

Final Report

Passionfruit Postharvest Best Practice Review

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Applied Horticultural Research

Project code:

PF18002

Project:

Passionfruit Postharvest Best Practice Review PF18002

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Funding statement:

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

Publishing details:

ISBN 978 0 7341 4564 2

Published and distributed by: Hort Innovation

Level 7 141 Walker Street North Sydney NSW 2060

Telephone: (02) 8295 2300 www.horticulture.com.au

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Summary

This project conducted a desktop review of postharvest management of passionfruit. This information was then combined with information and feedback specific to the local environment to develop an Australia passionfruit Postharvest Best Practice guide. This process involved wide consultation with wholesalers, growers and packers from large, medium and small-scale operations.

The 50pp. desktop review has been made available as an electronic document with limited numbers of hard copies provided to key industry members. Information is included from 112 peer reviewed papers, books and industry fact sheets. Sources include work on yellow passionfruit varieties, and even other tropical crops, as no information could be found on certain issues that was specifically on the varieties currently grown commercially in Australia.

The review highlights a number of new technologies and techniques which could have significant value for Australian growers. Examples of these include products that can delay fruit drop, ways to monitor initiation of ripening, detection of hollow fruit and different harvest methods. The review also reveals that there is much that we don't know about passionfruit. As a result, a number of "research needs" are identified on topics ranging from production methods to consumer facing packaging.

The Best Practice (BP) guide features sections on the effect of pre-harvest management on postharvest quality, harvest practices, postharvest handling and treatments, and packing and storage. It is illustrated with numerous photographs, diagrams and graphs demonstrating the effects of different practices on passionfruit quality. A small number of additional activities were conducted in order to generate specific information for the guide. These included storage trials at different temperatures, testing of three different waxes and temperature monitoring during transport. The guide is currently being developed for printing.

The BP guide will be promoted to industry members through an article in the Passion Vine magazine as well as a pre-recorded webinar which will be available via the Passionfruit Australia and AHR websites. A number of other communication activities have also been conducted, including presentation of highlights from the desktop review at a field day and several articles on different topics for the Passion Vine magazine.

The project has identified ways that packers and wholesalers can increase storage life of passionfruit. This will enable growers and wholesalers to shrink the wide fluctuations in fruit supply that restrict marketing and reduce grower returns. While the short timeframe for this project makes it difficult to assess levels of implementation, excellent feedback has been received so far from industry members. There appears to be a high level of interest in the project results and outcomes. It is, therefore, expected that the finalised BP guide will benefit all those involved in the passionfruit supply chain.

Keywords

Passionfruit, postharvest, best practice, harvest, storage, ethylene

Introduction

Consistent retail quality is essential in order to satisfy consumers. However, maintaining quality of passionfruit after harvest is challenging. Despite their sturdy appearance, passionfruit are fragile fruits that easily lose moisture, are susceptible to disease and rapidly deteriorate after harvest.

Current consumption of passionfruit remains less than 200g (two fruits) per person annually, with only 1 in 5 households purchasing passionfruit. Previous reviews of passionfruit supply chains have found that poor retail quality is a key issue limiting increased passionfruit consumption. Fruit often appear wrinkled and dry and may be only partially filled with pulp.

Another issue is the ongoing volatility of supply and, therefore, prices, which creates problems for growers and marketers alike. Managing harvest and extending storage life could help flatten some of the more extreme peaks and troughs in supply. This would potentially increase both marketing flexibility and returns for growers.

Passionfruit are produced from northern NSW right up into the far, wet tropics of northern Queensland. Relatively long transport times, therefore, are required in order to reach consumers in southern markets. Moreover, both purple and Panama varieties remain relatively niche, low volume crops; trucks carrying mixed loads have limited capacity to adapt to the specific needs of passionfruit. Fruit which has not been grown, picked and packed well is poorly equipped to face the challenges of extended transport and marketing.

This project has aimed to help growers and others in the supply chain understand and adopt best practice postharvest management for passionfruit. Activities have included a wide-ranging literature review, a number of small trials examining specific issues, visits to passionfruit growers in different regions and production of a BP guide for improved postharvest management of passionfruit.

It is hoped that growers are able to adopt these recommendations, in whole or in part, thereby extending storage life of passionfruit and improving retail quality.

Methodology

Task 1 - Review of postharvest management of passionfruit in Australia and overseas

An extensive review was conducted of peer-reviewed literature relating to postharvest management of passionfruit. This was primarily focused on articles from journals but also included information from previous Hort Innovation projects, websites and other information sources. In total, 112 papers were referenced to produce this review.

In some cases, examples were used from other tropical fruit as little information is available on Australian passionfruit. Indeed, there is surprisingly little information on passionfruit in general, perhaps because production is concentrated in less developed countries. Much of the published research originates in South America and relates to yellow passionfruit varieties, most of which are consumed as juice rather than fresh fruit. This information was included, although care is needed when relating this to Australian varieties.

Topics covered included:

- Pre-harvest effects on postharvest quality
 - Vine nutrition
 - Flowering and pollination
 - o Climate
 - Variety and cultivation
 - o Disease management
- Harvest
 - o How and when
- Postharvest treatments
 - Slowing ripening
 - Disease control
 - Waxes and coatings
- Packing and storage
 - Grading
 - Packaging
 - o Packing
 - Storage environment.

The 50pp. resulting report is attached to this report as **Appendix 1**.

Task 2 – Develop a Best Practice guide for Australian growers

The BP guide was developed by combining the knowledge collected for the desktop review with direct feedback from industry members and understanding gained from field visits. Interviews with key growers and members of the project steering committee, as well as visits to a range of different sized passionfruit production operations, provided additional ground truthing of what was potentially achievable in the Australian context.

Additional information on specific issues was generated through conducting a number of small trials. These were focused on areas where there was little or no information available in the literature, but were

considered important issues for Australian growers:

- Effect of two types of Liquidseal wax on quality and weight loss of Sweetheart and Misty Gem passionfruit
- Effect of Castle Chemicals fruit wax on quality and weight loss of Sweetheart and Misty Gem passionfruit
- Differences in quality of passionfruit stored at 2°C, 5°C and 8°C
- · Temperatures during transport of passionfruit

The BP guide is currently being formatted for printing. The draft copy is included as **Appendix 2** to this report.

The results of the waxes trials have been written up for inclusion in the Passion Vine magazine and are included as **Appendix 3** to this report.

Task 3 - Identify gaps in knowledge relating to postharvest management of passionfruit

Gaps in knowledge which became evident during the course of the project are included in the literature review as "Research Needs" at the ends of relevant sections. Examples include:

- Develop models to predict harvest maturity and drop of passionfruit
- Test use of the DA-meter to detect breakdown of chlorophyll in the fruit rind and, therefore, predict fruit drop
- Test whether ReTain and/or Harvista keep passionfruit attached to the vine until fully mature
- Test the effect of active vs passive harvesting on storage life and quality of purple passionfruit
- Investigate technologies to grade out passionfruit with low pulp content or unacceptable internal quality.

The full list is included in the "Recommendations" section of this report.

Task 4 - Communication

Key findings from the desktop review were presented at a field day on 18th September 2019.

Copies of the Review (printed hard copies and electronic versions) have been circulated among the project steering committee and promoted to Passionfruit Australia staff and board.

This information, together with key best practices summarised from the BP guide, has been combined in a recorded webinar. The webinar will be promoted to the industry in the Passion Vine magazine and made available by links on the Passionfruit Australia and AHR websites.

Three articles have been provided to the Passion Vine magazine. These cover topics of

- 1. Promoting the project itself (provided at the project commencement)
- Discussing the role of ethylene and use of ethylene absorbers and scrubbers (this was due to our becoming aware of a number of companies attempting to market their products to passionfruit growers)
- 3. Trial results on application of waxes.
- 4. Promoting availability of the BP Guide.

Outputs

- o Desktop review Postharvest management of passionfruit (50pp., Appendix 1)
- o Webinar Postharvest management of passionfruit (approx. 1 hour, link TBA)
- o Australian Passionfruit Best Practice Guide
- o Research reports Liquidseal and Castle waxes
- Articles submitted to the Passion Vine magazine on:
 - Passionfruit postharvest best practice review (introduction to the project, March 2019, included as **Appendix 4** to this report)
 - o Passionfruit and ethylene (May 2019, included as Appendix 5 to this report)
 - o Waxing trial results (October 2019, included as **Appendix 3** to this report)
 - New Best Practice guide for Australian Passionfruit (promotion of the BP Guide, scheduled November 2019)

Outcomes

The short timeframe of this project (approx. 7 months) makes it difficult to determine all of the outcomes from the work.

However, feedback from the project steering committee has so far been excellent. Members of the passionfruit industry have assisted with the small trials which were conducted. There has been strong interest in the results of these trials, particularly waxing and measurement of transport temperatures.

There has also been a high level of interest in some of the new technologies potentially relevant to the passionfruit industry, as discussed in the desktop review. Examples include the use of Harvista® to delay fruit drop, packaging and waxes to slow moisture loss and shrivel and data loggers to monitor temperatures in the supply chain. It is hoped that a number of these recommendations will be acted upon by the industry. For example, work on Harvista® / SmartFresh® has been discussed with company representatives, who are keen to work with the passionfruit industry conducting trials with these products. Increased industry awareness of these new technologies can potentially help growers find efficiencies in the production and harvest systems and maintain quality through the supply chain.

As a result of this project, members of the passionfruit industry will be better informed about key factors affecting passionfruit quality and actions they can take to adopt or approach postharvest best practice. These include:

- o Pre-harvest orchard management
- Harvesting methods
- Postharvest treatments
- o Packing
- o Cooling and storage
- Transport

Methods of extending passionfruit storage life have been described. If implemented, these could help packers and wholesalers significantly extend storage life, reducing some of the fluctuations in supply that constrain marketing programs and reduce returns to growers.

Monitoring and evaluation

1. To what extent has the project achieved its expected outcomes?

The project has exceeded its expected outcomes. These were a basic desktop review of postharvest management of passionfruit and a short best practice (BP) guide. In fact, both the desktop review and BP guide have grown to be substantial documents. These documents contain both overseas and local data, photographs taken at several different farms, new data and information on new technology highly relevant to the Australian industry. The project has also provided additional data and communications that were not anticipated in the original project plan. These have included additional farm visits, small trials examining three different types of fruit wax, temperature monitoring in supply chains.

2. How relevant was the project to the needs of intended beneficiaries?

The project has involved regular communication with the project steering committee, who have provided valuable information at all stages. The committee consisted of:

- o Aidan Hutton, JE Tipper wholesaler
- o Bruce McPherson, Bundaberg grower
- o Cynthia Barbagallo, Far North Qld grower
- o Dennis Chant, NSW grower
- o Jim Gordon, Sunshine Coast grower

Through the committee, a number of growers were visited during the course of the project. These included relatively large-scale producers with good packing facilities, including cold rooms, as well as small-scale producers who simply pack directly into cartons from harvest crates.

As a result, the resources could be adjusted to make them appropriate to the range of capacity within the industry. While best practice is identified, other options are nominated for those with more limited resources.

The project has, therefore, maintained relevance to the needs of the intended beneficiaries.

3. How well have intended beneficiaries been engaged in the project?

Two teleconferences have been held with the whole project steering committee. In addition, individual discussions have been held with individuals from the committee on specific issues. Growers have also been engaged in the small trials conducted. For example, Meiers Produce at Bundaberg have been open with information on harvest and cooling as well as assisting with temperature monitoring between Bundaberg and Sydney/Melbourne; JE Tipper provided fruit for the waxing trials and assisted with information on marketing, promotion, and key factors that they see affecting postharvest quality of passionfruit.

Outcomes have been communicated at various stages during the project, with final outcomes set to be communicated once the BP guide has been finalised.

4. To what extent were engagement processes appropriate to the target audience/s of the project?

Feedback indicates that the review was appropriately presented. The committee liked the "key points" boxes at the start of each section, as well as the pullout boxes with research and development needs as appropriate.

The BP guide is being modelled on one previously developed for the avocado industry, which gained the unanimous approval of the project steering committee. Similar, but passionfruit specific, information has been collated. For example, the pre-harvest section of the BP guide includes pre-harvest nutrition tables, instructions for taking a leaf sample for analysis, and suggestions for developing an effective fungicide program. A number of diagrams have been generated, and the guide will contain a large number of photographs illustrating specific techniques and issues.

Recommendations

One of the key conclusions from the desktop review was that there is much we don't know about passionfruit. There is even more that we don't know about <u>purple</u> passionfruit. Most of the recent international research has focused on yellow varieties that are primarily used for processing. These are not commercially grown in Australia. In some cases, even relatively basic physiological information is not clear in the peer reviewed literature, books or fact sheets.

As a result, a large number of research needs were identified. Clearly, the industry cannot do all of these tasks but needs to prioritise them for future investigation. These are summarised below:

Pre-harvest

Develop models to predict harvest maturity and drop of passionfruit. These could include minimum daily temperatures (ATmin) or hours above a critical temperature, such as 15°C (GDD).

Test use of the DA-meter to measure breakdown of chlorophyll in the fruit rind as an indicator of the initiation of ethylene production and, therefore, prediction of fruit drop.

Repeat trials by Willingham on acibenzolar, with the addition of other plant defense response elicitors (salicylic acid, chitosan), to determine whether these products can improve disease control. If appropriate, investigate potential to obtain a permit for acibenzolar (Bion®) for use on passionfruit.

Harvest

Test whether ReTain and/or Harvista keep passionfruit attached to the vine until fully mature. Assess whether this could potentially reduce the frequency of harvests and allow more fruit to be hand harvested from the vines.

Test the effect of active vs passive harvesting on storage life and quality of purple passionfruit. For example, examine the quality of purple passionfruit picked at breaker stage, cool stored for up to 10 days, then transferred to ambient conditions to complete ripening. Include measurement of brix, acid, colour, rots and subjective assessment of flavour. Evaluate the costs, benefits and commercial feasibility of picking fruit directly from vines. Outcome may be a guide as to what trellising systems are better for active/passive harvesting as well as circumstances where it is better to pick directly, and when it is better to wait for fruit drop.

Postharvest treatments

Trial the effects of relatively high (1-3ppm) 1-MCP treatment on shelf life of purple passionfruit actively harvested at breaker stage and allowed to drop naturally. Include fruit with relatively high disease load at harvest.

Test whether ripening and deterioration of 'breaker' passionfruit can be delayed using ethylene sachets in packaging; measure internal levels of ethylene in fruit stored in ethylene-free environments.

Conduct a preliminary trial on use of different waxes on purple passionfruit, including measurement of internal gas concentrations; this will test whether waxed fruit is likely to become anaerobic under ambient conditions. Measurements could include ethylene production and effects on flavour, chilling sensitivity and development of disease/disorders.

Investigate technologies to grade out passionfruit with low pulp content or unacceptable internal quality. These could include NIR devices, machine vision combined with weight measurements or even simple flotation techniques.

Packaging and modified atmospheres

Conduct a preliminary trial on packaging for purple passionfruit. Include carton liners as well as retail ready packs. Ensure packaging meets customer requirements and preferences, particularly with regard to minimising use of non-recyclable materials (e.g. recyclable punnet with thin plasticized overwrap) and using biodegradable materials (e.g. starch-based polymers) wherever possible.

Determine the optimum storage temperatures for purple and Panama passionfruit varieties, including defining the effect of cooling delays and the influence of both temperature and relative humidity on quality attributes and weight loss.

Develop models predicting storage life based on postharvest management.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

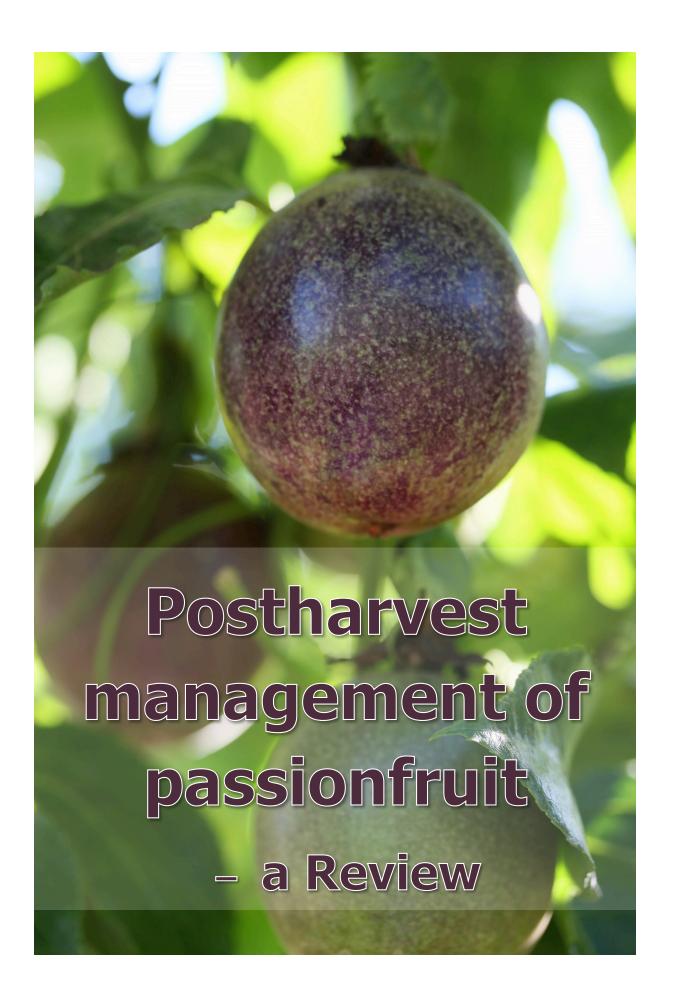
Acknowledgements

This project was greatly enhanced by the members of the project steering committee as well as individual growers who provided valuable time and advice to the project team.

- o Paul Meiers and family, Bundaberg grower
- o Ross Brindley, Bundaberg grower
- Aidan Hutton, JE Tipper wholesaler
- Bruce McPherson, Bundaberg grower
- Cynthia Barbagallo, Far North Qld grower
- Dennis Chant, NSW grower
- o Jim Gordon, Sunshine Coast grower

Appendices

- Appendix 1 Postharvest management of passionfruit A review
- Appendix 2 Australian Passionfruit Postharvest Best Practice Guide
- Appendix 3 Report on waxing trials (submitted to Passion Vine magazine, October 2019)
- Appendix 4 Article for Passion Vine magazine, March 2019
- Appendix 5 Article for Passion vine magazine, May 2019





This project has been funded by Hort Innovation using the passionfruit research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

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September 2019

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Executive summary

Good retail quality of passionfruit starts in the field, as well-nourished vines produce the best quality fruit. However, it is important to avoid excess nitrogen, and there are potential benefits if N is applied as ammonia rather than nitrate. Acidic soils (pH of 4.5 to 5.5) not only maximise fruit size and sweetness, but also tend to result in higher calcium levels in the fruit; high fruit calcium is a good predictor of quality and storage life for many fruits.

Passionfruit require long days and warm (not hot) conditions to flower, with dry conditions important for successful pollination. Flowers are most receptive immediately after they open. There is a direct relationship between the amount of pollen deposited on flowers and the size and weight of fruit that forms as a result, so it is essential there are plenty of bees in the orchard.

Weather also affects fruit flavour, with warm days (27-30°C) and cool nights (23-25°C) producing the best quality passionfruit. Days after pollination can be used to predict maturity in stable climates, however fruit development is strongly affected by changes in temperature. Predicting maturity would greatly assist marketing, but no Australian maturation models were found for purple passionfruit.

Disease management in the field also directly affects postharvest quality. The most effective programs include a range of cultural practices – such as sanitation and maintaining good air movement – as well as fungicides with varying modes of action. Plant defence elicitors may enhance these effects, and are a promising area of new research. Slight field infections can become major infections postharvest, increasing shrivel and prematurely ending storage life.

As fruit develop on the vine sugar levels rise, acidity falls and colour increases. Like other climacteric fruit, passionfruit can be harvested once physiologically mature, without loss of quality. This occurs when ethylene production increases and fruit start to change colour. Once fruit detach from the vine ethylene production increases many times over; passionfruit are one of the highest ethylene producers of any fruit.

In other parts of the world, passionfruit intended for fresh market are harvested directly from the vines. This avoids sunburn and bruising, reduces weight loss and avoids contamination by soil-borne pathogens. However, fruit are hard to see under vigorous canopies, while searching for them can damage the vines. Australian practice is to harvest purple passionfruit after natural drop. This allows harvest in low light (before sunrise) and maximises fruit flavour. However, fruit must be picked up as soon as possible (within hours) to retain quality.

Once passionfruit start to ripen their high rates of ethylene production and respiration mean they are hard to slow down. Ethylene is not just produced by the fruit, but accumulates inside the cavity, making it difficult to remove. There is some evidence that blocking ethylene production by treatment with 1-MCP (1-methylcyclopropene) can extend storage life. While 1-MCP is most effective if applied before passionfruit start to ripen, the fruit may fail to develop proper colour and

flavour. Relatively high doses of 1-MCP are needed to significantly extend storage life of partially coloured passionfruit.

Ethylene scavengers added to packaging, and ethylene scrubbing systems in rooms, may quickly become saturated if exposed to ripening passionfruit. There is little evidence of such technologies increasing passionfruit storage life, although they may help protect other fresh products in a mixed storage environment.

No fungicides are registered for postharvest use on passionfruit. Other options to reduce disease include heat treatments, biological control agents and essential oils. Essential oil derived from lemongrass (*Cymbopogon citratus*) has had considerable attention, with some successful trials on yellow passionfruit. While the importance of disease in postharvest deterioration of Australian passionfruit is unclear, infection does increase weight loss and shrivel.

Weight loss is a key factor in passionfruit deterioration. Waxes, coatings and packaging can all slow moisture loss from the passionfruit rind, delaying shrivelling. It is important, however, that these treatments do not reduce gas exchange to the point where the fruit pulp becomes anaerobic and develops off flavours. Carnauba based waxes are recommended by some authors, but it should be noted that all of this research was conducted on yellow passionfruit only.

Extensions of storage life in the order of 2 to 4 times longer have been reported using various types of packaging. Effective packaging may be as simple as a perforated bag or punnet overwrapped with plasticized film.

