were transferred to 4°C plus 65% RH to assess remaining shelf life.

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 60% RH				
Temp (°C)	RH (%)	1	2	3	5	7
1	90	X	X	X	X	X
4	90	X	X	X	X	X
10	90	X	X	X	X	X
15	90	X	X	X	X	
20	90	X	X	X		

Fruit assessment

Fruit quality

Once strawberries were held at 4°C plus 65% RH, they were daily assessed for quality until the end of shelf life. Fruit quality was assessed based on four main attributes (Loss of gloss, wet bruise, wilted calyx and mould) using a 3-score scale; where 1 = within allowance; 2 = at limit of allowance and 3 = exceeding allowance. The shelf life was determined when a berry showed any symptoms with score of 3 as presented in **Image 1**. The date and primary reason for each fruit reaching end of shelf life were recorded. Fruit were removed from punnets at the end of shelf life. Weight of whole punnet was measured at intake and at removal to calculate fruit weight loss.

Image 1. Symptoms of strawberries showing exceeding allowance (score 3).

Loss of gloss



Dull, matt surface with flat ridges, pronounced seeds

Wet bruise



Any presence of wet bruise

Mould



Any visible mould

Bruised tip/wilted calyx



Wilted/yellow/brown calyx

Fruit total soluble solids (TSS) and titratable acidity (TA)

Four punnets of berries were used to assess TSS and TA at intake and 5 days after storage. Six berries per punnet were deployed and each was cut in quarter. The juice was captured by squeezing berries through a cheesecloth. TSS was determined with two Ataga refractometers and TA of matching samples was measured by titration.

3. Results

Weight loss

Changes in fruit weight loss are presented in **Figure 1**. Weight loss of berries was affected by storage temperature, RH and duration. Weight loss increased with an increase in storage temperature and time when holding at the same RH. For berries picked in July, weight loss of fruit held at 15°C was lower than those held at 20°C because fruit kept at 20°C were exposed to high RH (92%). In general, weight loss of fruit at the end of storage treatment was around 2% or less, except for those held at 15°C and 20°C or 4°C with low RH. Humidity had a significant impact on weight loss. For instance, fruit stored at 4°C and 63% RH lost weight between 1.5 and 4 times more rapidly than those kept at 4°C plus 89-93% RH. In addition, high humidity storage reduced the temperature effect. For example, fruit stored at 10°C and 15°C plus 96% RH had the same weight loss. On average, when the berries reached the end of the shelf life, they lost 6.5% and 3.4% their weight loss for fruit picked in June and July, respectively. These findings highlight the importance of maintaining low temperatures and high RH (>90%) to minimise weight loss and extend shelf life.

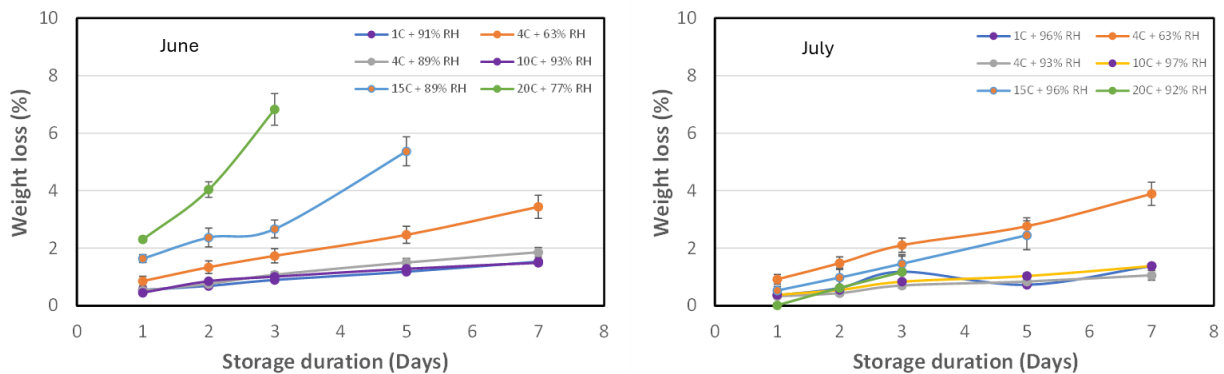


Figure 1. Changes in weight loss of berries harvested in June and July and stored under different storage temperatures and relative humidity over a period of 7 days (n=4).

Total soluble solid (TSS) and titratable acidity (TA)

Total soluble solid content of strawberries picked in June and measured at intake was 9.0 °Brix whereas those harvested in July had 8.8 °Brix. TA of berries measured at intake ranged between 0.77- 0.81%.

Shelf life

Averaged shelf life of strawberries stored at constant temperature and relative humidity (RH), and remaining shelf life following storage at 4°C and 63% RH after exposure to different temperatures and durations, is presented in Table 2. In general, fruit stored at lower temperatures and higher RH exhibited longer shelf life than those kept at higher temperatures and lower RH.