The benefits of more sophisticated modified atmosphere packages (MAPs) are less clear. These involve sealing the fruit inside a plastic film of defined gas permeability, resulting in high CO_2 / low O_2 atmospheres. However, increased humidity around the fruit seems to be more important than the balance of gases inside. Although flavour is rarely reported, some MAPs have resulted in both large storage life extensions and off flavours, suggesting that such systems are unlikely to be commercially acceptable. Moreover, increasing consumer resistance to plastics should be considered.

Another issue with passionfruit quality relates to fruit with low pulp content. There is potential to use near infrared spectroscopy to detect fruit with low pulp content, as well as estimate brix. This is a rapidly developing field, with costs likely to decrease in the future. Other options include machine vision systems that combine imaging with weight measurements and acoustic techniques.

Once packed, passionfruit should be cooled as soon as possible. Purple passionfruit may be stored as low as 3°C, although 6-8°C is a more usual recommendation and may be the best to retain flavour. Panama passionfruit are more chilling sensitive, and may be stored at around 10-12°C.

The review includes summaries of key points at the start of each section, as well as identified research needs where appropriate.



1 Introduction

To the casual observer, passionfruit appear hardy. Their thick outer shell looks like sturdy barrier, protecting the rich pulp from insect damage, bruising and decay. However, passionfruit present unique challenges in postharvest management, as well as some exciting opportunities.

Ripening begins while passionfruit are still attached to the vine. Ethylene production rises, colour develops, and finally the fruit naturally detaches, dropping to the ground. Ripening then progresses extremely rapidly, ethylene production increasing many times over. In fact, passionfruit has one of the highest rates of ethylene production of any fresh product.

Passionfruit also have a rapid respiration rate, and lose moisture easily. Significant weight loss can occur within only hours or days of detachment from the plant, which may be why some consumers regard wrinkled passionfruit as their normal edible condition! Packaging, atmospheric management and fruit coatings may slow ripening and moisture loss. However, such barriers need to balance moisture loss against gas exchange; if they are too effective the atmosphere inside the fruit is likely to become anaerobic, the pulp developing off flavours and aromas.

A sub-tropical fruit, passionfruit are also chilling sensitive. However, storage recommendations range from only 3°C to as high as 10°C. There is no guidance on Panama red passionfruit, which may be more chilling sensitive than purple varieties. Despite this, Australian retailers require all passionfruit be supplied at 8-12°C, which may not be optimal for quality.

This review has involved a thorough examination of peer reviewed literature relating to postharvest management of passionfruit. In some cases, examples are used from other tropical fruit, as little information is available on passionfruit themselves. Indeed, there is surprisingly little information on passionfruit in general, perhaps because production is concentrated in less developed countries. Much of the published research originates in South America and relates to yellow passionfruit varieties, most of which are consumed as juice rather than fresh fruit. This information is included, but care is needed when extrapolating from this to Australian varieties.

As a result, there is much we do not know about postharvest management of passionfruit. Indeed, not a single publication was found relating specifically to the Panama variety, which seems a major gap in knowledge. Even for purple passionfruit many questions remain; What is the optimal way to harvest? How important is it to cool fruit immediately after harvest? How can we improve management of disease? Can we use ethylene inhibitors/scavengers to slow ripening and improve quality? and what temperature should passionfruit be stored at anyway?

In short, this review raises more questions than it answers!



2 Pre-harvest effects on postharvest quality

The process of producing high quality passionfruit starts before the vines are even planted. As for other crops, growing a healthy plant produces quality fruit with maximum shelf life. Plant nutrition, variety and climate all influence the rate of fruit growth and maturation, as well as susceptibility to physiological breakdown during storage and transport¹. For example, wet conditions increase the likelihood of postharvest rots, as can physical damage from wind, rain and insects.

While some links between pre-harvest conditions and postharvest quality of passionfruit are relatively thoroughly researched, others have had little attention. Of particular interest to the industry could be models predicting fruit maturity. Accurate prediction of fruit drop could have major benefits for improving supply chain management of passionfruit. While none are well proven for passionfruit, examples from other fruit crops could prove useful.

2.1 Vine nutrition

Key point

Well-nourished plants produce the best fruit, with studies consistently showing that fertiliser improves quality. However, it is important not to over-fertilise, as high amounts of N, P or K may increase fruit acidity in some circumstances. Applying nitrogen as ammonia rather than nitrate could also have benefits for fruit quality. Moderate to high levels of calcium are critical for good postharvest quality of many fruit. Unfortunately, little specific information on calcium and passionfruit quality was found for this review. However, it is noted that calcium was higher in fruit grown in strongly acidic soils. Soil pH of 4.5 to 5.5 appears optimum for fruit quality.

Nitrogen

- The amount of N recommended for application to passionfruit varies widely, ranging from 578-1,320kg/ha² to 100-250kg/ha^{3, 4}.
- While additional N may increase yield, high rates may also increase fruit acidity; Shibuya found that 484kg/ha resulted in sweeter fruit than 727kg/ha ⁵.
- The form of N may also be important. Kondo and Higuchi⁶ (2013) found that applying nitrogen as ammonia (NH_4N) rather than nitrate (NO_3N) resulted in a higher sugar:acid ratio in harvested fruit.

¹ Arpaia ML. 1994. Preharvest factors influencing postharvest quality of tropical and subtropical fruit. HortScience 29:982-

² Menzel CM et al. 1993. New standard leaf nutrient concentrations for passionfruit based on seasonal phenology and leaf composition. J. Hort. Sci. 68:215-229.

³ Gilmour JG. 1983. A guide to grenadilla growing in Zimbabwe. Zimbabwe Agric. J. 80:83-92.

⁴ Sale PR. 1988. Passionfruit culture. MAF, Wellington, New Zealand.

⁵ Shibuya K. 1997. Examination of fertilisation amount. Ogasawara Subtropic. Agric. Centre. 62-66.

⁶ Kondo T, Higuchi H. 2013. Effects of nitrogen form and concentration in fertiliser on vegetative growth, flowering and leaf mineral contents of passion fruit. Trop. Ag. Develop. 56:123-128.



Potassium

- Trials using a hydroponic system demonstrated that potassium (K) increased fruit weight and number, with yield maximised at 6mmol K/L solution. As the concentration of K in solution increased, so did skin thickness, Vitamin C content and number of seeds per fruit⁷.
- The study also found that K did not affect total soluble solids (TSS) or titratable acidity of the pulp⁷.
- A similar trial by Kondo and Higuchi but using much higher levels of K found that 25mM/L K increased fruit acidity by 0.3% compared to 6.3mM/L K⁸. The authors suggest keeping leaf K content at approximately 2% may help reduce acidity in passionfruit.
- In opposition to these results, a large study in Brazil compared four passionfruit cultivars grown with six doses of N and K ranging from 0-0 to 250-625kg/ha N and K respectively. There was no effect of fertiliser rate on yield, TSS or acidity⁹.

Phosphorus

- Kondo and Higuchi¹⁰ reported a small, but significant, increase in acidity associated with 10mM/L P compared to 2.5mM/L or less in a hydroponic system. They also found reduced colour development in the skin of these fruit. It is suggested that excess P reduces quality of purple passionfruit.
- Poultry manure is generally very high in phosphorous. Application of up to 15t/ha poultry litter improved quality (juiciness and sweetness) of yellow passionfruit in Nigeria¹¹.
 Unfortunately, soil attributes were not reported, so it is not known whether this was correcting a deficit in the soil or providing an excess.

Calcium

- Calcium is critical to the strength of cell walls, control of membrane permeability and other
 functions within plant cells. Calcium deficiencies cause blossom end rot in fruit such as tomato
 and capsicum, as well as bitter pit in apple. Conversely, high levels of calcium are widely
 associated with improved fruit quality postharvest. Increased calcium has been reported to
 slow ripening, reduce diseases, and improve storage life¹².
 - For example, high calcium levels in avocado fruit reduce the incidence of disease and internal discolouration¹³, while vacuum infiltration of calcium postharvest can inhibit ripening for at least a week¹⁴.

⁷ Araujo RdC et al. 2006. Quality of yellow passionfruit (*Passiflora edulis* Sims f. *flavicarpa*) as affected by potassium nutrition. Fruits 61:109-116.

⁸ Kondo T, Higuchi H. 2013. Acidity of passion fruit as affected by potassium fertiliser. ActaHort. 984:385-392

⁹ Goncalves Dias D et al. 2016. Production and postharvest quality of irrigated passionfruit after N-K fertilisation. Rev. Bras. Fruit: 39:e553

¹⁰ Kondo T, Higuchi H. 2013. Effects of excess phosphorus application on passion fruit quality. Trop. Ag. Develop. 57:109-113

¹¹ Ani J, Kayode Baiyeri P. 2008. Impact of poultry manure and harvest season on juice quality of yellow passion fruit (*Passiflora edulis* var. *flavicarpa* Deg.) in the sub-humid zone of Nigeria. *Fruits*, 63:239-247.

¹² Winkler A, Knoche M. 2019. Calcium and the physiology of sweet cherries: a review. Scientia Hort. 245:107-115.

¹³ Hofman PJ et al. 2002. Tree yield and fruit mineral concentrations influence Hass fruit quality. Scientia Hort. 92:113-123.

¹⁴ Eaks IL. 1985. Effect of calcium on ripening, respiratory rate, ethylene production and quality of avocado fruit. J. Amer. Soc. Hort Sci. 110:145-148.



- There is a strong, positive relationship between firmness and calcium levels for fresh cherries¹⁵, while postharvest dips in calcium chloride (CaCl₂) have been shown to reduce rots, splitting and softening¹⁶.
- Calcium moves through the plant in water carried by the xylem tissue, so deposition in developing fruits depends on the rate of transpiration from the fruit itself. As fruits mature the lenticels/stomata over the fruit surface become widely spaced and may close. Calcium is likely to move instead to growing shoots, which have a much higher transpiration rate¹⁷. This means it is essential that calcium is readily available in the soil during the early stages of fruit development, ensuring that levels in the fruit are sufficient to support later development. It is extremely difficult to increase calcium levels in fruit during the later stages of fruit expansion.
- Foliar sprays are generally ineffective at increasing calcium levels in fruit.
 - For example, five different formulations of foliar calcium were applied 3-4 times to strawberries, raspberries, blueberries and blackberries during fruit development.
 None increased calcium levels or had any effect on postharvest quality¹⁸.
- No references were found for this review, specifically examining the effect of pre-harvest calcium levels on passionfruit quality. However, it seems likely that providing adequate calcium in the soil is essential for good quality fruit.

Soil pH

• It has previously been recommended that passionfruit vines are grown in soils with neutral to slightly acidic pH³.

- In Okinawa, passionfruit are grown in strongly acidic (pH 4.7) soils. There was no advantage in neutralizing the soil to bring pH closer to neutral. Instead, vine growth and flowering were significantly reduced if pH increased to 7.4¹⁹.
- O These results appeared confirmed by Niwayama and Higuchi²⁰, who found that purple passionfruit grown with soil pH 4.5 and 5.5 were significantly larger, heavier, dark-coloured and sweeter than fruit grown at pH 3.5 or 6.5 (Figure 1). Passionfruit were lower in calcium when grown at pH 3.5. Fruit grown at pH 6.5 were more acidic than those grown at lower pH. They also tended to be pale with thinner skin, making them more susceptible to wrinkling.

¹⁵ Measham PF, Richardson A, Townsend A. 2017. Calcium application and impacts on cherry fruit quality. ActaHort. 1161:375-381.

¹⁶ Wang Y, Long LE. 2015. Physiological and biochemical changes relating to postharvest splitting of sweet cherries affected by calcium application in hydrocooling water. Food Chem. 181:241-247.

¹⁷ Strik BC, Vance AJ. 2015. Seasonal variation in leaf nutrient concentration of northern highbush blueberry cultivars grown in conventional and organic production systems. HortSci. 50:1453-1466.

¹⁸ Vance AJ, Jones P, Strik BC. 2017. Foliar calcium applications do not improve quality or shelf life of strawberry, raspberry, blackberry or blueberry fruit. HortSci. 52:382-387.

¹⁹ Kondo T et al. 2017. Effects of neutralization of acidic soil on vegetative growth, flowering, and leaf mineral contents of passion fruit cultivated in Okinawa. ActaHort. 1178:93-98.

²⁰ Niwayama S, Higuchi H. 2019. Passionfruit quality under acidic soil conditions. Hort J. 88:50-56.

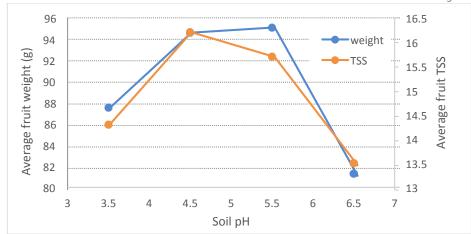


Figure 1. Effect of soil pH on quality attributes of hybrid purple passionfruit cv. "Summer queen". Data from Niwayama and Higuchi, 2019.

Multiple papers consistently report a positive correlation between fruit size and sweetness. In addition to the results shown above, a positive relationship between fruit size and TSS has also been demonstrated for yellow passionfruit 'Ovalado Grande'²¹. Adjusting soil pH to maximise fruit size is therefore likely to improve both yield and quality.

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²¹ Weber D et al. 2017. Correlations between production and quality characteristics for the yellow passionfruit selection 'Ovalado Grande' in southern Brazil. ActaHort. 1178:17-24.



2.2 Flowering and pollination

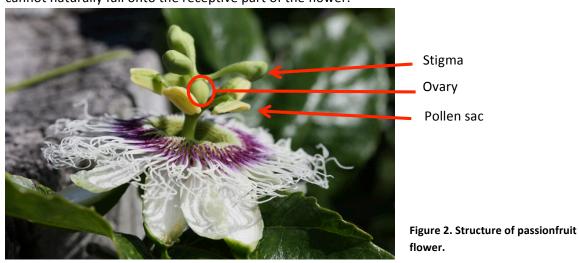
Key point

Passionfruit require long days and warm conditions to flower. Flowers need pollination in order to form fruit. There is a direct relationship between the amount of pollen deposited on the flower and the size and weight of the fruit formed as a result. Flowers are most receptive to pollen immediately after they open. Large insects such as carpenter bees are the best pollinators, but honeybees are also effective. If it rains within 2 hours of pollination the pollen is destroyed and the flower remains unfertilised.

In tropical regions, passionfruit flowering can occur year round, whereas in subtropical regions flowering and production mainly occur during summer. As a long day plant, at least 10 hours of sunlight are needed for purple passionfruit plants to flower²².

- Day lengths shorter than 11 hours can inhibit flowering²³.
- As flower buds only form between 15 and 30°C, high summer temperatures can also restrict flowering²⁴.
- In Japan, passionfruit are grown in greenhouses. Supplementary lighting with LEDs (especially red wavelengths), along with heating, are used to produce a winter crop. Conversely, greenhouses are actively cooled in summer, or flowers will not form²⁴.

Flowers must be pollinated, otherwise fruit will either fail to form, or form but be empty of pulp. Many purple passionfruit, and nearly all yellow passionfruit (and possibly Panama passionfruit), are self-incompatible to some degree²⁵. This means that although pollen can fertilise the stigmas on the same flower, fertilisation is improved if the pollen comes from a different flower or, better still, a completely different plant. Moreover, as the pollen sacs are located below the stigmas, pollen cannot naturally fall onto the receptive part of the flower.



²² Schotsmans WC, Fischer G. 2011. Passion fruit (*Passiflora edulis* Sim). In "Postharvest biology and technology of tropical and subtropical fruits. V4. Mangosteen to white sapote." Ed E.M. Yahia. Woodhead Publishing pp. 125-142.

²³ Nakasone HY, Paull RE. 1998. Tropical Fruits. Wallingford, CAB Int.

²⁴ Kumamoto O et al. 2017. Current situation of passion fruit production and the latest techniques. Res. Trop. Ag. 10:7-17.

²⁵ Keogh R, Mullins I, Robinson A. 2010. Pollination aware case study: Passionfruit. AgriFutures Case study 23.



The amount of pollen deposited on the stigma directly affects fruit set, weight and pulp content²². Hollow fruit are the result of poor, or partial, pollination. Achieving thorough pollination is therefore essential to producing good quality, well filled fruit.

Passionfruit pollen is heavy and sticky, so flowers are rarely fertilised by wind. Honeybees, stingless bees (*Trigona* spp.) and other insects can all transfer pollen. However, pollination and fruit set is improved if larger insects, such as carpenter bees, pollinate the flowers²⁶. There are eight Australian species of carpenter bees, with the two most common being *Xylocopa arauna* and *Xylocopa lieftincki*. The foraging behaviour and buzzing of carpenter bees further improves their effectiveness at pollinating passionfruit. Carpenter bees nest in logs, so providing suitable sites around the orchard may help increase their numbers²². However, only honey bees and stingless bees can be actively brought into orchards to increase pollination.





Figure 3. Carpenter bees Xylocopa lieftincki (left, J. Thynne) and X. arauna (right, G. Brooks)

In the case of purple passionfruit, the flowers generally open around dawn, closing later the same day. In contrast, yellow passionfruit flowers tend to open during the middle of the day and close late in the evening. The stigma is only receptive on the day the flower opens. It has maximum receptivity around an hour after the flower first opens, once the styles have fully re-curved from their initial, erect position. Once pollen grains are deposited on the stigma they take 1.5 to 2 hours to germinate and grow. If it rains before this occurs, the pollen is destroyed and the flower remains unfertilised ²⁶.

Research in Hawaii and South America shows that hand pollination of yellow passionfruit consistently produces the largest, heaviest fruit²⁷. While the cost of this is clearly prohibitive in a commercial setting, it does demonstrate the benefits of ensuring flowers are fully pollinated (Table 1).

9

²⁶ Akamine EK, Girolami G. 1959. Pollination and fruit set in the yellow passionfruit. Tech. Bull 39., Hawaii Ag. Expt. Stn.

²⁷ Rodriguez-Amaya DB. 2003. "Passion fruits". In Encyclopedia of Food Sciences and Nutrition. Ed. B. Caballaero. Oxford, Academic Press.



Table 1. Comparison of natural and hand pollination of yellow passionfruit. From Akamine and Girolani, 1959.

		•			-
Pollination method	Fruit set (%)	Fruit weight (g)	Number of seeds	Juice yield (g)	Appearance
Hand	100	112	277	50	
Natural	70	62	110	20	

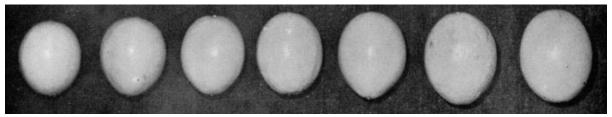


Figure 4. Effect of degree of pollination on fruit size. Number of pollen grains applied from left to right: 189, 228, 271, 358, 592, 1184, 1776. All fruit from the same plant. From Akamine and Girolani, 1959.



2.3 Climate

Key point

Passionfruit growth is strongly affected by temperature. Both low temperatures and constantly high temperatures increase acidity in fruit. Day temperatures of 27–30°C combined with nights of 23–25°C appear to produce the best quality fruit. High night temperatures can also trigger premature fruit drop. Compared to other crops, there is limited information on predicting harvest date of passionfruit. Growing degree-days and minimum temperatures models could be developed to predict fruit drop. In addition, the new 'DA meter' may be able to measure the start of ripening indirectly through chlorophyll loss in the peel; this could provide a more accurate prediction of maturity and fruit drop.

Effects of temperature and moisture

 Passionfruit production is highly reliant on climate. Although climate can be controlled to some extent (for example, passionfruit are grown in greenhouses in Japan), fruit harvested in winter are often more acidic than those harvested in summer, containing 5.3% acid compared to 2.2% acid under warmer conditions²⁸.



Figure 5. Greenhouse production of passionfruit with LED lighting in southern Japan. From Kumamoto et al 2017.

- Higher temperatures reduce fruit development time. In studies, fruit drop occurred >90 days after pollination when purple passionfruit were grown at a constant 20°C²⁹ but only 54 days after pollination when fruit grew at a constant 30°C²⁸.
- While high temperatures reduce acidity in the ripe fruit, it may be daily minimums, not maximums, that most affect fruit development³⁰.
 - Fruit grown with day/night temperatures of 27°C/21°C was less acid than fruit grown at 24°C/16°C³¹.

²⁸ Kozai N et al. 2007. Effect of night temperature regime on fruit quality of 'Summer Queen' passion fruit (*Passiflora edulis* x *P. edulis* f. *flavicarpa*) harvested in winter. Jpn. J. Trop. Ag. 51:70-72.

²⁹ Shimoi S, Wamocho LS, Agong SG. 1996. Ripening characteristics of purple passion fruit on and off the vine. Postharvest Biol. Technol. 7:161-170.

³⁰ Shinohara T et al. 2013. Effect of accumulated minimum temperature on sugar and organic acid content in passion fruit. J. ISSAAS 19:1-7.

³¹ Macha MMAK et al. 2006. Effect of temperature regime and soil moisture level on the fruit quality of 'Summer queen' passionfruit (*Passiflora edulis* x P. *edulis flavicarpa*). Jap. J. Trop. Ag. 49:47-48.



- Purple passionfruit grown with day/night temperatures of 33°C/28°C had significantly lower acidity than fruit grown at 23°C/18°C or 28°C/23°C BUT also contained significantly lower sugars, mainly due to reduction in sucrose. The 28°C/23°C temperature regime produced the sweetest fruit³².
- Similarly, fruit grown with day/night temperatures of 30°C/25°C had lower acidity than fruit grown at 30°C/20°C²⁸.
- However, growing fruit at a *constant* 30°C increased acidity from 2.8% to 3.3%²⁸.

Predicting harvest date

Unpredictable fruit drop is one of the key issues faced by passionfruit growers. Fruit can appear coloured and ready to harvest, yet remain attached to the vines. Conversely, a storm can prematurely detach fruit. Better prediction of harvest date, or control of fruit drop, would have major benefits for passionfruit supply chain management.

 Shinohara³⁰ modelled accumulated minimum temperatures (ATmin) during passionfruit development, finding this measure was better correlated with fruit development than days after pollination (DAP). Fruit reached an acceptable sweetness (15% TSC) when ATmin was but only dropped below 3% acidity when ATmin was. More than half of the fruit dropped before acids fell to this level. It is concluded that high night temperatures can trigger premature fruit drop.

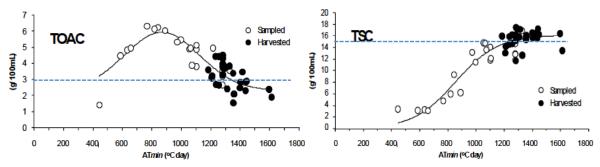


Figure 6. Changes in total organic acids (TOAC) and total sugars (TSC) in relation to accumulated minimum temperatures during development of purple passionfruit 'Summer Queen'. Fruit were sampled from the vines (O) or harvested at fruit drop (\bullet). Blue dotted lines indicate acceptable levels. From Shinohara et al., 2013.

- Growing degree-days (time x (temperature base temperature)) are commonly used to estimate harvest dates for other fruit crops, as they generally provide a better estimate than time alone (DAF). However, it is critical to know the base temperature, below which development is significantly slowed.
 - For example, growing degree-days (GDD) for different varieties of papaya range from GDD using a base temperature of 15°C. However, according to Salinas et al, accuracy of harvest date prediction can be improved using a higher base temperature³³.

³² Utsunomiya N. 1992. Effect of temperature on shoot growth, flowering and fruit growth of purple passionfruit (*Passiflora edulis* Sims var. *edulis*). Scientia Hort. 52:63-68.

³³ Salinas I, Hueso JJ, Cuevas J. 2019. Fruit growth model, thermal requirements and fruit size determinants in papaya cultivars frown under subtropical conditions. Scientia Hort. 246:1022-1027.



- GDD (base temperature 4-5°C) is often used to predict harvest dates for stonefruit, with temperatures during the 30 days after full bloom used for the calculation³⁴.
- Harvest maturity can also be predicted using non-destructive measurements with a portable near infrared device the DA meter. The DA meter indirectly detects initiation of ethylene production in the fruit by measuring chlorophyll degradation in the skin. This is particularly useful for highly coloured fruits (such as passionfruit perhaps!), as it is not possible to accurately judge loss of green chlorophyll if it is obscured by dark anthocyanins. The DA has provided a better predictor of harvest date than GDD for certain stonefruit varieties, such as plums³⁵.

Research need

Develop models to predict harvest maturity and drop of passionfruit. These could include minimum daily temperatures (ATmin) or hours above a critical temperature, such as 15°C (GDD).

Test use of the DA-meter to measure breakdown of chlorophyll in the fruit rind, as an indicator of the initiation of ethylene production and, therefore, prediction of fruit drop.

³⁴ Infante R. 2012. Harvest maturity indicators in the stone fruit industry. Stewart Postharvest Rev. June 1-6.

³⁵ Bonora E et al. 2014. A new simple modelling approach for the early prediction of harvest date and yield in nectarines. Scientia Hort. 172:1-9.



2.4 Variety and cultivation method

Key point

Although different cultivars vary widely in their response to the environment as well as in yield and fruit quality, there appears to be little effect of rootstock on these attributes. There do not appear to be significant quality enhancements from growing organically or using 'alternative' (e.g. biodynamic) methods. In most studies conventionally grown passionfruit had lower acidity, different – as opposed to reduced – antioxidants, and better size and yield than organic fruit.

- Tolerance of chilling temperatures varies among species of *Passiflora*, with species originating
 in tropical lowlands exhibiting chilling injury (measured as electrolyte leakage) well before
 symptoms were observed on species from cooler climates³⁶.
 - o While this work was done on leaves, fruit are likely to have a similar response
 - o Hybrids were intermediate between original species
 - Resistance to chilling increased gradually, with P. edulis forma flavicarpa < P. maliformis < P. cincinnata Masters < P. edulis < P. caerulea
- Many grafted plants show strong differences in fruit quality when grafted onto different root stocks. However, perhaps surprisingly, several studies on yellow passionfruit have failed to find significant differences in fruit quality attributes when *P. edulis* was grafted onto various wild and cultivated rootstocks³⁷.
- Several Brazilian studies have examined quality differences between organic and conventionally grown passionfruit.
 - Although one study³⁸ found higher levels of anti-oxidant tocopherols (Vitamin E) and ascorbic acid (Vitamin C) in organic fruit, the researchers also found nearly double the carotenoid content in conventional fruit. This suggests the conventionally grown fruit were more strongly coloured.
 - A second study³⁹ also found an increase in Vitamin C in organic passionfruit, but this was countered by higher total phenolics in conventionally grown fruit.
 - Such results are complicated by the fact organic fruit were smaller; bioactive compounds are reported as percentages rather than quantity/fruit, which makes comparison of actual health impacts more difficult.
 - Pacheco et al⁴⁰ compared conventional production of yellow passionfruit to 'alternative' management strategies (neem oil, organic fertilizers etc.). Fruit grown conventionally had higher TSS and acid content as well as higher yields.

³⁶ Patterson BD, Murata T, Graham D. 1976. Electrolyte leakage induced by chilling in *Passiflora* species tolerant to different climates. Aust. J. Plant Physiol. 3:435-442.

³⁷ Salazar AH, Pereira da Silva DF, Bruckner CH. 2015. Effect of two wild rootstocks of genus *Passiflora L*. on the content of antioxidants and fruit quality of yellow passion fruit. Bragantia Campinas 75:164-172.

³⁸ Pertuzatti PB et al. 2015. Carotenoids, tocopherols and ascorbic acid content in yellow passion fruit (*Passiflora edulis*) grown under different cultivation systems. LWT. 64:259-263.

³⁹ De Oliveira AB et al. 2017. Effects of organic vs conventional farming systems on quality and antioxidant metabolism of passion fruit during maturation. Scientia Hort. 222:84-89.

⁴⁰ Pacheco ALV et al. 2017. Yield and quality of yellow passion fruits according to organic fertilisation and alternative phytosanitary management. Rev. Bras. Agro. Sust. 7:84-90.



2.5 Disease management

Key point

Diseases occurring in the field directly affect fruit quality, and can continue developing after harvest. An effective disease management program is essential in order to produce high quality fruit. Programs involving a range of different products and practices, including azoxystrobin, are most likely to be effective while also minimising development of resistance. Orchard sanitation, using clean planting material and maintaining good air circulation around vines also helps minimise disease.

Passionfruit are affected by numerous pre-harvest diseases which affect postharvest quality of fruit. The two most serious are fruit scab (*Cladosporium oxysporum*), which is most prevalent during cool wet weather and alternata spot (*Alternaria alternata*) which can cause major fruit loss during the warm, wet periods from October to April. Other diseases include anthracnose (*Colletotrichum gloeosporoides*), brown spot (*Alternaria passiflorae*), Septoria fruit spot (*Septoria passifloricola*) and Phytophthora blight (*Phytophthora nicotianae*)⁴¹. Fruit infected by Septoria spot in the field ripens unevenly, while *Phytophthora* spp. causes water-soaked, dark green patches on the skin that eventually dry out and disintegrate⁴⁹.



Figure 7. Initial (left) and advanced symptoms of anthracnose on harvested fruit

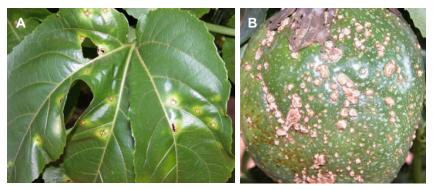


Figure 8. Scab symptoms on a passionfruit leaf (left) and fruit (photo by AM Almeida)

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⁴¹ Willingham SL et al. 2002. Combinations of strobilurin fungicides and acibenzolar (Bion) to reduce scab on passionfruit caused by *Cladosporium oxysporum*. Aust. Plant Path. 31:333-336.



An effective disease management program is essential to produce high quality fruit. A range of fungicides are registered for use on passionfruit, including azoxystrobin, pyraclostrobin, iprodione, mancozeb, phosphonic acid and a range of copper products (Infopest.com.au).

Willingham et al⁴¹ reported on using combinations of strobilurin fungicides and a plant defense response activator – acibenzolar– to control copper and fungicide resistant scab. Acibenzolar, marketed as 'Bion', is an analogue of salicylic acid (Vitamin C) reported to induce resistance to a range of fungal pathogens. It is currently registered in Australia as a seed treatment for cotton. The trial was conducted in a northern NSW passionfruit orchard with severe symptoms of scab and alternata spot. Adding acibenzolar increased the percentage of marketable fruit in all cases, although in some cases the difference was not significant. The best results were achieved using azoxystrobins with/without acibenzolar.

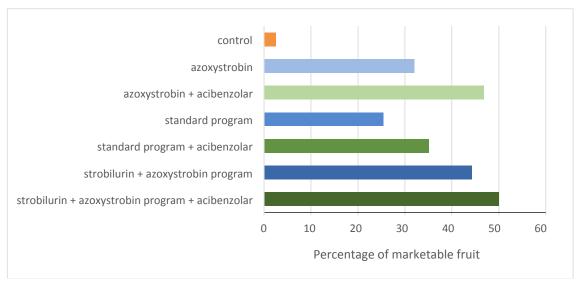


Figure 9. The effect of different fungicide programs on the percentage of marketable fruit. Standard program; mancozeb and copper oxychloride + iprodione after rain. Strobilurin program; strobilurins +/- acibenzolar replace standard program at flowering (2 sprays) and prior to harvest (2 sprays). Derived from Willingham et al, 2002.

Other products that may help protect passionfruit plants against disease include salicylic acid, chitosan (extracted from crustaceans) and jasmonates. These act to enhance and retain the plants' natural defences against fungal pathogens, with the effects potentially retained during postharvest storage⁴². Results are generally variable, but this remains an active area of research for many crops.

Orchard sanitation, particularly removing dropped and diseased fruit, and reducing humidity around the fruit by pruning to keep the canopy open, can also help reduce the impact of diseases⁴⁹.

Research need

Repeat trials by Willingham on acibenzolar, with the addition of other plant defence response elicitors (salicylic acid, chitosan), to determine whether these products can improve disease control. If appropriate, investigate potential to obtain a permit for acibenzolar (Bion®) for use on passionfruit.

⁴² Terry LA, Joyce DC. 2004. Elicitors of induced disease resistance in postharvest horticultural crops: a brief review. Postharvest Biol. Technol. 32:1-13.



3 Harvest

In Australia, purple passionfruit are harvested after natural fruit drop. This ensures that they have reached maximum maturity, developing the best possible colour and flavour. However, this creates challenges for the whole supply chain. If fruit drop doesn't occur when expected, marketing arrangements are thrown into chaos. Moreover, once drop occurs passionfruit must be picked up immediately to avoid sunburn, dehydration and disease. If fruit drop occurs earlier than expected, labour needs to be accessed urgently in order to pick fruit up.

Managing harvest and fruit drop better could have major benefits for the whole supply chain.

Panama passionfruit are picked directly from the vine when heavy and fully coloured. Purple passionfruit could also be harvested directly from the vine, especially if allowed to ripen under controlled conditions.

3.1 When to harvest

Key point

Ethylene production starts to rise and colour change occurs while passionfruit are still attached to the vine. However, ethylene production increases at least fourfold after fruit detach. Fruit harvested at 'breaker' stage ripen normally, developing similar flavour and colour to fruit allowed to drop. As with other climacteric fruit, reports indicate that it is possible to harvest 'breaker' fruit, cool to slow ripening during storage and transport, then allow to fully ripen at the market destination.

Products are available which can inhibit ethylene production while fruit are attached to the plant. Application could delay fruit drop, allowing fruit to mature on the vine. More fruit could then be harvested at once, and on a predictable schedule.

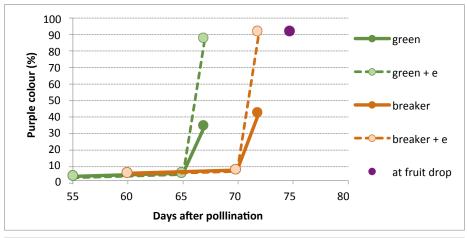
Many climacteric fruit, particularly tropical and subtropical fruit such as bananas, mangoes, avocadoes and tomatoes, are harvested while still unripe but physiologically mature. Ethylene can be used to trigger ripening, achieving the same or similar end quality when compared to vine ripened fruit. This facilitates harvest, transport and storage, and results in a uniformly ripe product at retail.

- To some extent, the same effect can be achieved with purple passionfruit. Arjona and Matta⁴³ harvested passionfruit 55 or 60 days after pollination (DAP), stored the (green or breaker) fruit for 10 days at 10°C, then transferred the fruit to 20°C and exposed half to 10µl/L ethylene. After a further 2 days at 20°C, development of purple colour and sugars were compared to fruit that dropped naturally at around 75 DAP.
 - Treatment with ethylene resulted in acceptable colour development (Figure 10), whereas the untreated fruit remained largely green or pale yellow.
 - Treatment with ethylene slightly reduced total sugars in the ripe fruit. Untreated fruit harvested at 60 DAP had the same sugar levels as those that dropped naturally.
 - There was no effect of treatment on juice pH, and no shriveling was reported.

⁴³ Arjona HE, Matta FB. 1991. Postharvest quality of passion fruit as influenced by harvest time and ethylene treatment. HortScience 26:1297-1298.



- In this trial, fruit harvested while green, two weeks before natural drop, achieved acceptable appearance and reasonable (although slightly decreased compared to breaker fruit) sugar levels after 10 days cold storage then ripening with ethylene.
- Fruit harvested at breaker stage then stored for 10 days before ripening, achieved the same quality as naturally dropped fruit.



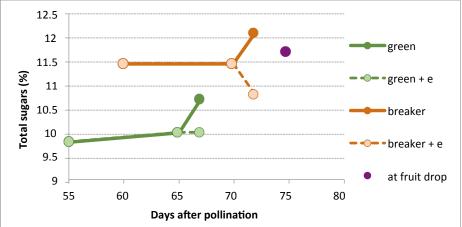


Figure 10. Development of purple colour (top) and total sugars (below) in passionfruit harvested 55 or 60 DAP, stored for 10 days at 10°C, treated or not with ethylene, then assessed after a further 2 days at 20°C. Note that fruit labelled 'breaker' was still green at harvest, also that passionfruit were not measured on removal from storage; values are estimated from other information. Data derived from Arjona and Matta, 1991.

- The results of Arjona and Matta's study show that passionfruit harvested close to natural drop attain better quality than the fruit harvested while still green. This was confirmed by Shiomi et al⁴⁴, who conducted a detailed study of purple passionfruit colour, respiration, ethylene production, and biochemistry during maturation and ripening on and off the vine.
 - o Fruit picked 70 DAP or later appeared to go through a normal climacteric (Figure 11).
 - Fruit picked 80 or more DAP had reasonably high rates of ethylene production (40-50μl/kg/h) at harvest. However, this increased dramatically during subsequent storage, with maximum rates of approx. 1,000μl/kg/h recorded for fruit picked 50 DAP or later.

⁴⁴ Shiomi S, Wamocho LS and Agong SG. 1996. Ripening characteristics of purple passionfruit on and off the vine.



- The onset of ethylene production coincided with development of purple colour in the fruit. All fruit harvested 80 DAP or later developed acceptable skin colour (>75% purple).
- Both Brix and TA declined at similar rates in fruit harvested 70 DAP or later.
- The authors suggest that fruit picked at 80 DAP, or possibly 70 DAP (with ethylene treatment), may have better quality than fruit allowed to drop naturally, due to reduced impacts and soil contact.

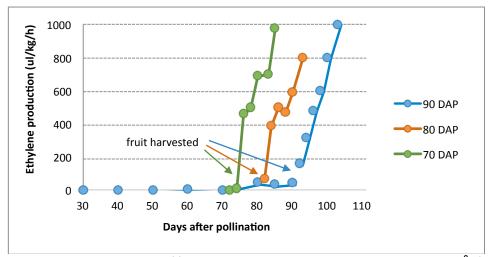


Figure 11. Ethylene production of fruit while attached to the vine, then during storage at 25°C following harvest at either 70, 80 or 90 days after pollination (DAP). Data derived from Shiomi et al, 1996.

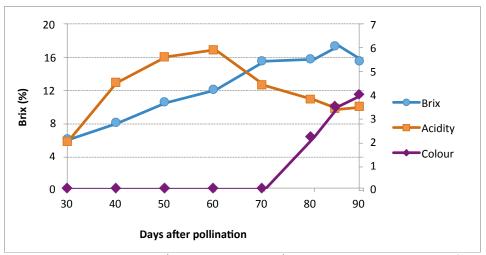


Figure 12. Changes in % Brix, TA (measured as citric acid) and purple colour development of passionfruit during maturation on the vine. Data derived from Shiomi et al, 1996.

- Similar results were reported by Pongener et al⁴⁵, who also found that ethylene production increased rapidly after harvest when fruit were picked at 50% or 75% coloured. These fruit ripened with acceptable Brix and acidity, whereas fruit harvested mature green did not.
- Pinzon et al⁴⁶ recommend picking purple passionfruit once the fruit is approximately 50% coloured, although maximum pulp volume is achieved once the fruit is 85-95% coloured.

⁴⁵ Pongener A et al. 2014. Physiological and quality changes during postharvest ripening of purple passionfruit (*Passiflora edulis* Sims). Fruits 69:19-30.



- Ethylene production increases at least four-fold once mature fruit drop from the vine. As ethylene initiates detachment, a few fruit dropping may trigger more to do the same. This may explain the results of Shinohara et al³⁰, who found that fruit are often triggered to drop before they are fully mature.
- A detailed study of passionfruit ethylene production found that purple passionfruit harvested at the mature green stage do not respond to ethylene applied immediately after harvest. In this they appear similar to avocadoes, which have a "tree factor" which prevents them responding to ethylene both before and immediately after harvest. In mature green passionfruit this inhibition period appears to last up to 6 days, whereas in 'breaker' fruit it is only 1-2 days⁴⁷. It seems possible this may be an adaptation to prevent premature detachment by green fruit in response to ethylene released by ripening, dropped fruit.
- There are two products available which can delay or reduce ethylene production/perception by ripening fruit. While neither is currently registered for use on passionfruit, this may be an area for future development:
 - Aminoethoxyvinylglycine (AVG), marketed as ReTain, inhibits the production of ethylene in plant tissues. It is used to prevent premature fruit drop in apples, extend flowering in cherries, increase firmness and delay harvest in pome and stone fruit.
 ReTain may be applied in order to allow fruit to develop more colour or larger size without detaching from the tree⁴⁸. It is currently registered for apples, cherries and stone fruit in Australia.
 - o 1-methylcyclopropane (1-MCP) or "SmartFresh" is a gas primarily applied postharvest. 1-MCP irreversibly blocks ethylene receptors in the fruit, stopping both production and perception of ethylene. In the last few years a liquid formulation "Harvista" has been developed, which can be sprayed on the orchard pre-harvest. The objective is to keep fruit on the tree, allowing it to develop larger size and better colour with consistent maturity (Figure 13). Harvista is currently registered for apples in Australia, with a pending application for use on pears.

⁴⁶ Pinzon IMdeP, Fischer G, Corredor G. 2007. Determinacion de los estados de madurez del fruto de la galupa (*Passiflora edulis* Sims). Agron. Colomb. 25:83-95.

⁴⁷ Shiomi S et al. 1996. Postharvest ripening and ethylene biosynthesis in purple passionfruit. Postharvest Biol. Technol. 8:199-207.

⁴⁸ Watkins CB. 2009. Managing physiological processes in fruits and vegetables with inhibitors of ethylene biosynthesis and perception. ActaHort. 880:301-310.







Figure 13. Harvista application to pears, and the spray equipment used to deliver 10L/Ha in 750-1,000L water. Photos by Hannah James, AgroFresh.

Research need

Test whether ReTain and/or Harvista keep passionfruit attached to the vine until fully mature. Assess whether this could potentially reduce the frequency of harvests and allow more fruit to be hand harvested from the vines.



3.2 How to harvest

Key point

In most parts of the world, fruit destined for fresh market are picked directly from the vines as they start to change colour. At this time they are physiologically mature, so will attain similar quality to vine ripened fruit. Picking directly from the vines (instead of from the ground) avoids physical damage, reduces weight loss, prevents contamination from soil and improves storability. However, it can also damage the vines, means harvest must be conducted after sunrise and may not be possible if plants are large and/or vigorous.

In Australia, purple passionfruit are harvested by simply picking them up from the ground. The fruit must be picked up as soon as possible after natural fruit drop to avoid sunburn, increased rots and dehydration. Using a "Roll-in", originally designed to pick up golf balls, can help make picking up dropped passionfruit relatively quick and easy. Waiting for fruit to drop means harvest is straightforward and can be started before dawn but reduces marketing flexibility and can create labour and logistical issues.

- As previously acknowledged, in Australia purple passionfruit destined for the fresh market are allowed to drop naturally, then picked up from the ground. However, in other countries they are often picked at 'breaker' stage, when the skin is at least 50% coloured. This can be done using a thumbnail to break the pedicel at its natural abscission zone.
 - Paull and Chen⁴⁹ suggest that purple passionfruit should be picked by cutting or clipping from the vine once they are >75% purple. They state that these light purple fruits are more suitable for long distance transport than fruit allowed to fully mature. Fruit harvested earlier than this stage do not develop proper flavour.
 - The authors note that fruit may also be harvested after natural drop. However these fruit are more likely to have physical damage, increased rates of water loss and potential for disease.
 - Rodriguez-Amaya⁵⁰ makes a similar statement with regard to harvest of yellow passionfruit:

"Harvesting usually consists of allowing the ripe passion fruits to fall from the vine, after which they are picked from the ground, graded and marketed. In contact with the soil, fruits lose their quality in a few days...This harvesting method causes mechanical damage, reduces storage life, and results in poor quality for marketing. Ideally, the fruits should be picked from the plant, keeping 3cm of the peduncle."

 A Guyana guide⁵¹ to postharvest management of passionfruit likewise states that fruit intended for fresh market should not be allowed to drop to the ground, as dropped fruit deteriorate more quickly than picked fruit:

"Fallen fruit....are very susceptible to sunburn damage (and) quickly lose moisture, typically resulting in a 10-20% loss in fresh weight within several days."

⁴⁹ Paull RE, Chen CC. 2014. Passion fruit: Postharvest quality maintenance guidelines. Fact sheet F_N-44, College of Trop. Ag and Human Res. Uni. Hawaii Manoa.

⁵⁰ Rodriguez-Amaya DB. 2012. Passion fruit. In "Tropical and subtropical fruits: postharvest physiology, processing and packaging", 1st Edit. Ed. M. Siddiq. John Wiley and Sons.

⁵¹ Passion fruit: Postharvest care and market preparation. Tech. Bull. 14, 2004. Published by the Ministry of Fisheries, Crops and Livestock; New Guyana Marketing Corp.; Nat. Ag. Res. Institute.