Strawberries held at 1°C under high RH (91–96%) had a shelf life of 22.4 to 23.9 days, whereas those stored at 10°C under the same RH had a shelf life of 15–16 days, approximately 7 days shorter. Fruit stored at 4°C and 93–98% RH had a 3–4-day shorter shelf life compared with those stored at 1 °C and 90–93% RH. In addition, storage at 4°C and 63% RH reduced shelf life by 3.9–4.5 days compared with storage at the same temperature but at 89–93% RH.

Remaining shelf life of berries at 4°C and 63% RH decreased with increasing pre-storage temperature and duration. For example, fruit held at 20°C for 2 or 3 days prior to transfer to 4°C exhibited a reduction in shelf life of approximately 7–8 days, corresponding to a 43–56% loss compared with fruit maintained at 1°C. Similarly, berries stored at 10°C for 2 days showed a reduction in shelf life of 16% and 25%, respectively, relative to those kept at 1°C. These results suggest that strawberries should be cooled and stored at low temperature as rapidly as possible after harvest to maximise shelf life.

The percentage of fruit reaching end of shelf life (ESL) due to loss of gloss was 94.7% and 80.3% for fruit picked in June and July, respectively. The secondary causes of ESL were calyx deterioration (60.8% in June) and wet bruising (25.5% in July).

Table 2. Heat map of averaged shelf life of strawberries once stored at constant temperature and RH, and remaining shelf life held at 4°C and 63% RH after storage at different temperatures and duration (green → red: high → low).

June

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 63% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	91	22.4	15.6	14.8	14.7	11.8	11.7
4	89	19.6	14.4	15.1	14.5	11.5	10.7
10	93	15.2	15.8	11.1	13.5	10.3	8.6
15	89		13.3	10.5	9.8	5.5	
20	77		12.0	8.1	6.5		
4	63	15.7					

July

Storage conditions		Storage duration (days) prior to transfer to 4°C plus 63% RH					
Temp (°C)	RH (%)	Constant	1	2	3	5	7
1	96	23.9	17.6	16.2	12.7	12.3	9.6
4	93	19.3	14.4	15.2	13.8	13.2	10.9
10	97	16.5	14.6	13.6	9.7	9.2	9.5
15	96		13.5	12.7	10.0	6.5	
20	92		10.1	9.2	6.3		
4	63	14.7					

Shelf life model

In general, shelf life data across all temperature and duration treatments showed a moderate to strong fit to the regression model ($R^2 = 0.67$ – 0.75), except for fruit harvested in July and stored at 1 °C. These results suggest that the model can be used to predict the remaining shelf life of strawberries under variable supply chain conditions.

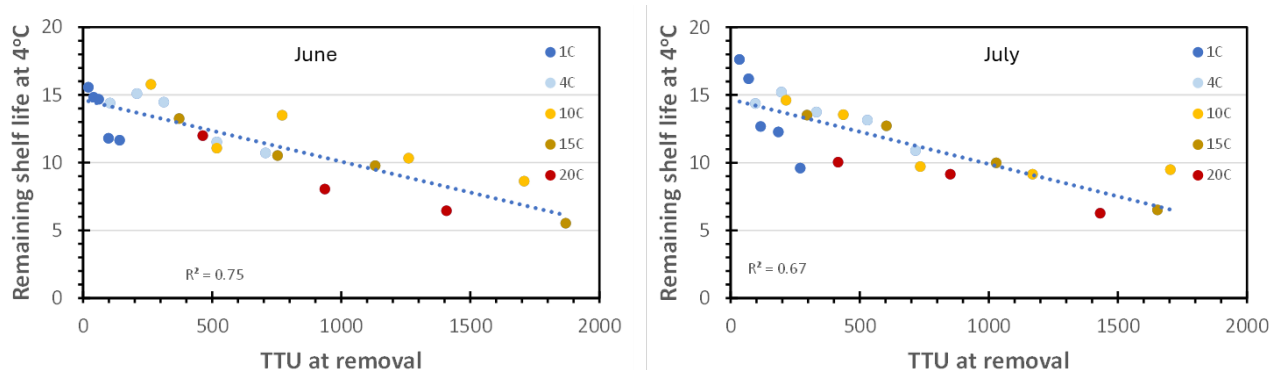


Figure 3. Relationship between remaining shelf life of strawberries harvested in June and July and stored at 4°C and time x temperature unit (TTU) from harvest to the end of storage treatment.



4. Summary and next steps

These time–temperature trial results demonstrate the potential of the model to predict the remaining shelf life of strawberries. However, further validation using fruit from the same cultivar, production region, and harvest season is required to confirm the robustness of the model. In addition, other factors influencing fruit quality and shelf life, such as delays in cooling and pre-harvest environmental conditions, should be investigated.