- The guide recommends fruit be cut or clipped at the join in the stem, leaving approx.
 4cm attached to reduce water loss and decay.
- Matta et al⁵² confirm this, also noting that fruit picked up after natural drop suffer rapid dehydration and may be contaminated with soil-borne pathogens.
- Similarly, Schotsmans and Fischer²² suggest that harvesting should be done by hand, preferably in the early hours of the day when fruit is cooler. Again, the authors advise against allowing fruit to drop naturally due to the risk of bruising and infections.
- Allowing fruit to drop potentially allows contamination by soil-borne human pathogens.
 Although passionfruit skin is inedible, pathogens on the skin can potentially transfer into the flesh during preparation, as well as contaminate cutting boards and knives used for other products. Fortunately, survival of pathogens on passionfruit skins is low.
 - E. coli and Salmonella salford inoculated onto passionfruit skins were undetectable (without enrichment) after 6 days at 10°C. Low levels of Listeria innocua persisted, and could be detected by direct plating, but the population decreased significantly during storage⁵³.

Unlike purple passionfruit, Panama passionfruit are clipped from the vine when around 75% coloured.

Wherever possible, harvesting should be conducted during the cool of the early morning or evening. Any remnants of the flower blossom need to be removed

Research need

Test the effect of active vs passive harvesting on storage life and quality of purple passionfruit. For example, examine the quality of purple passionfruit picked at breaker stage, cool stored for up to 10 days, then transferred to ambient conditions to complete ripening. Include measurement of brix, acid, colour, rots and subjective assessment of flavour. Evaluate the costs, benefits and commercial feasibility of picking fruit directly from vines. Outcome may be a guide as to what trellising systems are better for active/passive harvesting as well as circumstances where it is better to pick directly, and when it is better to wait for fruit drop.

⁵² Matta FB et al. 2006. Studies on postharvest quality of passion fruit. Bull. 1153, Mississippi Agricultural and Forestry Experiment Station.

⁵³ Behrsing J et al. 2003. Survival of *Listeria innocua*, *Salmonella salford* and *Escherichia coli* on the surface of fruit with inedible skins. Postharvest Biol. Technol. 29:249-256.



4 Postharvest treatments

4.1 Slowing ripening

Key point

Passionfruit are one of the highest ethylene emitters of all fruit. Most is produced by the pulp and seeds, with production highest once fruit approach full purple colour. Ethylene is not only emitted into the storage environment but accumulates inside fruit.

Reducing ethylene would be expected to slow ripening and extend storage life. However, ethylene continues to have effects at very low concentrations, so reducing it below physiological levels is likely to be challenging.

Options to reduce ethylene include blocking production and perception using 1-methylcyclopropene (1-MCP) or removing it from the storage environment through oxidation processes. While 1-MCP is more effective applied before fruit start to ripen, fruit may fail to develop proper colour and flavour. Relatively high doses of 1-MCP to 'breaker' passionfruit can delay, but not prevent, normal ripening. There is little or no data regarding the effects on passionfruit ripening of using ethylene scavengers in packaging or oxidation systems in storage rooms. However, scavengers are likely to rapidly become saturated while room-based systems may not remove ethylene accumulating inside fruit.

Once climacteric fruit such as passionfruit start to ripen, the process can be slowed, but not stopped. Attempting to prevent ripening once it has started can result in poor quality of the ripe fruit, as it interrupts the normal changes that occur.

Passionfruit start ripening while they are attached to the plant. However, as shown in Figure 11, ethylene production shifts into high gear once fruit are detached from the plant. This likely contributes to their rapid senescence and short storage life. Slowing this process seems likely to improve storability.

The majority of ethylene is produced by the passionfruit arils, with smaller amounts produced by the seed and virtually none by the fruit peel. When passionfruit are 'turning', more ethylene is produced by the arils than by the whole fruit⁵⁴. As a result, passionfruit accumulate significant levels of ethylene internally during ripening.

⁵⁴ Mita S et al. 1998. Differential expression of genes involved in the biosynthesis and perception of ethylene during ripening of passionfruit (*Passiflora edulis* Sims). Plant Cell Physiol. 39:1209-1217.



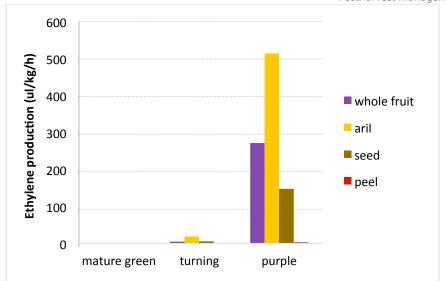


Figure 14. Ethylene production by different parts of the passionfruit during ripening. Derived from Mita et al, 1998.

- The minimum level of ethylene considered to be physiologically active ranges from around 1ppm to 0.1ppm (parts per million in air). Ethylene needs to be reduced below this threshold to stop its effects on ripening and senescence⁵⁵.
- The high ethylene production rate of passionfruit makes it challenging to reduce ethylene below 1ppm in the storage environment. Moreover, the structure of passionfruit, with their internal cavity and relatively thick skin, means they will readily accumulate significant levels of internal ethylene.
- Burg and Burg⁵⁶ measured internal ethylene concentrations in a range of fruit during ripening.
 Passionfruit were the highest by far, with 466 to 530ppm. In comparison, tomatoes recorded 3 to 30ppm, while around 8ppm ethylene can accumulate inside the cavity of rockmelons during ripening⁵⁷.

Removing this ethylene from ripening fruit would require a very high flow rate of ethylene free air, which may not be possible without dehydrating the fruit.

⁵⁵ Reid MS. 2002. Ethylene in postharvest physiology. In "Postharvest technology of horticultural crops" University of California publication 3311, 3rd edition.

⁵⁶ Burg SP and Burg EA. 1962. The role of ethylene in fruit ripening. Plant Physiol. 37:179-189.

⁵⁷ Lyons JM, McGlasson WB and Pratt HK. 1962. Ethylene production, respiration and internal gas concentrations in cantaloupe fruit at various stages of maturity. Plant Physiol. 37:31-36.

Table 2. Threshold concentrations of ethylene, and maximum rates of ethylene production during ripening, for various fruits. Data from Reid, 2002, and other sources.

	Threshold concentration for ripening/senescence (ppm)	Maximum ethylene production during ripening (μl C ₂ H ₄ /kg.h)
Avocado	0.1	100 – 350
Banana	0.1 – 1.0	8 – 12
Citrus	0.1	0.1
Mango	0.1 – 0.4	5 – 10
Passionfruit	Unknown	370 – 1,000
Rockmelon	0.1 – 1.0	80 – 150
Tomato	0.5	5 – 20

Blocking ethylene – 1-methylcyclopropene

The application of 1-methylcyclopropene (1-MCP) to control ripening was first discovered in 1994. Since then it has revolutionised the storage of apples in particular, greatly extending storage and shelf life. It has also found uses in a wide range of other climacteric and non-climacteric fruits and vegetables. In certain cases 1-MCP can decrease rots, reduce susceptibility to chilling injury, prevent physiological disorders, slow ripening and limit expression of bruising.

- 1-MCP is applied as a fumigant at extremely low doses, usually in the order of 0.5 to 1 parts per million in air (0.00005 to 0.0001%). It has extremely low toxicity and leaves behind negligible residues, undetectable with normal laboratory methods.
- 1-MCP binds irreversibly to ethylene receptors, blocking both production and perception of ethylene. Eventually new binding sites are synthesised and ripening continues. How soon this occurs is governed by the metabolic activity of the product. In the case of apples stored at close to 0°C the effects can last for months, whereas leafy green vegetables may recover sensitivity to ethylene in only 1-2 days.

Variability in ripening after 1-MCP application has limited use of this technology for fruits eaten when ripe and soft (like bananas and pears) as the effects cannot easily be 'turned off'. Moreover, 1-MCP can disassociate ripening events such as colour development and softening, as well as result in uneven texture and loss of flavour and aroma. However, responses are time and concentration dependent, allowing careful attenuation of the dose for fruit where ripening and softening (eventually) are desirable⁴⁸.

1-MCP has most effect if it is applied when fruit is mature but before ripening initiates. Application after fruit has started to ripen has highly variable results. While it can still slow ripening and



senescence processes⁵⁸, the difference between treated and untreated fruit may not be enough to justify its use.

There are many studies on the use of 1-MCP on climacteric tropical fruit, such as mangoes, avocados, mangosteen and others, but few examples of commercial application. While researchers report that 1-MCP applied to unripe fruit delays ripening, this may negatively impact other quality attributes. It can also result in uneven ripening within the batch. This is because individual fruit recover ethylene sensitivity at different rates, as has been observed for avocados⁵⁹.

- In the case of papaya, although application of 1-MCP to mature green fruit successfully delays ripening, the fruit develop a rubbery flesh texture. Better results are achieved if papayas are treated at the 25% coloured stage as application simply slows normal ripening processes.
 Combining 1-MCP with modified atmosphere packaging allowed a commercially significant extension in storage life⁶⁰.
- Researchers in Kenya⁶¹ applied 1-MCP to purple passionfruit harvested at mature green and turning stages of maturity at two different sites. Increases in soluble solids during ripening were slowed for one group of mature green fruit, but not for the other. Applications of 1-MCP to fruit already ripening appeared to increase accumulation of carotenoids, but had little effect on respiration rates or sweetness.
- Another study⁶² also treated mature green and turning purple passionfruit, using relatively high doses of 2ppm and 4ppm 1-MCP. In this case, the researchers reported that 1-MCP delayed ripening related changes at both fruit maturities:
 - The ethylene climacteric was delayed in time and reduced in volume for passionfruit from both maturity levels, with the higher 1-MCP dose producing the greatest response
 - Sugars (TSS) were unaffected by 1-MCP treatment but drops in acidity were slightly delayed
 - Peel colour development was delayed by 1-MCP treatment, with fruit picked while still green failing to achieve full dark purple colour
 - The researchers state that shelf life under ambient conditions was extended by 3-4 days by 1-MCP

⁵⁸ Huber DJ. 2008. Suppression of ethylene responses through application of 1-methylcyclopropene: A powerful tool for elucidating ripening and senescence mechanisms in climacteric and non-climacteric fruits and vegetables. HortScience 43:106-111.

⁵⁹ Marques JR et al. 2010. A comparison of various systems for long term storage of Hass avocado fruit. Acta Hort. 880:317-324

⁶⁰ Paull RE and Chen NJ. 2014. Recent advances in postharvest management of papaya. ActaHort. 1024:321-328.

⁶¹ Baraza A et al. 2013. Effect of agro-ecological zone and maturity on the efficacy of 1-methylcyclopropene (1-MCP) in extending postharvest life of purple passion fruits (*Passiflora edulis* Sims). Acta Hort 1007:73-80.

⁶² Ambuko J et al. 2015. Efficacy of 1-methylcyclopropene in purple passionfruit (*Passiflora edulis* Sims) as affected by dosage and maturity stage. Int. J. Postharv. Tech. Innov. 4:126-137.



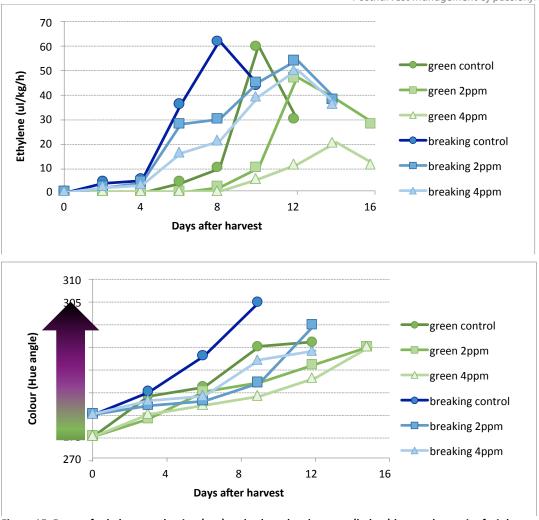


Figure 15. Rates of ethylene production (top) and colour development (below) by purple passionfruit harvested at mature green or breaking colour stages, then treated with 0, 2 or 4ppm 1-MCP. Derived from Ambuko et al, 2014.

• Dutra *et al.*⁶³ took a different approach, using 1-MCP to protect fully ripe yellow passionfruit from *Colletotrichum gloeosporioides* (anthracnose). While exposure to 1-MCP did not affect other aspects of fruit quality (TSS, TA etc.), the diameter of the anthracnose lesions was consistently reduced in the treated fruit, regardless of dose applied. Application of 1-MCP has been shown to suppress some diseases (e.g. grey mould) in other fruit. This is believed to be because it suppresses ethylene, the production of which can stimulate germination and growth of certain fungi⁶⁴.

⁶³ Dutra JB et al. 2018. Use of hot water, combination of hot water and phosphite, and 1-MCP as postharvest treatments for passion fruit (*Passiflora edulis* f. *flavicarpa*) reduces anthracnose and does not alter fruit quality. Hort, Environ Biotech. 59:847-856.

⁶⁴ Shenglong D et al. 2018. The combined effect of 1-methylcyclopropene and citral suppressed postharvest grey mould of tomato fruit by inhibiting growth of Botrytis cinereal. J. Phytopathology. 167:123-134.



Removing ethylene

- Removing ethylene from the environment can also slow ripening. This is particularly challenging for passionfruit given the large volumes of ethylene they produce. However, methods of removing/reducing ethylene include:
 - o reacting, usually using potassium permanganate
 - o destroying, using ozone or a high temperature catalytic oxidiser
 - o venting by continuous fresh air movement
 - o sorbing on a high surface area material such as activated charcoal
- The majority of ethylene-scavenging sachets and other packaging materials use potassium permanganate (KMnO₄) to oxidise ethylene, releasing CO₂ and water. This oxidation process converts the bright purple KMnO₄ to brown manganese dioxide; once the material has turned brown it is no longer effective at scavenging ethylene. To facilitate this reaction, the KMnO₄ is coated onto a porous, inert material with a high surface area. Materials used include clays, silica gel (SiO₂), zeolites, alumina (Al₂O₃) and activated carbon. Some of these materials can adsorb ethylene themselves, improving the efficiency of the system⁶⁵.
 - o In general, smaller particle sizes are more effective at removing ethylene⁶⁵.
 - Substrate type also matters; one study reported that silica gel removed 73 to 100% of ethylene after one hour whereas the same particle sizes of Al₂O₃ removed only 45 to 50% of ethylene⁶⁶.
 - Ethylene removal is also affected by temperature and humidity; scavenging is reduced at very high (>80%) or low (<60%) RH.



Figure 16. Potassium permanganate (KMnO₄) coated clay beads. Some beads have already been oxidised, turning a brownish colour.

- Ethylene scavengers can range from large filters installed over cold room vents to small sachets inserted into cartons or punnets, and even printed labels and pads for use in packaging. Removal of ethylene is limited by air circulation past the materials. For example, high rates of air circulation may be needed in order to pass all of the air inside a cold room through a filter. Air movement may be even more limited inside cartons or packages.
- Variable results are reported in the literature from use of KMnO₄ based ethylene scavengers:

⁶⁵ Alvarez-Hernandez M et al. 2018. Current scenario of adsorbent materials used in ethylene scavenging systems to extend fruit and vegetable postharvest life. Food Bioprocess. Technol. 11:511-525.

 $^{^{66}}$ Spricigo P et al. 2017. Nanoscaled platforms based on SiO₂ and Al₂O₃ impregnated with potassium permanganate use colour changes to indicate ethylene removal. Food Bioprocess. Technol. 10:1622-6130.



- Papaya packed with ethylene absorbing sachets remained more acid and less sweet during storage compared to the controls, suggesting that ripening was reduced⁶⁷.
- o Increases in sugars and loss of acids during ripening of mangoes was slightly delayed by including 20g KMnO₄/kg of fruit inside PVC trays, but firmness was unaffected.
- Vermiculite based sachets (12/carton) had little effect on the quality of cantaloupe melons⁶⁸.
- Maniwara et al¹⁰⁸ compared three different types of packaging for purple passionfruit:
 perforated film, polypropylene-polyethylene film and polypropylene-polyethylene film with
 incorporated ethylene scavenger. Accumulation of ≥5ppm ethylene inside the package was
 delayed for up to one week by the inclusion of the ethylene scavenger (Figure 17). However,
 by far the best way of reducing ethylene around the fruit was using a perforated film package.

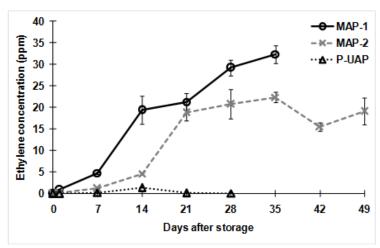


Figure 17. Ethylene concentrations inside a sealed film package (MAP-1), sealed film package with ethylene scavenger (MAP-2) and perforated bag (P-UAP). From Maniwara et al., 2015.

- There are research reports of a palladium-based scavenger, which is far more efficient than KMnO₄. The palladium is impregnated onto zeolite, as would be KMnO₄. One gram of this material can absorb up to 4.1 ml of ethylene at 100% RH or 45.6 ml ethylene under dry conditions⁶⁹. This material was shown to be extremely effective at preventing accumulation of ethylene from stored tomatoes⁷⁰. While this sounds useful, no commercial products appear to be available based on this technology, probably due to the cost of such materials.
- Ethylene can be eliminated from the general storage environment using catalytic devices or ozone (O₃) generators.
 - Ozone based systems generally pass room air through a chamber where ozone reacts with ethylene, eliminating it. Ozone is prevented from exiting the chamber using a catalyst, which converts it back to normal oxygen.

⁶⁷ Bastos VFA et al. 2014. Effect of ethylene absorber sachets during storage of papaya. Conference Proc. Frutas e Hortalicas. Ilheus, Brasil. 26:1418-1423.

⁶⁸ Sa CRL et al. 2008. Efeito do KMnO4 e 1-MCP com atmosfera modificado na conservação poscolheita de melao Cantaloupe Rev. Cienc. Agronom. 39:60-69.

⁶⁹ Smith AWJ et al. 2009. A new palladium-based ethylene scavenger to control ethylene-induced ripening of climacteric fruit. Platinum Metals Rev. 53:112.

⁷⁰ Mansourbahmani S et al. 2018. Study on the efficiency of ethylene scavengers on the maintenance of postharvest quality of tomato fruit. J. Food Measure. Character. 12:691-701.



- While commercial devices are available, there are few references in the peer reviewed literature verifying the effectiveness of these systems.
- New ozone systems are available which maintain low levels of ozone continuously in the room air. For example, rockmelons stored with 0.15ppm O₃ during the day and 0.3ppm O₃ at night had lower levels of internal ethylene and reduced softening compared to those in normal air⁷¹.
- No references were found which examined whether reducing ethylene in the storage environment slowed ripening, or maintained quality, of fresh passionfruit.

Research need

Trial the effects of relatively high (1-3ppm) 1-MCP treatment on shelf life of purple passionfruit actively harvested at breaker stage and allowed to drop naturally. Include fruit with relatively high disease load at harvest.

Test whether ripening and deterioration of 'breaker' passionfruit can be delayed using ethylene sachets in packaging; measure internal levels of ethylene in fruit stored in ethylene-free environments.

⁷¹ Toti M, Carboni C, and Botondi R. 2018. Postharvest gaseous ozone treatment enhances quality parameters and delays softening in cantaloupe melon during storage at 6°C. J. Sci Food Agric. 98:487-494.



4.2 Reducing rots

Key point

Limited tools are available for reducing postharvest disease development on passionfruit. Perhaps the most promising is the use of short duration heat treatments. These kill spores on the surface, as well as induce defense responses within the fruit itself. Other options include biological control agents, essential oils and other defence elicitors such as chitosan or methyl jasmonate.

In other countries, passionfruit are commonly treated with fungicides such as prochloraz and imazilil in order to control postharvest rots⁷². However, this is not an option for Australian growers, as there are no fungicides registered for postharvest application to passionfruit. Instead, growers need to focus on minimising pre-harvest infection, as well as using cultural and alternative methods where available.

Improving fruit defences

Postharvest rots may alternatively be inhibited using a physical or chemical treatment that increases resistance of the fruit to disease. Heat treatments, for example, can kill pathogens on the outside of a fruit as well as promoting the formation of 'heat shock proteins' that provide resistance against other stresses – including fungal attack. Chitosan, ascorbic acid, methyl jasmonate and other chemicals have also been found to increase plant defences against pathogens⁴².

- Initial work on heat treatments of passionfruit tested long exposure times of 2 to 4 hours, with temperatures ranging from 35°C to 53°C⁷³. While the 35°C treatment reduced weight loss and maintained colour, higher temperatures (unsurprisingly) damaged the fruit peel.
- Venancio et al⁷⁴ also tested a mild heat treatment of 35°C, but for one hour. This was applied with/without addition of 2% CaCl₂, but had little effect on the rate of deterioration of yellow passionfruit.
- In contrast, Dutra et al⁶³ tested much higher temperatures for shorter time periods. These had no effect on weight loss or physico-chemical attributes, but significantly reduced development of anthracnose on yellow passionfruit. The best treatment was a dip in 47°C water for five minutes, which reduced lesion diameter by 65–75%.

⁷² Fischer IH, Rezende JAM. 2008. Diseases of passion flower (*Passiflora* spp.) Pest Technology Reviews. Global Science Books. 19pp.

⁷³ De Campos AJ et al. 2005. Hydrothermal treatment on the maintenance of postharvest quality of passionfruit. Rev. Bras. Frutic. 27 :383-385.

⁷⁴ Venancio JB et al. 2013. Post harvest conservation of yellow passion fruits by hydrothermal and calcium chloride treatments. Cientifica Jaboticabal. 41:122-129.



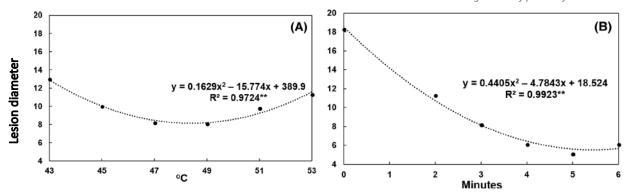


Figure 18. Effect of a 5 minute dip in 43°C to 53°C water (A) or a 0 to 5 minute dip in 47°C water (B) on the development of anthracnose lesions on yellow passionfruit. From Dutra et al, 2018.

 Research in Venezuela also found that a five minute dip in 47°C water was the best treatment for controlling postharvest rots of yellow passionfruit, with significantly better effects than treatment with 1,000mg.L⁻¹ thiabendazole fungicide⁷⁵.

Biological controls

There is a large volume of research on the use of biological control agents to control diseases. Potential microbial bio-controls include fungi, yeasts and bacteria. Most are effective through competition for nutrients and space. Other mechanisms include parasitism of the fungal pathogen, production of antibiotics, and induced resistance in the host⁷⁶.

While results often appear promising, studies are largely laboratory based, with fewer trials conducted under commercial conditions. Nonetheless some commercial products are becoming available. For example, Serenade (*Bacillus subtilis*) is registered for pre-harvest control of anthracnose (*Colletotrichum* spp.) on tropical fruit crops.

- *Trichoderma* spp. have been proposed as a biological control agent on a range of fruit crops. The fungus can parasitise the mycelia of other fungal species as well as competing for space and nutrients
- Although *Trichoderma* spp did not prevent development of lesions on papaya fruit inoculated with *Colletotrichum gloeosporoides*, application reduced lesion diameter by half when applied 24 hours after infection, and by up to 75% when applied before infection⁷⁷.
- *Trichoderma* has previously reduced infection of passionfruit in the field; *T. harzianum* was as effective as carbendazim and hexaconazole fungicides when applied in greenhouse trials.
- De Rocha⁷⁸ tested 3 isolates of *T. koningii* against *C. gloeosporoides* on yellow passionfruit and found that it could limit spread of disease after harvest.

⁷⁵ Aular J, Ruggiero C and Durigan J. 2001. Effect of thiabendazole and warm water applications on postharvest response of passion fruit. Bioagro. 13:79-83.

⁷⁶ Sharma RR, Singh D and Singh R. 2009. Biological control of postharvest diseases of fruits and vegetables by microbial antagonists: A review. Bio. Control. 50:205-221.

⁷⁷ Landero Valenzuela N et al. 2015. Biological control of anthracnose by postharvest application of *Trichoderma* spp. on maradol papaya fruit. Biol. Control. 91:88-93.

⁷⁸ DeRocha J de R. 1998. Controle biologico de *Colletotrichum gloeosporoides*, agente da antracnose do maracujazeiro (*Passiflora edulis*), com *Trichoderma koningii*. Summa Phytopathol. 24:272-275.



- Bacillus subtilis has also been tested as a biological control agent for postharvest diseases.
 However, a solution of B. subtilis metabolites was ineffective against postharvest rots on yellow passionfruit⁷⁹.
- *B. subtilis* was also ineffective when tested as a control method for anthracnose in bananas (*Colletotrichum musae*). Although in this case *Trichoderma* provided 56% inhibition of infection, this was much lower than the fungicide carbendazim which provided 100% control⁸⁰.

Essential oils

As with biological control agents, the use of essential oils to control postharvest disease – particularly anthracnose (*Colletotrichum gloeosporioides*) – is a popular area of research but one where there has been limited commercial application. Moreover, as with biological controls, much of the research conducted has been in-vitro, with more limited trials using whole fruit.

- For example, although copaiba essential oil and oleoresin (extracted from *Copaifera* spp. trees) could inhibit anthracnose growth in vitro on PDA plates, it was ineffective when applied to whole, inoculated yellow passionfruit⁸¹.
- An Kenyan study⁸² found that *Alternaria* spp was the most common pathogen infecting passionfruit, with anthracnose, *Fusarium* spp and *Penicillium* spp less common. Rosemary and eucalyptus essential oil were tested in vitro for efficacy against these pathogens, with rosemary proving most effective. Although the authors suggest that these oils could be used to control postharvest disease on passionfruit, no 'in vivo' study was conducted.
- Essential oils from two species of verbena (*Lippia sidoides, Aloysia citrodora*), African basil (*Ocimum gratissimum*), guava (*Psidium guajava* var. *pomifera*) and lemongrass (*Cymbopogon citratus*) were added to PDA to test their effects on anthracnose isolated from passion fruit. All prevented germination of conidia and inhibited mycelial growth at concentrations of 1μl/ml⁸³. Later trials by the same group found that lemongrass oil provided slightly better inhibition of anthracnose on inoculated yellow passionfruit than verbena or African basil oil (Figure 19)⁸⁴.
- Twenty eight essential oils were screened for their activity against anthracnose (*Colletotrichum gloeosporoides*). The most promising was oil derived from lemongrass (*Cymbopogon citratus*), which was tested using yellow passionfruit. Treatment with 0.12 or

⁷⁹ Benato EA et al. 2002. Avaliação de fungicidas e produtos alternativos no controle de podridões pós-colheita em maracujá-amarelo. Summa Phyto 28:299-304.

⁸⁰ Oliveira ES de, et al. 2016. Alternatives to fungicides in the control of banana anthracnose. Summa Phytopath. 42:340-350.

⁸¹ Araujo Neto SE de et al. 2014. Anthracnose postharvest control in yellow passion fruit with application of copaiba oil. Rev. Bras. Frutic. 36:509-5014.

⁸² Waithaka PN et al. 2017. Control of passion fruit fungal diseases using essential oils extracted from rosemary (*Rosemarinus officinalis*) and Eucalyptus (*Eucalyptus agglomerata*) in Egerton University main campus, Kenya. Int. J. Microbiol. https://doi.org/10.1155/2017/2814581

⁸³ Souza Junior IT, Sales NLP and Martins ER. 2009. Fungitoxic effect of concentrations of essential oils on *Colletotrichum gloeosporioides*, isolated from the passion fruit. Biotemas. 22:77-83.

⁸⁴ Aquino CF et al. 2012. Chemical characterisation and action of essential oils in the management of anthracnose on passion fruits. Rev. Bras. Frutic. Jaboticabal. 34:1059-1067.



- 0.25mg/L⁻¹ essential oil resulted in decay rates not significantly different to passionfruit treated with Sportak® fungicide⁸⁵.
- Lemongrass oil was further investigated by Moura et al. 86, who confirmed the antifungal effects of both the pure essential oil and a number of its derivatives on whole yellow passionfruit. The best results were gained using aqueous extracts and citral, these products successfully inhibiting >50% of spore germination at the concentrations tested.

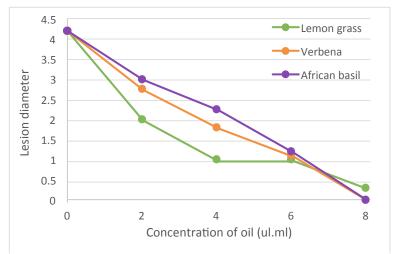


Figure 19. Effect of different concentrations of essential oil extracted from lemongrass, verbena or African basil on the size of lesions on yellow passionfruit inoculated with anthracnose. Derived from Aquino et al., 2012.

Although sanitisers are not intended to control rots, they can prevent the spread of pathogens in wash water and potentially reduce fungal and bacterial populations on fruit skin. Sanitisers should always be used if passionfruit are washed so as to prevent cross contamination. No sanitiser can reduce disease if pathogens have already penetrated the fruit.

- Wild passionfruit Passiflora setacea DC from Brazil dipped in two different sodium hypochlorite (bleach) solutions were no different in storage life from untreated controls⁸⁷.
- In contrast, anthracnose growth was reduced by 54% when bananas inoculated with anthracnose were dipped in a 0.4% bleach solution⁸⁰. However, it should be noted this is an extremely high concentration of chlorine. Chlorine dioxide and potassium sorbate solutions had no effect.

⁸⁵ Anaruma ND et al. Control of *Colletotrichum gloeosporoides* in yellow passion fruit using *Cymbopogon citratus* essential oil. Braz. J. Microbiol. 41:66-73.

⁸⁶ Moura GS et al. 2012. Control of anthracnose in yellow passion fruit by lemon grass (*Cymbopogon citratus*) derivatives. Arquivos Instit. Biol. 79:371-379.

⁸⁷ Rinaldi MM et al. 2017. Postharvest conservation of *Passiflora setacaea* DC fruits submitted to different sanitisers and storage temperatures. Braz. J. Food Tech. 20: e2016046



4.3 Waxes and coatings

Key point

While numerous studies have examined application of waxes to passionfruit, all those accessed trialed application to yellow fruit. Moreover, while some product reduced weight loss and disease without affecting sugars, no studies examined the effects on flavour. Coatings that significantly reduce rind permeability could potentially result in anaerobic conditions inside the rapidly respiring fruit. If this occurs, off flavours are likely.

Passionfruit are susceptible to postharvest weight loss, resulting in obvious shriveling and softening. Fruit potentially lose up to 50% of their initial weight during storage and retail. However, most of this weight loss is from the inedible peel; the pulp itself is less affected (Figure 20). Moreover, some weight loss may intensify pulp flavour, effectively concentrating sugars and acids in the remainder.

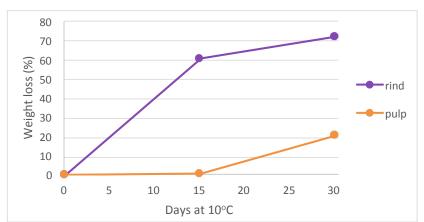


Figure 20. Weight loss of the pulp and rind of passionfruit during storage at 10°C. After 15 days 50% of the fruit surface was shriveled, with virtually all of the fruit weight loss due to rind dehydration. Derived from Arjona *et al.*, 1994.

However, weight loss and the associated shrivelling that results are generally considered undesirable. Shrivelling detracts from the fresh appearance of the fruit, and greatly reduces value. As the rind is not edible, passionfruit appear to be an ideal candidate for the use of waxes and coatings.

- Patel et al⁸⁸ reported an experiment whereby yellow passionfruit were dipped in solid or liquid paraffin based waxes combined with a range of packaging materials. Both waxes reduced weight loss without affecting sugar, acid or scores for juice flavour, and were most effective when combined with plastic packaging.
- Da Silva et al⁸⁹ similarly found that waxes were effective at reducing weight loss of yellow passionfruit. In this case rubber tree latex was rated the best treatment, followed by carnauba wax.
- Carnauba wax (extracted from the carnauba palm) is recommended for yellow passionfruit by the Guyana marketing authority⁵¹. It is noted that liquid paraffin wax also provides a good

⁸⁸ Patel RK et al. 2009. Waxing, lining and polyethylene packaging on the shelf life and juice quality of passion fruit during storage. J. Food Sci. Technol. 46:70-74.

⁸⁹ Da Silva LJB et al. 2009. Alternative covering in the shelf life conservation of yellow passionfruit produced in organic system. Rev. Bras. Frutic. Jaboticabal 4:995-1003.



result, but that this product does not create the same glossy appearance as the carnauba product.

- A carnauba wax product (fruit wax) was also tested by Mota et al¹⁰², along with Sunny Side
 Citrus wax (maleic resin) and Sparcitrus (polyethylene/maleic resin). Sparcitrus proved
 phytotoxic, while the citrus wax failed to significantly reduce moisture loss. The fruit wax was
 judged best overall, as it reduced moisture loss and softening as well as delaying the onset of
 disease by approximately 6 days.
- Another study evaluated propolis (bee resin) as a coating for passionfruit⁹⁰. Propolis is thought
 to have antimicrobial properties in addition to reducing moisture loss. Dipping in 2.5%
 propolis solution did not influence sugars or acids, and still permitted some gas exchange by
 the fruit while also significantly reducing weight loss.

It is noted that all of the above studies were focused on yellow, rather than purple passionfruit. The extremely high respiration rate of purple passionfruit means that restricting gas exchange through the peel risks anaerobic conditions developing in the internal cavity. This could result in undesirable off flavours and odours, even if objective measures of sugars and acids are unaffected. None of the papers sourced for this review evaluated the effect of waxing on fruit flavour.

Research need

Conduct a preliminary trial on use of different waxes on purple passionfruit, including measurement of internal gas concentrations; this will test whether waxed fruit is likely to become anaerobic under ambient conditions. Measurements could include ethylene production, and effects on flavour, chilling sensitivity and development of disease/disorders.

⁹⁰ Da Cunha MC et al. 2017. Propolis extract in postharvest conservation of yellow passionfruit. Interciencia 42:320-323.



5 Packing and storage

5.1 Grading for quality

Key point

Automated graders that use NIR to measure fruit quality attributes on-line are increasingly common. Applying this technology to passionfruit is particularly challenging as the fruit has a thick peel and non-homogenous pulp. However, models have been developed which can estimate both percentage sugars and pulp content of whole passionfruit. These could be used to grade out fruit which have low pulp content or are below minimum brix, diverting them to juice production.

Density, and therefore pulp content, could also potentially be measured using flotation, machine vision plus weight or acoustic techniques. However, no references testing these technologies for passionfruit were found.

Near infrared spectroscopy

Automated fruit graders have become increasingly sophisticated in the last few years. While once products were graded according to size alone, new colour vision systems can detect external blemishes and internal defects as well as measuring sugars, acids, dry matter and firmness. Even small fruit such as blueberries and cherries are commonly sorted on-line according to their quality attributes.

This is largely possible due to improvements in the application of visible and short wave near infrared (NIR) spectroscopy. While the visible spectrum (400-700 nm) is dominated by pigments such as chlorophyll and anthocyanins, the wavelengths used for NIR (780-2500 nm) cause vibration and rotation of O-H and C-H bonds of organic compounds (such as sugars and acids). The characteristics of the reflected or transmitted radiation therefore depend on the chemical and physical characteristics of the product⁹¹.

⁹¹ Nicolai BM et al. 2007. Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: A review. Postharvest Biol. Technol. 46:99-118.



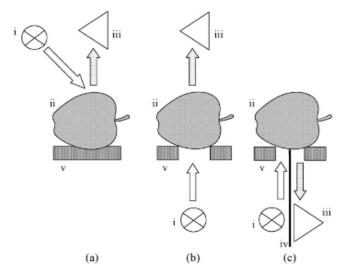


Figure 21. Setup for the acquisition of reflectance (a) transmittance (b) or interactance (c) spectra showing the light source (i) fruit (ii), detector (iii), light barrier(iv) and support (v). The light barrier is used in the interactance mode to prevent radiation directly entering the detector. From Nicolai et al., 2007⁹¹.

Application of NIR to measure quality attributes is simplest for products with homogenous flesh and thin skins. It is more difficult to develop models for fruit with thick skins or complex internal structures – such as passionfruit. This is because the penetration of NIR radiation into fruit tissue is limited and calibration models are more difficult to develop for products with multiple tissue types.

- Oliveira et al.⁹² attempted to develop an NIR model to predict soluble solids and acidity of passionfruit, tomato and apricots. While the method provided a high level of accuracy for apricots, they were unable to use NIR on passionfruit. They suggest that the passionfruit's thick skin prevented use of this technology. The researchers were also unable to develop a model for tomatoes due to its heterogeneous internal structure. The seeds inside a passionfruit are also heterogeneous, a factor which may have added to the difficulty of this application.
- Greater success was reported by Alamar et al.⁹³, working with frozen passionfruit pulp. In this case the objective was to detect samples adulterated by adding water. The model provided an excellent prediction of moisture content and reasonable accuracy with regard to soluble solids, so was able to accurately detect adulterated samples.

⁹² Oliveira GA et al. 2014. Comparison of NIRS approach for prediction of internal quality traits in three fruit species. Food Chem. 143:223-230.

⁹³ Alamar PD et al. 2016. Quality evaluation of frozen guava and yellow passion fruit pulps by NIR spectroscopy and chemometrics. Food Res. Int. 85:209-214.



- Despite the challenges posed by measurement of whole fresh passionfruit, a team of Japanese researchers⁹⁴ has successfully developed models for determining a number of quality attributes, using Vis/SWNIRS wavelengths in the range 603 – 1090 nm.
 - Up to 12 factors were used to predict soluble solids (%), acidity, ascorbic acid, ethanol concentration, peel firmness and percentage pulp.
 - The best results were gained using interactance measurements delivered by a portable optic fibre bundle.
 - Soluble solids content was estimated with over 90% accuracy, and percentage pulp with around 87% accuracy.
 - Other attributes were more difficult to predict, although reasonable results were also obtained for estimating firmness and ethanol content.
 - The authors conclude that Vis/SWNIRS is a feasible method to rapidly and nondestructively evaluate passionfruit quality, so could be adapted to an on-line application.

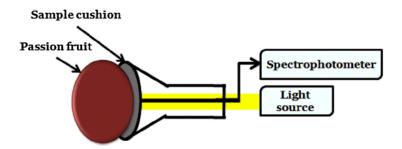


Figure 22. Configuration of equipment used for interactance measurements of passionfruit. From Maniwara et al, 2014.

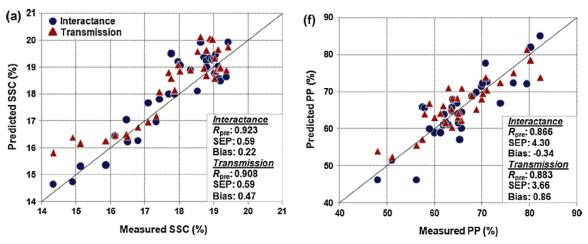


Figure 23. Predicted versus measured soluble solids (left) and percentage pulp (right) of passionfruit from Vis/SWNIR spectroscopy. From Maniwara et al., 2014.

⁹⁴ Maniwara P et al. 2014. The use of visible and near infrared spectroscopy for evaluating passion fruit postharvest quality. J. Food Eng. 143:33-43.



Other technologies

A range of other technologies have been tested to detect voids in fruit. While none have specifically examined passionfruit, they provide some options for future detection of passionfruit with unacceptable levels of internal pulp.

- The easiest method to detect fruit density is by flotation. Adjusting the concentrations of salts added to the flotation solution mean it can provide the optimum specific gravity so that good quality products sink but those that are immature or have voids or internal rots float. The method is commonly used to detect immature mangoes⁹⁵ and chestnuts with internal rot. However, it is notoriously unreliable; one trial found that 1 in 4 chestnuts that sank actually contained internal rots, while some that floated were rot free⁹⁶.
- Density can also be estimated using machine vision combined with load cell measurement of fruit weight. This method has been successfully used for spherical fruit such as oranges, but is more difficult to apply to irregularly shaped fruit⁹⁷.
- Acoustic and vibrational methods have been demonstrated experimentally as an effective way to detect internal voids. For example, Diezma-Iglesias et al⁹⁸ detected hollow heart in seedless watermelons with 94% accuracy using acoustic impulses. Aweta (www.aweta.com) offers equipment that measures resonant frequencies inside fruit that are produced by light tapping. However, no acoustic-based technology has achieved commercial success. This is due to interference by the noise and vibrations produced by an operating grading machine⁹⁷.

Research need

Investigate technologies to grade out passionfruit with low pulp content or unacceptable internal quality. These could include NIR devices, machine vision combined with weight measurements or even simple flotation techniques.

⁹⁵ Lizada, MCC. 1991. Postharvest physiology of mango: A review. ActaHort. 291:437-453.

⁹⁶ Shuttleworth, LA. 2011. The biology and management of chestnut in southeastern Australia. PhD Thesis, University of Sydney http://hdl.handle.net/2123/10082

⁹⁷ Walsh K. 2016. Nondestructive assessment of fruit quality. In "Advances in postharvest fruit and vegetable quality". Eds RBH Wills and JB Golding. CRC Press. pp 39-62.

⁹⁸ Diezma-Iglesias B, Ruiz-Altisent M and Barreiro P. 2004. Detection of internal quality in seedless watermelon by acoustic impulse response. Biosyst. Eng. 88:221-230.



5.2 Packaging and modified atmospheres

Key point

Packaging provides a simple way to increase relative humidity (RH) around the fruit, reducing moisture loss and delaying wrinkling. Packaging can be as simple as a perforated plastic bag, or a sophisticated plastic laminate that uses the respiration of the passionfruit to increase CO_2 and decrease O_2 inside the package. Plastics are also available that incorporate ethylene scavengers, so may slow ripening processes.

There are clear benefits from using packaging to increase RH. The benefits of generating a modified atmosphere (low O₂, increased CO₂) are less certain. Modified atmosphere packaging (MAP) needs to be designed for a specific storage temperature and based on the respiration rate of the product; conditions outside these parameters can result in ineffective or damaging atmospheres.

While some researchers have reported significant increases in shelf life from using MAPs, even moderate changes to the package atmosphere increase the likelihood of anaerobic conditions developing inside the fruit. These are likely to result in off flavours. Similarly, although an ethylene scavenger may initially reduce ethylene accumulation inside the package, passionfruit's high rate of ethylene production means it is likely to quickly become saturated, and therefore ineffective.

Packaging

While waxing provides one way to directly reduce moisture loss from the fruit, packaging provides another. Packaging increases humidity around the fruit, reducing transpiration and, therefore, weight loss.

- Schotsmans et al⁹⁹ found no difference in weight loss, firmness or shriveling between purple passionfruit packed in perforated LDPE bags compared to unlined fibreboard cartons. However, the degree of perforation is not described; large holes may have allowed a high rate of air exchange, so failing to provide the high humidity which would have reduced weight loss.
- In contrast, perforated polyethylene packaging increased shelf life from 4 to 16 days under ambient conditions (temperature not recorded) in northern India. Storage was also extended using non-perforated bags, cling film and *Phrynium* spp. leaves, resulting in 22, 13 and 16 days' storage life respectively¹⁰⁰.
- Adding 6 x 3mm diameter holes to 15 x 30cm bags made of various plastic films improved quality of purple passionfruit compared to the same bags without holes. The best results were achieved with the thinnest films (25 or 30μm). After 30 days at 5°C, fruit in these bags had lost 10% weight and had <7% rots, compared to 45% weight loss and 32% decay in the unpackaged controls¹⁰¹.

⁹⁹ Schotsmans WC et al. 2008. Quality changes of purple passion fruit (*Passiflora edulis*) during storage. ActaHort. 773:239-

¹⁰⁰ Lemtur K, Biswas PK, and Sema A. 2013. Juice percentage and shelf life of passion fruit *Passiflora edulis* as affected by post-harvest treatments and storage conditions. Int. J. Farm Sci. 3:18-21.

¹⁰¹ Singh A et al. 2007. Effect on shelf-life and quality of passion fruit with polyethylene packaging under specific temperature. J. Food Sci. Technol. 44:201-204.



- Shrink wrapping with thin (15μm) cryovac film virtually eliminated weight loss of yellow passionfruit¹⁰². Depending on the film permeability, it seems possible that an anaerobic atmosphere may have developed in these fruit, but unfortunately the effects on flavour were not recorded.
- A simple plasticized film overwrap can have clear and obvious benefits for reducing shrivel and increasing storage life¹⁰³. For example, purple passionfruit overwrapped with 'Vinipel' film reportedly remained in good condition for 10-12 days at 18°C, or 16 days at 6°C + 8 days at 18°C²².

Modified atmosphere packaging

In some cases packaging may also alter the concentrations of oxygen and carbon dioxide around fruit. Modified atmosphere packaging (MAP) uses the respiration of the product to reduce oxygen (O_2) and increase carbon dioxide (CO_2) around the product (Figure 24). After a time, the respiration rate of the product balances the rate of gas diffusion through the plastic, stabilising the atmosphere inside (Figure 25). The atmosphere that develops inside the package is therefore a function of the diffusion rate through plastic, the respiration rate of the passionfruit and the surface area of the package. Respiration rate may be reduced, while high CO_2 inhibits ethylene production and ripening.

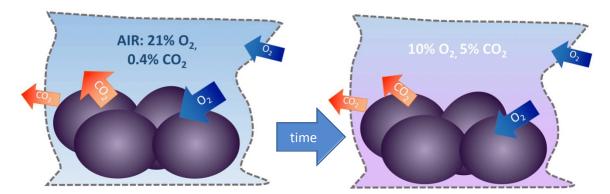


Figure 24. Respiration by passionfruit inside a sealed package depletes O_2 and increases CO_2 (left). After a time, diffusion through the plastic and respiration by the product come into balance, resulting in a stable modified atmosphere inside the package (right).

¹⁰² De Mota WF et al. 2003. Waxes and plastic film in relation to the shelf life of yellow passion fruit. Scientia Agric. 60:51-57.



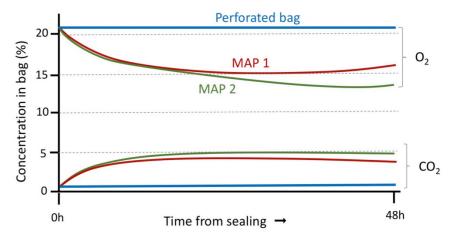


Figure 25. Concentrations of O₂ and CO₂ inside a perforated bag (–), high permeability LDPE bag (–) or medium permeability LDPE bag + ethylene scavenger (–) containing 500g of purple passionfruit. Derived from Maniwara et al, 2012 ¹⁰⁷.

However, temperature strongly affects respiration rate. Changes in temperature have a bigger effect on product respiration than plastic permeability. MAP's therefore need to be designed for a specific storage temperature; higher temperatures are likely to result in O_2 falling dangerously low, while lower temperatures may fail to achieve the target atmosphere.

- The primary mode of action of packaging in increasing storage life is reducing moisture loss by increasing RH around the product. For example, Arjona et al¹⁰³ overwrapped passionfruit with a plasticized PVC film. Although the CO₂ concentration never exceeded 0.5%, O₂ fell as low as 13%, indicating the film was much more permeable to CO₂ than O₂. While the effects of this atmosphere on respiration are likely to be insignificant, storage life was increased due to a reduction in shrivelling and weight loss, with fruit still generally acceptable after 30 days at 10°C.
- Diaz et al.¹⁰⁴, stored purple passionfruit in Xtend bags, which are designed to modify both humidity and the internal atmosphere. Unfortunately, the atmosphere inside the bags was not reported. Unwrapped control fruit were discarded after 16 days at 10°C whereas evaluations of packaged fruits continued for 33 days.
- Another commercial product, Activebag®, has also been tested for use with purple passionfruit^{105, 106}. As with Xtend, the major benefit appears to be reduction of weight loss. There was no difference between the MAP product and an ordinary LDPE bag in terms of weight loss, TA, sugars, respiration rate or ethylene production. Although rots are stated to be higher in the standard bag, no data is presented supporting this.

¹⁰³ Arjona HE, Matta FB and Garner JO. 1994. Wrapping in polyvinyl chloride film slows quality loss of yellow passion fruit. HortSci. 29:295-296.

Diaz RO et al., 2012. Postharvest behaviour of purple passion fruit in Xtend bags during low temperature storage. ActaHort. 934:727-732

Yumbya P et al. 2014. Effect of modified atmosphere packaging on the shelf life and postharvest quality of purple passion fruit (*Passiflora edulis* Sims.). J. Postharvest Technol. 02:25-36.

¹⁰⁶ Owino WO et al. 2016. Efficacy of Activebag packaging on postharvest quality of purple passion fruit (*Passiflora edulis* Sims). ActaHort. 1120:85-90.



- Maniwara et al^{107, 108} compared a perforated package to a medium permeability film package and a lower permeability film package which incorporated "ethylene absorbing agents".
 - Oxygen and CO₂ inside the package with the scavenger is consistent with this film having a 15-20% lower oxygen transmission rate than the standard MAP. This suggests that the respiration rate was similar in both packages, and not significantly reduced by the addition of the ethylene scavenger.
 - While ethylene accumulation was delayed by one week in the package with ethylene scavenger (Figure 17), it then remained at physiologically active levels.
 - Storage life in the perforated film, MAP and MAP with ethylene scavenger were estimated as 25, 30 and 45 days respectively. However, off odours and flavours were apparent in the MAP + ethylene scavenger package after 35 days, so this may be an overestimation of acceptable storage life.
- Chen et al¹⁰⁹ took a different approach, flushing bags containing purple passionfruit with O₂ so as to achieve concentrations of up to 90%. The treatment was relatively transitory, the bags returning to normal O₂ levels within five days of sealing. However, exposure to 70 or 90% O₂ reduced respiration and shrinkage during subsequent storage. It is unclear why this occurred. Moreover, the cost and technical difficulty of this treatment is likely to be significant.

Research need

Conduct a preliminary trial on packaging for purple passionfruit. Include carton liners as well as retail ready packs. Ensure packaging meets customer requirements and preferences, particularly with regard to minimising use of non-recyclable materials (e.g. recyclable punnet with thin plasticized overwrap) and using biodegradable materials (e.g. starch-based polymers) wherever possible.

¹⁰⁷ Maniwara P et al. 2012. Study on the effect of active packaging on passion fruit postharvest quality. Proc. Int. Conf. Agric. Eng. Jan 2012.

¹⁰⁸ Maniwara P et al. 2015. Changes of postharvest quality in passion fruit (*Passiflora edulis* Sims) under modified atmosphere packaging conditions. Int. Food Res. J. 22:1596-1606.

 $^{^{109}}$ Chen FP et al. 2018. Effect of high O_2 atmospheric packaging on postharvest quality of purple passion fruit (*Passiflora edulis* Sims). J. Food Process Preserv. 42: e13749.



5.3 Packing

Key point

Passionfruit should be size graded and packed carefully to avoid damaging the fruit. Any adhering calyx tissue should be removed before packing, and damaged or diseased fruit discarded. Vent cartons and stack so as to permit cooling.

- Discard rotten, bruised or over-ripe fruits before packing. Passionfruit should always be size graded, so that cartons appear to contain reasonably homogeneous product¹¹⁰.
- While passionfruit are not normally washed, they should not be packed dirty. Brushing can remove superficial dirt, as well as any adhering calyx or leaf tissue. The dried calyx should also be removed before packing as it is a potential source of decay⁴⁹.
- Ideally, passionfruit should be packed carefully. Large fruit may be pattern-packed. This avoids damage from stems scratching other fruit in the carton.
- Cartons should have vents covering at least 5% of the surface area, and be stacked so as to allow ventilation by cooling air. No information on use of carton liners was found for this review; while these would reduce moisture loss, they also make cooling more difficult.



Figure 26. Grading passionfruit by size, and pattern-packing of large fruit

¹¹⁰ Bora PS, and Narain N. 1997. Passion fruit. In: *Postharvest Physiology and Storage of Tropical and Subtropical Fruits*. Ed. SK Mitra. CAB International.



5.4 Storage environment

Key point

Temperature is a key determinant of fruit and vegetable storage life. Recommended storage temperatures for purple passionfruit range from 3°C to 10°C, suggesting that the chilling sensitivity of the fruit is poorly understood. The optimum storage temperature for Panama passionfruit is likewise unknown, but, as a tropical variety, is likely significantly higher than that for purple types. Maintaining high humidity (85-90%RH) is also essential to reduce shrivelling and weight loss.

While products are warm they lose moisture. Moisture loss may increase if warm products are placed inside a cold room and are not cooled quickly. This is because air at, for example, 5°C and 90% RH contains 6g water/m³ whereas air inside a warm passionfruit (e.g. 30°C) contains over 30g water/m³; this creates a strong osmotic pressure, the cold air pulling moisture from the warm fruit. Cooling passionfruit as soon as possible, and ensuring they cool quickly, minimises moisture loss.

Passionfruit are chilling sensitive, so although cooling can extend storage life it is important not to cool them below their physiological limit. Chilling injury symptoms include surface and internal discolouration, water soaked areas, off flavour development and increased decay¹¹⁰. However, storage temperature recommendations vary by source and variety.

- Estimated storage life for Australian (ripe) purple passionfruit is 3-5 weeks at 5 to 9°C. 111
 - According to the University of California, Davis Fact Sheet on passionfruit (postharvest.ucdavis.edu), partially ripe purple passionfruit should be stored at 7-10°C, however fully ripe fruit can be stored at 5-7°C.
 - Paull and Chen⁴⁹ recommend an even lower storage temperature for purple passionfruit, suggesting they should be forced air cooled to 10°C then stored at 3 to 5°C for up to 5 weeks.
 - Storage of purple passionfruit at 4-5°C is reported to increase the fruit saleable life by 50% compared to storage under ambient conditions²².
- Surprisingly, Schotsmans et al⁹⁹ found no benefit from cooling purple passionfruit to 10°C compared to leaving them at 20°C. Even though respiration rate was reduced by cold storage, weight loss, firmness and changes in soluble solids were similar. Unfortunately humidity was not reported. If RH was lower at 10°C than at 20°C, this may have reduced any benefits from cooling the fruit.
- This is different to the results of Kishore et al. 112, who found that cold storage reduced weight loss and retained eating quality better than leaving fruit under ambient conditions (25°C). The best results were gained by storage at 8°C.

 $^{^{111}}$ Wills RBH et al. 1989. Postharvest. An introduction to the physiology and handling of fruit and vegetables.

¹¹² Kishore K et al. 2011. Effect of storage temperature on physico-chemical and sensory attributes of purple passion fruit (*Passiflora edulis* Sims). J. Food Sci. Technol. 48:484-488.

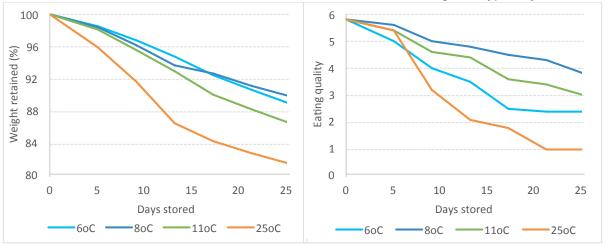


Figure 27. Effect of temperature on weight loss (left) and eating quality (right) of purple passionfruit stored at approx. 70%RH. Derived from Kishore et al., 2011.

- Yellow passionfruit appear to be more chilling sensitive than purple passionfruit. Numerous papers report severe chilling damage at 5°C, resulting in increased shriveling and weight loss compared to fruit stored at 10°C⁵². For example, after 15 days at 5°C 84% of the passionfruit rind was shriveled, compared to 40% and 50% at 10°C and 15°C respectively¹⁰³.
- No information was available on how delays in cooling affected quality and disease development during subsequent transport and retail; or defining the effects of relative humidity on weight loss and shriveling.

Research need

Determine the optimum storage temperatures for purple and Panama passionfruit varieties, including defining the effect of cooling delays and the influence of both temperature and relative humidity on quality attributes and weight loss.

Develop models predicting storage life based on postharvest management.







AUSTRALIAN
PASSIONFRUIT
Postharvest Best
Practice Guide





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01. Introduction

Consistent retail quality is essential in order to satisfy consumers. However, maintaining quality of passionfruit after harvest can be challenging. Despite their sturdy appearance, passionfruit are fragile fruits that easily lose moisture, are susceptible to disease and rapidly deteriorate after harvest.

Passionfruit are produced from northern NSW right up into the far, wet tropics of northern Queensland. Most passionfruit farms are relatively small, family operations with basic packing facilities. Many do not have cold rooms, relying on centralized depots to cool fruit. However, trucks carrying mixed loads have limited FDSDFLWWRDGDSWWRWKHVSHFL4FQHHGVRISDVVLRQIUMW Moreover, relatively long transport times are often required in order to reach consumers in southern markets.

Fruit which has not been grown, picked and packed well is therefore poorly equipped to face the challenges of extended transport and marketing.

The fruit faces other issues too. Volatility in supply and, therefore, prices, is an ongoing issue for growers and marketers alike. Managing harvest and extending VWRUDJHFRØGKHOS DWWHQVRPHRIWKHSHDNVDQG troughs in the volumes of fruit arriving at wholesale markets. Increasing consistency of supply through improved postharvest management would help to market fruit better as well as improve returns for growers.

Maintaining passionfruit quality through the supply chain starts with growing a good quality product in the orchard. Well managed harvest, cooling and packing operations will ensure passionfruit stay in good condition right up until they reach the retail shelf. Postharvest treatments such as packaging and waxing can also help passionfruit stay fresher for

This guide summarises best practice for passionfruit supply chains. Wherever possible, options are included to suit both larger operations and small family farms with limited capacity for postharvest improvements. The key issue is to understand what is happening within the fruit once it is detached from its source of water and nutrients and starts its journey to market.

02. Pre-harvest

Postharvest handling can only deliver high quality fruit if it is grown well from the start. Only a healthy plant will produce quality fruit with maximum shelf life. Plant nutrition, variety

is included in *The Passionfruit Growing Guide*

P

BBMO

VINE NUTRITION

Healthy soils and well-nourished plants produce the best quality fruit. Maintaining a biologically active soil helps suppress plant diseases as well as store and cycle water and nutrients. Fertilisers improve yield and quality. However, over-fertilising can increase fruit acidity.

BEST PRACTICE

- Well-nourished, healthy plants produce the best fruit
- Leaf analysis can help determine whether the elements that are key to producing good quality fruit (nitrogen, potassium, calcium and boron) are within recommended ranges
- ✓ Soils should be somewhat acidic, with pH below 6.5, but above 3.5
- Optimise irrigation to prevent either too little or too much water
- ✓ Good pollination is essential to maximise yield and quality; the amount of pollen GHSRWHGRGREWLHFWONODWHWR size and pulp content
- Encourage bees into the orchard and avoid using pesticides that could harm potential pollinators
- Implement a pre-harvest disease management program that includes SRGKWKWKGLHHW/PRGHRIDFWLRQ
- Practise good orchard hygiene, destroying rotting fruit and ensuring there is good air circulation around the vines

Nitrogen

1LWURHIXHOVHHWDWLHURWKV5RHUVDUH

produced in the leaf axils, plants with strong vegetative growth can also potentially produce the most fruit. However, nitrogen is very mobile in the soil and easily leached, especially if there is heavy rainfall. For this reason, it is best applied frequently in small quantities. For example, some agronomists recommend application through fertigation every 2 to 4 weeks.

7KHIRUPRIQLWURJHQPDLQ5MQFHIULWTDOLW\
Japanese researchers have found that applying
nitrogen as ammonia (e.g. sulphate of ammonia) rather
than nitrate (e.g. calcium nitrate) resulted in sweeter
fruit. Urea is usually the cheapest way to add nitrogen,
but must be well watered in to avoid losing nitrogen to
the air as ammonia gas.

Potassium

Like nitrogen, potassium is essential for passionfruit vine health and productivity. Potassium is a major component of fruit; Rigden (2011) estimates that 4.3kg of potassium is removed for every tonne of fruit production, compared to 3.3kg of nitrogen and 0.3kg of phosphorus. Providing adequate potassium is essential for good fruit production. Increasing levels of potassium increase fruit weight, rind thickness and Vitamin C content.

However, excess potassium inhibits the uptake of calcium, which is also essential for good fruit quality. It can also result in more acidic fruit.

Potassium is very mobile in both plant and soil, so easily leached under heavy rainfall. Like nitrogen, potassium is best applied in small amounts at 2 to 4 week intervals, with the most frequent applications during peaks in fruit development.

Calcium

Calcium is critical to the strength of cell walls. High levels of calcium are widely associated with improved

postharvest quality for many fruit. Increased calcium has been reported to slow ripening, inhibit disease and improve saleable life of fruit such as avocados, papaya and apples.

Calcium moves through the plant in the xylem (water holding) vessels. Movement is passive, depending on the rate at which transpiration is pulling water from the roots to the expanding leaves and fruit.

BOFLRGH4FLHQFRDMHVWKHGLVRUGHUEORVVRPHQG rot' in fruit such as tomatoes and capsicums. This is due to the collapse of rapidly dividing cells within the expanding fruit. Blossom end rot usually occurs because of high humidity, which reduces transpiration rates to the point where calcium cannot be transported WRZKHUHLWLVQHHGHGBOFLRGH4FLHQFDOVRRFFBV due to low calcium levels OR excess potassium and magnesium in the soil.

As passionfruit mature, transpiration rates decrease. It is therefore essential to have adequate levels of FDOFLR DYDLODEOHLQWKHVRLOZKHQIU&W4UVWIRUPD is when they accumulate enough calcium to support later development. Foliar applications of calcium are

RIWHQIR®GWREHLQHHFWLYHDWUDLVLQJFDOFL®OHYHOVLQ fruit. This is because calcium moves through the water stream; fruit are supplied with water by the roots, not the surrounding leaves.

Calcium can be applied as gypsum (calcium sulphate), lime (calcium carbonate), dolomite (calcium magnesium carbonate) or cal-nitrate (calcium nitrate/calcium ammonium nitrate). Both lime and dolomite increase soil pH, whereas gypsum does not. Calcium is relatively immobile and insoluble, so is best applied during spring and/or at the end of the dry season, as rain helps incorporate it into the soil (Rigden, 2011).

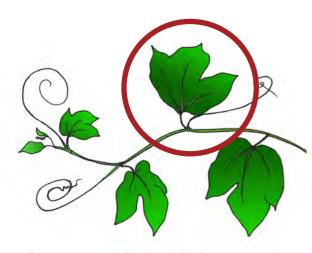
Leaf tissue analysis

Leaf sampling is generally conducted during cooler months, when development has slowed. Take leaf samples from representative vines spaced around the orchard. Select the last fully expanded leaves from healthy shoots. These are usually the fourth to eighth leaf from the growing tip. Keep cool until ready to VKLLY send for analysis. Optimum leaf nutrient ranges for passionfruit are reproduced from Rigden (2011) in the table below.

Optimum leaf nutrient levels, using the youngest fully expanded leaf

	NUTRIENT		OPTIMUM RANGE	NOTES
MACRONUTRIENTS	N	Nitrogen	4.25 to 5.25%	Essential for growth but easily leached
	Р	Phosphorus	0.25 to 0.35%	Passionfruit have low requirements for P
	К	Potassium	2.0 to 3.6%	May be low due to leaching, LQV I LHQWIHUWLOLVHURUFRPSHWL with Ca or Mg
	Ca	Calcium	1.0 to 2.5%	Uptake reduced if soils are acidic, lacking Ca or have excess Mg or K
	S	Sulphur	0.2 to 0.6%	5DUHOGH4FLHQW
	Mg	Magnesium	0.3 to 0.5%	H4FLHQFLHVPRVWOLNHOLQOHDFKH acidic, sandy soils
MICRONUTRIENTS	В	Boron	40 to 60mg/kg	Boron must be managed carefully to DYRLGERWKGH4FLHQFDQGWR[FLWV
	Cu	Copper	5 to 20mg/kg	Copper sprays for disease control MBOODGGVKLHQW&
	Fe	Iron	100 to 200mg/kg	5DUHOGH4FLHQW
	Mn	Manganese	50 to 350mg/kg	5DUHOGH4FLHQW
	Zn	Zinc	>50mg/kg	Low levels are common in sandy soils
	Na	Sodium	<0.15%	If high levels are detected, check irrigation water EC

02.PRE-HARVEST 02.PRE-HARVEST



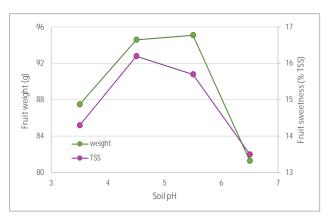
Test the youngest fully expanded leaf.

SOIL PH

6RLOSDHDWOL5XHEHVWKHDELOLWRIWKHSODWWRWDNHU

up essential nutrients. Strongly acidic or alkaline soils limit nutrient availability. For example, both N and P are most available if soil has a neutral pH (pH 6.5 to 7.5). Potassium is limited by pH below 5.5 whereas boron is equally available between pH 5 and 7.5.

Passionfruit prefer a somewhat acidic soil. Rigden (2011) recommends soil should have pH 5.5 to 6.5 (measured using a water based test). However, new research (Niwayama and Higuchi, 2019) suggests that HYHQORZHUSPDEHEHQH4FLDOWRIUEWTDOLWSDSOH passionfruit growing in soils adjusted to pH 4.5 and 5.5 were larger, heavier, more strongly coloured and sweeter than fruit grown at pH 3.5 (strongly acidic) or pH 6.5 (very slightly acidic). Fruit grown under relatively neutral soil conditions tended to have more acidic juice and were relatively pale and thin skinned, increasing shrivel. Nitrogen fertilisers tend to reduce soil pH, whereas lime and dolomite applications increase pH.



cv. Summer queen. Data from Niwayama and Higuchi, 2019.

Irrigation

Passionfruit have a relatively high water requirement. While wilting is an obvious sign of water stress, fruit TIDOLWDQGLHOGDUHGUDPDWLFDOODHFWHGZHOOEHIRUH wilting occurs. However, too much water can also have negative impacts. It is important to get irrigation right, especially when fruit are forming. During this time, plants must be irrigated enough for calcium to be transported through the xylem vessels to the developing fruit.

TOO LITTLE WATER

- · Reduced uptake of calcium and boron
- 5HGKHG5RZHULQJDQGIUKWVHW
- · Small fruit with low pulp content
- Premature fruit drop

TOO MUCH WATER

- · Anaerobic soil, reducing vine health
- · Increased root rots e.g. Phytophthora, which can
- · Leaching of nitrogen and potassium
- · Increased susceptibility to disease

Monitoring soil moisture is the best way to determine how much irrigation is required and when. Tensiometers are relatively cheap, can be accurate in sands, and work well so long as soils remain relatively moist. More sophisticated tools such as the WildEye® 7LPHRPDLQ5H5HFWRPHWU\\5RU(QYLUR6FDQp (capacitance) are used to monitor soil moisture in the root zone, with information provided via a web or app based interface.

Passionfruit are very sensitive to salinity, so it is also important that water is good quality. Mulching can help WRUHGKHZDWHUMHDVZHOODVSURYLGLQJEHQH4WVLQ terms of weed control, reduction in root diseases and improved nutrient uptake.

Comprehensive information on irrigation for passionfruit is included in The Passionfruit Growing Guide. A range of fact sheets are also available through the Growcom website.

Flowering and pollination

3DVVLRIUXLWDUHDRGDSODWVPHDLPRVW5RHUV

form when days are more than 11 hours duration. (HFWRIVRLOSRQTBOLWDWWULEWHVRIKEULGSWSOHSDVVLRQIUWW Flowering tends to concentrate in spring and autumn. Buds form between 15 and 30°C, so high temperatures GWLQJVRPHUFDQLQKLELW5RZHULQJ

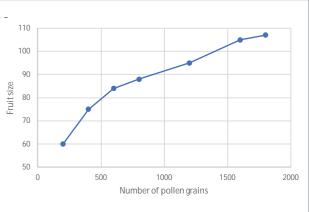
Both purple passionfruit and Panama varieties are VHOIFRPSDWLEOHPHDQLQJWKH5RZHUVFDQEHIHUWLOL by their own pollen. However, the pollen sacs are positioned below the stigmas, meaning that pollen cannot naturally fall onto the receptive part of the 5RZHUNRVVSROOLQDWLRQEHWZHHQGLHUHQWSODQWV likely to maximise fruit set and yield.

\$SDVVLRQIU&WSROOHQLVKHDYDQGVWLFN5RZHUVDUH rarely fertilized by wind. Instead honeybees, native EHHVHJFDUSHQWHUEHHV5LHVDQGRWKHULQVHFWV WUDQVIHUSROOHQEHWZHHQ5RZHUV)ORZHUVDUHPRVW receptive about an hour after they open, remaining receptive for only a few hours. If it rains within two hours of pollination the pollen is destroyed.

The amount of pollen deposited on the stigma GLUH BYND H BYN U K WH WU K BYL LK TDAG S XO S content.

Hollow fruit are the results of poor pollination. Achieving thorough pollination is therefore essential to SURGNHJRRGTWOLWXHOO4OOHGIUWW

- ☐ Encourage native bees, e.g. carpenter bees, into the orchard by providing nesting sites such as old logs
- ☐ If honeybee hives are available, locate them nearby to ensure a good bee population
- ☐ RUGVSUDUUVHEWUEUGHVWKDWDHEWSROOUDWRUX
- Plant windbreaks; wind not only physically damages vines and causes wind-rub blemishes on fruit, it discourages foraging by bees.



Relationship between the amount of pollen deposited on the 5RZHUDQGWKHVLJHRIWKHUHVØWLQJIUMWHULYHGIURPNDPLQH and Girolami, 1959.





Fully pollinated and poorly pollinated fruit cv. Misty Gem

6WUKWWHRIDSDVVLRQIUWW5RZHU

DISEASE MANAGEMENT

3DVVLRIUXLWDUHDHEWHGEXPHURXVSUHKDUHVWD GLVHDVHVWKDWDHEWIUXLWIIXDOLWIKHPRVWVHULRXVDÜHÜ

alternata/brown spot (Alternaria alternate and Alternaria passiflorae respectively) which cause major fruit loss during the warm, wet periods from October to April; and anthracnose (Colletotrichum gloeosporoides), which is most severe in cool, wet periods.

LVHDVHVRFFWULQJLQWKH4HOGGLUHFWODHFWIUWW quality. Even if symptoms are minor at harvest, diseases continue developing during storage and transport. Weight loss is increased, and large, sunken lesions may form.

to producing high quality fruit. Fungicide programs LQYROYLQJSURGKWVZLWKGLHUHQWPRGHVRIDFWLRQ DUHPRVWOLNHOWREHHHFWLYH\$DQJHRII\@JLFLGHV are registered for use on passionfruit, including azoxystrobin, pyraclostrobin, iprodione, mancozeb, phosphonic acid and a range of copper products. KHFNWKH\$90BU-OIRSHVWZHEVLWHVWRFRO4UP UHJLVWUDWLRQRIVSHFL4FSURG**K**WV

Strobilurin fungicides (e.g. azoxystrobin) are very HHFWLYHDQG\(\text{QOLNHSURWHFWLYHI\(\text{Q}\)JLFLGHVHJFRSSHU

based products), are partially mobile within the plant. However, the risk of resistance developing is high. To

☐ 6WDUWWKHEURSSLEEDHUWKDGLHUHWSURGXFW

- Do not use more than twice consecutively
- Only use a strobilurin for (maximum) one in every three fungicide applications
- ☐ RRWDSSOPRUHWKD#HWLPHVDXDOO□

Maintaining good orchard hygiene is another way to reduce disease pressure on fruit:

- ©HHFWLYHGLVHDVHPDQDJHPHQWSURJUDPLVHVVHQWLDO Ensure there is good air circulation, keeping the canopy open by training and pruning vines
 - Do not allow ground covers to smother vine bases
 - Regularly clean any cutting tools used to trim plants with an appropriate disinfectant, such as bleach (100ppm chlorine)
 - Control insects such as fruit spotting bug and fruit 5LHVDVGDPDJHSURYLGHVHQWU\$RLQWVIRUURWV
 - ☐ Healthy plants are more disease resistant; practices that improve vine health will help reduce the impact of diseases.





6PDOOVSRWVRIGLVHDVHREVHUYHGLQWKH4HOGOHIWFDQFRQWLQMWRGHYHORSDIWHUKDUYHVWKDYLQJPDMRUQHJDWLYHHHFWVRQIUMWTDOLWN (right)

03. Harvest

3MSOHSDVVLROIUKWDUHMMOOKDUYHVWHGDIWHUODWMDOIUKWGURS7KLVHOVMHVWKHKDYHUHDFKHG RSWLPRPDWWLWGHYHORSLQJWKHEHVWSRVVLEOHFRORWDQG5DYRWRZHYHUWKLVFUHDWHVFKDOOHQJHV IRUWKHV\SOFKDLQDVLWFDQEHGLF\SWWRSUHGLFWSUHFLVHO\SKHQWKLVZLOORFF\102QFHIU\text{kWGURS} WKHRWWEHSLFNHG%LPPHGLDWHOWRDYRLGV&EWQDQGUHGNHWKHULVNRIVKULYHOOLQJDQGGLVHDVH 3DQDPDSDVVLRQIUMWDUHSLFNHGGLUHFWONJRPWKHYLQHZKHQKHDYDQGIDORRORDHG3DSOH SDVVLRQIU**k**WFDQDOVREHKDUYHVWHGGLUHFWONJRPWKHYLQHHVSHFLDOONIDOORZHGWRFRPSOHWHULSH under controlled conditions

HOW AND WHEN TO HARVEST

is, ripening occurs in response to ethylene gas, and is accompanied by a large increase in respiration rate. Ripening can be triggered by ethylene in the external environment as well as through production by the fruit itself. Fruit start to produce ethylene once they are physiologically mature, while still attached to the vine.

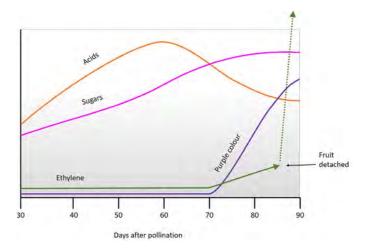
BEST PRACTICE

- For purple varieties, both picking up dropped fruit and harvesting directly from vines have advantages and disadvantages; either method may be used depending on circumstances
- · If picking up dropped fruit, maintain good ground cover to provide cushioning and avoid contamination
- · Pick up regularly to reduce the risk of sunburn and decay
- ✓ Panama varieties must be harvested directly from the vine
- ✓ Never pull fruit directly from vines, but either clip or snap at the natural joint in the fruit stem
- ✓ Harvested fruit should be picked while cool, kept shaded at all times and transferred to the packing facility as soon as possible

(WKOHQHVWLPØDWHVFKDQJHVLQFRORØDQG5DYRØ **3DVVLRIUXLWDUHEODVVL4HGDVDEDLPDEWHULEIUXLWZKDW**D. Passionfruit can be picked once 34 coloured, ZLWKRWDHFWLQJ5DYRWRUFRORW7KHVWHPVKRØG break easily at the natural joint above the fruit, or fruit can be snipped from the vine with a piece of stem

> Never pull fruit directly from the vine, as this creates an open wound. Wounds not only allow rots to develop, but increase moisture loss and shrivelling.

Under some circumstances, picking directly from the vine rather than allowing fruit drop, may optimise fruit quality. However, both methods have advantages and disadvantages. Combinations of picking up dropped fruit and harvesting mature fruit directly from vines may provide the best results.



Changes in sugars, acids, colour and ethylene production during maturation of passionfruit. Initiation of ethylene production WULJJHUVFKDQJHVLQFRORINDQG5DYRNJ(WKOHQHSURGNWLRQ increases more than 20x once fruit detach from the vine. Derived from Shiomi et al., 1996

03.HARVEST 03.HARVEST



If picking up dropped fruit:

- ☐ Maintain good groundcover don't let fruit fall onto
- ☐ While moving through the orchard, shake the trellis to release fruit caught up in the vines or about to naturally detach
- ☐ Aim to pick up while temperatures are cool, such as during the early morning
- ☐ Pick up daily, or even twice daily, during hot weather to avoid sunburn; do not leave dropped fruit in the sun during the middle of the day
- ☐ Note that fruit will roll into the row centres if plants are mounded, increasing sunburn risk

Overhead pergola systems and A-frames provide shade for dropped fruit.



Purple passionfruit can be harvested once 3/4 to fully coloured (top left). Fruit picked while half coloured (top right) will fail to GHYHORSPD[PRFRORWDQG5DYRW





Purple passionfruit with mature vines growing on vertical trellis systems can be allowed to drop naturally then picked up from the ground (left) whereas Panama types grown on overhead trellises need to be harvested directly from the vines (right)

Advantages and disadvantages of different harvesting methods for purple passionfruit

	ADVANTAGES	DISADVANTAGES	WHEN TO USE
PICK UP DROPPED FRUIT	Fruit are fully ripe and ready to eat at harvest Quick and easy Can start before dawn (when the weather is cool) No damage to vines	Fruit may have reduced quality and storage life due to damage, disease or sunburn Reduces ability to plan transport and marketing	Mature vines Cool or overcast weather Overhead pergolas and A-frames where there is cushioning, groundcover
HARVEST DIRECTLY FROM VINES	Maximises storage life Avoids damage Avoids contamination from the ground Prevents fruit sunburn Can be scheduled, allowing PRUHHFLHQWWUDQVSRUW and marketing	Fruit may not be fully ripe at harvest Searching for fruit can damage vines, especially the growing tips Harvest workers must be trained Needs to be done during daylight	Panama types e.g 3DQGRUD0FMVUHG Young vines If sunburn is likely (e.g. single wire systems during hot weather) If there is bare soil under vines

MANAGING HARVEST

Once passionfruit have detached from the vine, ethylene production increases by 10 to 20 times. There is some evidence this burst of ethylene can trigger other maturing fruit to drop, also. This may explain why, at times, fruit drop all at once.

Remember that passionfruit are alive and respiring. This means they are consuming oxygen and releasing carbon dioxide, fueling their ripening processes. However, once fruit have detached from the vine they are reliant on stored energy reserves to stay in good

Keeping harvested fruit as cool as possible is essential to slow down the inevitable processes of deterioration, shrivelling and decay.

- Pick passionfruit in the coolest part of the day
- ☐ Keep harvested fruit shaded at all times
- ☐ Transfer harvested fruit to the packing shed as soon as possible.



04. Postharvest handling and treatments

BEST PRACTICE

- Ideally, fruit should be packed and cooled on the same day it is harvested
- If fruit is to be packed at a later date, then measure pulp temperature:
- If fruit is hot (>30°C) then immediately cool below 15°C, preferably using a forced air systemy
- If fruit is warm (20 to 30°C) then place in a cold room
- If fruit is already **cool** (<20°C), keep shaded and protected
- Forced air systems cool passionfruit rapidly, avoid condensation and reduce total moisture loss compared to room cooling
- · Simple forced air systems can be constructed for bins placed in a standard cold room
- As passionfruit are one of the highest ethylene producers of all fruit, attempting to reduce ethylene levels during storage LIGEIOWDQIOLNHOWRLEHDIMWRDJH life
- Wash water must be clean, with a sanitiser added if water is recirculated instead of run to waste
- **₩**BPDL**®**IWKH5REIBWEH removed and fruit dried before packing
- Waxes can add a glossy appearance to fruit and delay weight loss and shriveling, EWWKHH-FWIZOOGHSHQROVKHDUHW\ and growing conditions
- Cooling is the best way to reduce moisture

Once climacteric fruit such as passionfruit start to ripen,

to prevent ripening once it has started can reduce the quality of the ripe fruit, as it interrupts normal changes

passionfruit as they are one of the highest ethylene PIDO IDADA/

handled carefully to maintain postharvest quality.

PACKHOUSE RECEIVAL

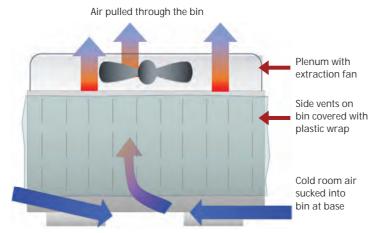
KHHHUSRVVLEOHIUXLWVKRXOGEHSDENHGDG

cooled on the same day it is harvested.

If fruit is to be packed immediately, then it can be cooled after packing.

If fruit is going to be packed later, then actions depend on fruit temperature:

- z If fruit is hot (>30°C pulp temperature), then immediately cool below 15°C, preferably using a forced air system, and pack within 2 days
- z If fruit is warm (20 to 30°C pulp temperature), then place in a cold room and pack within 2 days
- z If fruit is already cool (<20°C pulp temperature), and overnight temperatures are below 25°C, then keep shaded and protected from wind and pack the next



Forced air cooling system for use with bins

If cool room facilities are unavailable, placing damp hessian sacking on top of bins can help keep fruit cool and increase humidity inside the bin.

Cooling fruit

Simply placing a bin (or pallet) of fruit in a cool room does not make it cold. Cooling rates of full bins can be very slow, even if there is good air circulation within the room. Bins have a small surface area compared to their volume, and it is only at the surface that heat can move out of the fruit and into the surrounding air.

Though the top layer cools, fruit in the centre may take hours or even days to cool to room temperature. Cooling rates are even slower if fruit is in unvented wooden bins rather than vented plastic bins.

2QHZDWRLQFUHDVHWKHHHFWLYHVWIDFHDUHDLVE\ using a forced air cooling system. If only 1–3 bins are to be cooled at a time, this can be done easily within an existing cold room. A fan (such as an old cold room fan or industrial fan) needs to be mounted onto a plenum which covers the top of the bin. Blocking the side vents RIWKHELQZLOOLQFUHDVHWKH#LHQFRIWKHVVWHP The cold room air can be pulled through the harvested fruit. This method can cool fruit up to 10x faster than simply placing the bin in the cold room.

Slowing ripening

Ripening is triggered by ethylene gas. Ethylene is active at very low concentrations, usually expressed as parts per million (ppm). Only 0.1 to 1ppm (0.00001 to 0.0001%) can trigger ripening in many fruit. Ethylene can come from the external environment (other fruit.

decaying vegetation, petrol engines) or be produced by

Passionfruit have extremely high rates of ethylene production. The majority is produced by the seeds and pulp inside passionfruit rather than the outer rind. As a result, the fruit can accumulate very high internal levels of ethylene during ripening. For example, whereas rockmelons may accumulate up to 8ppm ethylene in the internal seed cavity and tomatoes up to 30ppm, passionfruit have recorded internal concentrations of over 500ppm!

There is a range of devices that can remove ethylene from the storage environment. These generally involve oxidizing ethylene using potassium permanganate FRQWDLQHGLQVLGHDLU4OWHUVWUDSSLQJHWK\0HQHZLWK PDWHULDOVLQFRUSRUDWHGLQWRSODVWLF4OPVRUUHDFWLQJWF ethylene with ozone. Such devices have been shown WREHH-FWLYHIRUDUDQJHRIRWKHUW\$HVRIIU&WG&LQJ cold storage.

However, keeping ethylene below physiologically active OHYHOVGWLQJSDVVLRQIUKWVWRUDJHLVHWUHPHOGEDW -WPDDOVRKDYHOLWWOHHIFWRQSDVVLRQIUMWVWRUDJHOLIH DQGTDOLWDVVLJQL&DQWHWKOHQHFRQFHQWUDWLRQVDUH still likely to accumulate inside the fruit.

Installation of ethylene removal devices in cold rooms and/or use of ethylene absorbing packaging materials therefore seems unlikely to provide value for money.

> The best way to slow ripening is by managing temperature

Threshold concentrations of ethylene, and maximum rates of ethylene production during ripening, for various fruits. Data from Reid, 2002, and other sources.

	Threshold concentration for ripening/decay (ppm)	Maximum ethylene production during ripening (µl C ₂ H ₄ /kg.h)
AVOCADO	0.1	100 – 350
BANANA	0.1 – 1.0	8 – 12
CITRUS	0.1	0.1
MANGO	0.1 – 0.4	5 – 10
PASSIONFRUIT	Unknown	370 - 1,000
ROCKMELON	0.1 – 1.0	80 – 150
TOMATO	0.5	5 – 20

WASHING

Fruit must be washed if they have been contaminated by dust in the growing environment or soil adhering after ground harvesting.

It is essential that wash water is clean. Dirty water can not only result in human pathogens contaminating the fruit, it can also spread diseases, increasing postharvest rots.

- ☐ Single use wash water does not need to contain a sanitiser, but should be clean i.e. drinking water
- ☐ If wash water is recirculated, it must contain a sanitiser such as 50-100ppm chlorine (0.01% active LQJUHGLHQW1RWHWKDWFKORULQHLVLQHHFWLYHDWand shrivel rapidly accelerated. pH>7.5 and is rapidly de-activated if the water is dirty.

MANAGING DISEASE

The best way to control disease postharvest is by avoiding pre-harvest infection.

There are no registered postharvest fungicides for passionfruit. There is some evidence of hot water dips reducing disease (e.g. 4 minutes in 47°C water), but these have not been tested in the Australian environment.

To reduce risk of disease:

- Always ensure that any dried remains of the 5RHUDUHUHPRHGEHIRUHSDNLQ
- Use fans during packing or storage to help dry fruit that have been harvested while wet due to rain or
- Avoid packing wet fruit
- Do not store under saturated humidity e.g. in sealed plastic packages, as this encourages growth of surface mould.



WAXES AND COATINGS

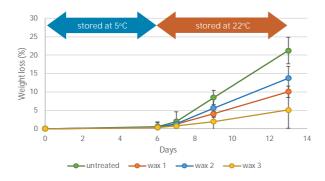
Waxes can add an attractive gloss to fruit as well as delay shriveling. However, it is important that waxes are correctly applied; thick waxes can inhibit gas exchange between the inside and outside of the fruit, resulting in GHYHORSPHQWRIR5DYRWV

Recent research indicates that waxes may be more HHFWLYHDWSUHYHQWLQJZHLJKWORVVDQGVKULYHOIRUFY Misty Gem than for cv. Sweetheart. An example is shown EHORZIRUFYOLVWMPIUMWDOWKRMKHHFWVRIZD[QJ were similar, cv. Sweetheart fruit lost relatively more weight in all cases. It can be seen that very little weight loss occurred during cold storage. However, once fruit were transferred to simulated retail display, weight loss

In this trial, waxes 1 and 2 both provided acceptable results. The wax gave the fruit an attractive appearance and shrivel was both delayed and less severe. In contrast, DOWKR**J**KZD**Z**DVWKHPRVWH**H**FWLYHDWSUHYHQWLQJ ZHLJKWORVVLWUHVØWHGLQR5DYRWV/DUJHVWNHQ lesions appeared on some fruit, possibly due to ammonia content in the wax.

In summary, waxes can delay shrivel and extend DFFHSWDEOHOLIHRISDVVLRQIUKWRZHYHUHHFWLYHQHVV is likely to vary between varieties and possibly between regions. It is strongly recommended to test wax suitability on a batch of typical fruit before applying more

It should also be noted that controlling temperature LVDKLKOHHEWHDRUHGRIPRLVWHORVVDQ shrivel.



(HFWRIZD[QJRQZHLJKWORVVRISDVVLRQIUKWFY0LVWKP during cold storage followed by ambient display. Bars indicate standard deviations. AHR data



Condition of untreated (left) and waxed (right, wax 1 from trial) passionfruit cv. Misty Gem after 6 days cold storage plus 3 days at ambient conditions.

05. Packing and storage

RRGFRQVLVWHQWJUDGLQJDQGSDFNLQJHQVWHVWKDWIUKWSUHVHQWZHOODWZKROHVDOH PDUNHWVJHWWLQJWKHEHVWSRVVLEOHSULFH&ROLQJIU&WSURSHUODOVRUHWDLQVIUHVK DSSHDUDQFHDQGLVHVVHQWLDOWRPD[PLVHVWRUDJHOLIHWKLQNRIFRROLQJDVDGGLQJYDOMZLWK HOHFWULFLW%HFDMHFRROLQJFDQJUHDWONWHQGVWRUDJHOLIHLWFDQDOVRLQFUHDVHPDUNHWLQJ 5H[ELOLW)UWWKDWKDVEHHQKDQGOHGFRUUHFWODQGNHSWDWRSWLPRWHPSHUDWWHFDQ SRWHQWLDOOEHVWRUHGIRUVHYHUDOZHHNVWKHUHEREWDLQLQJEHWWHUSULFHV

GRADING AND PACKING

Passionfruit are usually size graded by count per carton. For purple passionfruit these generally range from Size 90 (90 fruit per carton) to Size 140 (140 fruit per carton). The standard industry carton is the T35; 375mm (L) x 280mm (W) x 188mm (H), which carries DUR@GNJRIIUWW7ZHOYHFDUWRQV4WLQDVLQJOHODHU on a standard pallet.

Cartons should have vents which cover at least 5% RIWKHLUV**W**IDFHDUHDWRDOORZH**H**FWLYHFRROLQJ)RU standard cartons this suggests total vents should be approximately 124cm². This could be achieved by, for example, eight vents measuring 80mm x 20mm. Note that many carton designs do not have this amount of venting; choose the one that is closest.

Large sizes of fruit (e.g. 90, 100) can be pattern packed; WKLVWDNHVORQJHUWKDQVLPSO4OOLQJFDUWRQVE**X**WJUH improves presentation at market. The larger, Panama types are more often sold pattern packed than purple varieties.

Passionfruit are usually graded into Class 1 and Class 2 based on external appearance. Fruit should not be packed if they are diseased, deformed, physically GDPDJHGRUSRWHQWLDOOFRQWDLQIUKW5\0DUYDH6OLJK V@EWQRIIUKWDHFWHGVFUDWFKHVVF\DQG EOHPLVKHVDHFWLQJFP ² downgrade quality but do not make fruit unsaleable.

\$DFNLQJOLQHVKRØGFRPSULVHDQREHURIGLHUHQW

- ☐ Bin tipper (if harvesting into bins)
- ☐ IUXUWKRSSHUUWKPRU5RRU
- Wash step (optional).

BEST PRACTICE

- Accurate grading for both size and quality, and pattern packing of larger fruit, greatly improves market presentation
- If applying wax, use a spray applicator and brushes to distribute the coating and polish fruit
- ✓ Packing lines should include an air dryer if fruit are washed or waxed
- ✓ Plastic packaging materials (e.g. plasticised RMDSRSEWDHDEHFWLM way to reduce moisture loss and shrivel and extend storage life, but currently have very limited commercial acceptance
- ✓ Purple varieties should ideally be stored at 5 to 9°C and Panama types at 10 to 12°C
- Forced air cooling is the fastest and most H**F**LH**WD**WRFRROSDFNHGI**W**W
- If forced air systems are not available, room cooling may be optimised by ensuring the room is functioning well, there is good air circulation around cartons and RH is >70%
- ✓ Trucks don't cool fruit; fruit should be pre-cooled before loading
- Temperature is the most important factor DHFWL@WRDJHOLIHDQTDOLWRIILIK passionfruit

05.PACKING AND STORAGE 05.PACKING AND STORAGE



Pattern packing large fruit takes time but greatly improves presentation at market

- Z Grading table with good lighting and comfortable VWDQGLQJDUHDIRUVWD•
- z Waxing unit, with soft brushes to disperse and polish coating (optional)
- Z Air dryer if washing /waxing
- z Sizer unit with diverging belts or rollers
- z Accumulators for each size band
- Z Carton packing stands



A well-lit inspection table with rollers to rotate fruit is essential for **H**FWLYHJUDGLQJ



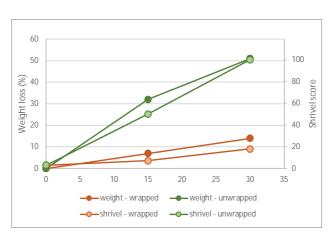
Waxing fruit requires a spray applicator as well as a series of brushes to disperse and polish the coating



PACKAGING

Passionfruit are normally packed straight into unlined cardboard cartons. While this maximises air movement DUR\(GWKHIU\(WFDUGERDUGFDQDEVRUEVLJQL4FDQW \) amounts of moisture. Cartons therefore contribute to moisture loss from the fruit. Well-perforated liners could potentially reduce fruit shriveling during storage and transport. However, carton liners also increase costs and are not generally commercially used.

2YHUZUDSSLQJZLWKDIRRGJUDGHSODVWLFLVHG4OPJUHDWO\ dramatically increase breakdown and shriveling. increases storage life. Passionfruit may be placed in punnets or on small trays for overwrapping. plasticised 4OPVGRQRWHFHVVLYHORRGLIWKHDWPRVSKHUH inside the package (in terms of CO² or O²), but do increase relative humidity. Although this may result in VXHU4FLDOPRØGGHYHORSLQJDIWHUHWHQGHGVWRUDJH life is still increased compared to unwrapped fruit. Unfortunately, although this type of packaging reduces food waste, it (potentially) increases plastic waste. Commercial acceptance of this type of presentation is limited.



LHUHQFHVLQZHLJKWORVVDQGVKULYHOVFRUHRISDVVLRQIUMWSDFNF LQWRSQQHWVRYHUZUDSSHGZLWKSODVWLFLVHG39&OPFRPSDUHGW those left unwrapped. Derived from Arjona et al., 1994.

It is not recommended to package passionfruit in VHDOHGSODVWLF4OPVWKDWDUHGHVLJQHGWRPRGLIWKI' atmosphere (increase CO2 and reduce O2) around the fruit. Passionfruit continue to respire at a very high rate after harvest, especially if they are warm. Unless WKH4OPLVHWUHPHO\$HUPHDEOHWRJDVHW2vels DUHOLNHOWRIDOOYHU\0RZUHV\0WLQJLQRDYR\0VLQ the fruit. Such packages are also likely to accumulate ethylene, further increasing senescence.

COOLING

What temperature?

Temperature management is key to extending storage life and retaining quality of passionfruit. However, the fruit are chilling sensitive, so it is also important not to

drop temperatures too low. Chilling damage is a factor of time as well as temperature. Even temperatures close to 0° OUH OUNHOWRFD MHV LJQL 4FDQWGDPDJH if the exposure time is short. More than four weeks storage at 2 to 3°C can induce chilling damage in purple passionfruit. Chilling symptoms such as development of sunken patches and increased mould may only appear once fruit return to ambient conditions.

In contrast, only a few days at high temperatures will

Storage recommendations for passionfruit are:

Purple varieties: 5 to 8°C and >85% RH Panama types: 10 to 12°C and >85% RH



Condition of passionfruit cv. Sweetheart (left) and cv. Misty Gem (right) following one month of storage at 2, 5 or 8°C then 3 days at ambient. Slight chilling damage, appearing as sunken patches on cv. Sweetheart and mould on cv. Misty Gem, occurred at the lowest temperature.

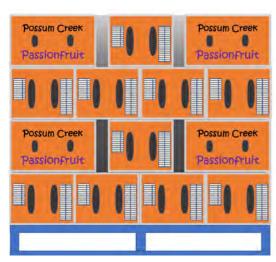
Cooling after packing

While fruit is warm it will lose moisture, even if it has been placed inside a cold room. As stated in the section on packhouse receival, it is essential to cool fruit as soon as possible, especially if the pulp temperature is 30°C or more. Forced air cooling is the best way to achieve this.

Forced air systems for packed fruit involve placing the pallet against a plenum containing a fan. The top and rear of the pallet are covered with a tarpaulin. Air is then pulled evenly through the cartons via the side vents. Forced air systems avoid condensation on the fruit and reduce moisture loss.

Many passionfruit packhouses have limited capacity to install forced air systems, and rely instead on room cooling. This reduces cost and is easy to do. However, full pallets of packed fruit can take a long time to FRRO7KHH**F**LHQWRSHUDWLRQRIFROGURRPVFDQEH maximised by:

- ☐ Air stacking pallets, alternating between 12 and 11 cartons per layer
- Ensure the gaps between cartons align with the pallet fork spaces, as this will maximise air circulation
- Use corner protectors to stabilise the pallet



Air stacked pallet. Alternating between 11 and 12 cartons per layer allows air to circulate through gaps in the load.

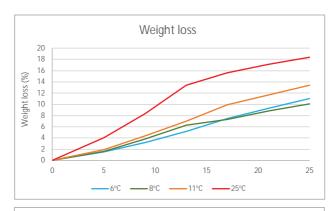
- Not overloading the cold room
- ☐ Spacing pallets as widely as possible
- Ensuring there is good air circulation within the
- ☐ Adjusting the thermostat settings so as to minimise WKHWHPSHUDWWH5KWWWLRQVDOORZHGEHIRUHWKH bottom) of purple passionfruit stored at approx. 70%RH. Derived FRPSUHVVRUWWQVRQR•

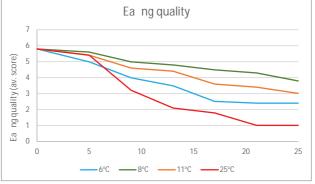


- Recording temperature inside the room to check that it is functioning correctly
- ☐ Minimising door opening and ensuring seals are in good condition
- Ensuring cold room panelling is well sealed and internally dry
- ☐ (VXULWKHEROGURRP5RRULVDVWKLENDV5RVVLEOH□ DGDWHUSURRIHG#DRUWKGRRUV5RRUVDUH DERPPRIVEXUEHRIKHDWQ40WUDWQR

Testing pulp temperature using a probe thermometer is the only way to know if fruit are cooling.

Cooling fruit reduces moisture loss and shrivel, inhibits development of disease and slows ripening and VHQHVFHQFHSURFHVVHVVKKDVWKHORVVRI5DYRW





from Kishore et al., 2011

Estimated storage life of Australian passionfruit is 3-5 weeks at 5 to 9°C, compared to less than one week under ambient conditions. Cooling is therefore the HDVLHVWDQGPRVWHHFWLYHZDWRLQFUHDVHVWRUDJHof[wit]. At best, they can maintain the temperature that of passionfruit. Cooling adds value for wholesalers, UHWDLOHUVDQGFRQVRHUVDQGLVWKH4UVWVWHSWR increasing consumption of passionfruit.

Cooling for transport Trucks don't cool fruit.

If fruit is loaded onto the truck while warm, it is very likely to arrive at the destination still warm. Truck cooling systems cannot create enough air movement DURQGSDOOHWVWRDURQGSDOOHWVWRHHFWLYHOKRRQRQAHQQFKORULGH4OPVORZVTDOLWQRVVRIHOORZ

Bundaberg to Sydney or Melbourne arrived Melbourne 0 arrived Sydney 1.5 2.5 Days a er packing

Typical transport temperatures for passionfruit that were not pre-cooled before transport to Melbourne, and fruit that was pre-cooled for 6 hours before transport to Sydney. In both cases minimal cooling occurred inside the truck. Although 15°C is not RSWLPRWKLVIUWWZRØGEHH\$HFWHGWREHVLJQL4FDQWOEHWWHU quality than fruit at 22.5°C. AHR data.

7(03(5\$85) is the most important quality of fresh passionfruit

fruit were at when loaded.

This is particularly an issue for passionfruit, as they are likely to be shipped with mixed loads. For example, if passionfruit are transported with sweetpotato, the truck thermostat may be set at around 15°C, or not turned on at all.

REFERENCES

Arjona HE, Matta FB, Garner JO. 1994. Wrapping in passionfruit. HortScience. 29:295-296.

Akamine E.K. and Girolami G. 1959. Pollination and fruit set in the yellow passion fruit. Tech. Bull. 39, Hawaii Agric. Exp. Stn., University of Hawaii.

Kishore K, Pathak KA, Shukla R and Bharali R. 2011. (HFWRIVWRUDJHWHPSHUDWWHRQSKVLFRFKHPLFDODQG VHQVRUDWWULEWHVRISWSOHSDVVLRQIUWW3DVVL5RUD edulis Sims). J. Food Sci. Technol. 48:484-488

Niwayama S. and Higuchi H. 2019. Passionfruit quality under acidic soil conditions. Hort J. 88:50-56.

Reid MS. 2002. Ethylene in postharvest physiology. In "Postharvest technology of horticultural crops" University of California publication 3311, 3rd edition.

Rigden P. 2011. The Passionfruit Growing Guide, 2nd Edition. Queensland Government, Passionfruit Australia and Hort Innovation.

Shiomi S, Wamocho LS and Agong SG. 1996. Ripening FKDUDFWHULVWLFVRISWSOHSDVVLRQIUWWRQDQGRWKH vine. Postharvest Biol Technol. 7:161-170.

" For more information on growing, packing and marketing passionfruit:

Passionfruit Australia - passionfruitaustralia.org.au and Hort Innovation - horticulture.com.au



1 Central Ave, Eveleigh NSW 2015 p: (02) 9527 0826 info@ahr.com.au ahr.com.au



Appendix3-Liquidsealand Castle Chemicalax trial

Aim

To test the effect of fruit waxes on postharvest storage life, respiration rate and internal atmosfresh passionfruit.

Method

Trial 1 Liquidseal

Cartons of fresheetheart and Mistypassionfruit were obtained from Sydney Markets. Each carton was divided into three groups and dipped into:

- 1. Water only
- 2. Liquidseal LSBFoPHB(idPH) wax
- 3. Liquidseal MG w(M/G)

Passionfruit dipped Bridte Hwaxair dried uccess fylln contrast heMG wax was very viscous, leaving a thick layer of product on the fruite at after leaving for a period in this was necessary to wipe the excess off each fruit using a parsent result, fruit dipped in MG explanation to the glossy effect gained using BioPH.



Figurel. Passionfruit dipped in MG wax were allowed (ta) this roll the excess wiped off with paper (tb) With listinguit driedwith a dull appeara (tc) especially when compared to the gloss gained by dipping f(td) in BioPH

Trial 2 Castle Chemicals

Cartons of fresh Sweetheart and Misty Gem passionfruit were obtained from Sydney Markets. E was divided into the the things and dipped into:

- 1. Water only
- 2. Castle passionfruit wax

Weight lossBoth trials

Thirtyfruitper treatmen/dereindividuallynumbere/dweighed, then stored in vented contancers at 8 6 dayssimulatingostwaxingransport and distribution. The fruit were then moved to ambient conditionary (approx. 22) and assessed for weight loss and shrivel, as shown below. Measurements of weight shrivel were repeated after an additional 2, 4 and 7 days atiansbienticons photographed on removal from storageaster 4 and 7 days at anobientitions

Shrivellingvas graded using the following scale

- O. None smooth and fresh
- 1. Very slightwrinkling visible, but fruit still mostly smooth
- 2. Slight wrinklingffecting up to 50% of surface
- 3. Moderate wrinkling affecting 60% of surface but fruit still round
- 4. Severe wrinkling affecting whole fruit, noticeable shrinkage in size, soft



Gas measurementsiquidseal trial only

Internal atmosphere was measured using a small PVC tube inserted into the centre of each pass tube was initially sealed using silicone, however this reacted with the passionfruit skin. The proc then repeated with tubes sealed in place -

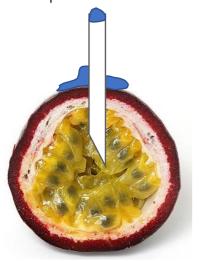


Figure Insertion of gas sampling tube to measure the passionfruit internal atmosphere.

was extracted from the top of each tube using a Mocon Checkpoint

extract sufficient gas for analyseissusmements were poolsysible

Respiration measurements were made using two fruit of each type sinto a small plastic container with sampling septum. The containers visually sealed for 1.5 to 2 hours before gascaled featernallysis Respiration rate was calculated as:

(Change in $\Omega Q(\%)$ ÷ 100) x container volume (m) as mI used produced

Gas (ml) weight $(kg) \times time (hours) = ml/kg/h$

Results

Trial 1 Liquidseal

All fruit lost very little weight during storagiethata@evidence of mould or storageter, weight loss accelerated greatly once fruit were transferred to ambient conditions.

Both the MG abidPHwaxes reduced the rate of weight loss in MistyloGvenveruthe benefit was less for the Sweetheart variety, where weight togs in the street to the untreated controls. The Misty Gem control fruit lost weight faster than the equivalent Sweetheart fruit, suggesting of these passion fruit may naturally have had less wax or a more porous streetware, allowing inc moisture loss.

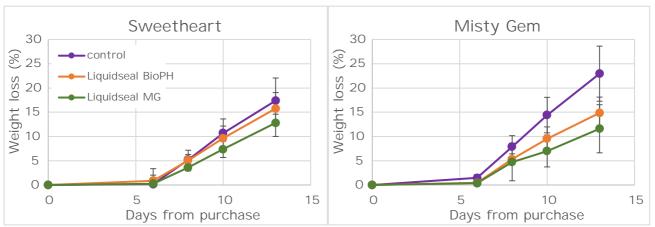


Figure3 Weight loss of Sweetheart and Misty Gem passionfruit left untreated or dipped in Liquidseal BioPH or MG wax were stored and some formal transferred to another transferred transferred to another transferred transferre

Shrivel scores was erally consistent with weight loss. Again, larger differences in appearance were evident for Misty Gem than for Swellen Mach wax had the most effect on visual shrivelling, particularly for Misty Gem fruit, with the effects retained even after be with even with deficient example, after 4 days at ambient more than 70% of Sweetheart and 90% of Misty Gem were rashrivel score 3 or 4 (moderate to severe). In comparison, less than 40% of Sweetheart and 10% treated with MG waxe rand as moderate shrivel moneats ever eshrive fruit dipped in BioPH were intermediate between the sentimes.

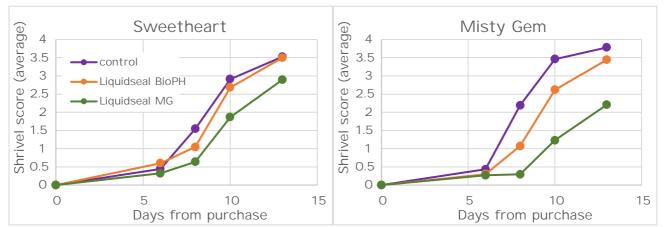


Figure4. Average shrivel score Sweetheart and Misty Gem passionfruit left untreated or dipied inor in the remainder of the trial. Fruit were stored of the remainder of the trial.

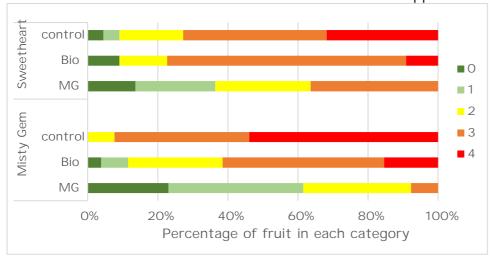


Figure5 Percentage Sofveetheart and Misty Gem passionifhuishrivel scores 0 (none), 1, 2, 3 or 4 (severe) following 6 days at 8°C and 4 days under ambient conditions. Fruit were left untreated or dipped in Liquidseal BioPH or MG wax.

Despite this apparent good result for MG wax, a number of dowers/ieldesSoweree forbit developed large sunken lesion to appear of the thenderlying issue had collaps the company has now advised that this is most likely caused by high levels of ammonia in this product; new formulations are be developed with reducenmonia to mitigate this Notice over of NO2 and relatively high levels occurred in the internal atmospheres, especially in the large application weetheart fruit dipped in the MG wax recorded in the envelsors low as 3% parcend to an average of 100% of the the controls and Billow Holipped fruit.

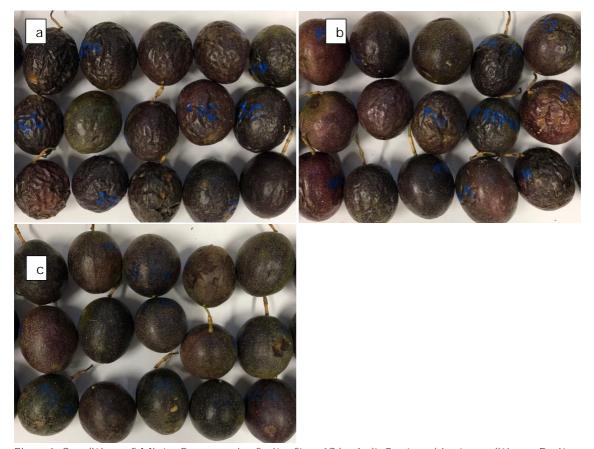


Figure Condition of Misty Gem passionfruit after Cdays at ambient conditions. Fruit were left untreated (a) or dipped in Liquids BibPH(b) or MG wax (c).

Appendix Waxing trials repoahr

Measurements of respiration rate appeared to confirm that ignific and investoricted gas exchange Respiration rates of passion provided in Mayaxaveraged 25% lower than untreated fruit of the same variety, where the same variety is a separation of the same variety. The effective most pronounced for Misty Gem, especially in the first feed as after treatment, where respiration rate was half that of the controls. It could be expected respiration rate of senescence and decay. However, large restriction respiration rate can produce neglectives on flavour and aroma.

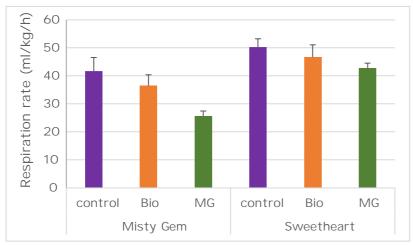


Figure 7. Respiration rate (average 20 of COLLICTION and Consumption, n=3) during storage under ambient conditions for Misty Gem and Sweetheart passile fruit treated or dipped dipidsela BioPH or MG wax.

While formal taste testing was not poissibite halved samples were tasted by AHR staff. Slight off flavours were detected in some of the MG treated fruit. This suggested that this product make the point where fermentative activity occurred within some fruits.

Trial 2 Castle Chemicals

As observed in the Liquidseal trial, fruit lost very little weight ducingvittoragevidence of mould or shrivel. However, weight loss accelerated greatly once fruit were transferred to ambier conditions.

The untreated Misty Gem and Sweetheart variety fruit lost weight at similar rates during ambier Treatment with Castle wax reduced the rate of weight loss for both varieties. However, as was



Figure Weight loss of Sweetheal Miaby Gem passion fruit left untreated or dipped in Castle wax. Fruit Were stored at 8 for 6 days after purchase then transferred to ambient conditions for the remainder of the trial.

Shrivel scores were generally consistent with weight lossying the vapped rance of shrivelling after transfer to ambient conditions. Again, larger differences in appearance were evident for Mi than for Sweetheart. After three days at ambient, only 15% of waxed Misty Gem fruit had slight wherea 30% of the untreated fruit had either slight or moderate shrivelling. The waxed fruit generates and glossier appearance, so appeared more attractive overall. This effect was retained trial was ended after 7 days at ambients conditi



Figure9. Average shrivel score Sweetheart and Misty Gem passionfruit left untreated or dipped in Castle wax. Fruit we 8°C for 6 days after purchase then transferred to ambient conditions for the tra

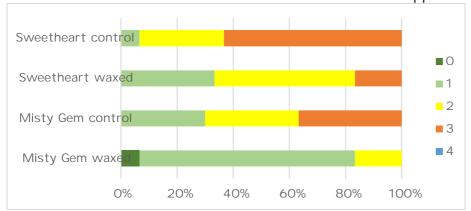
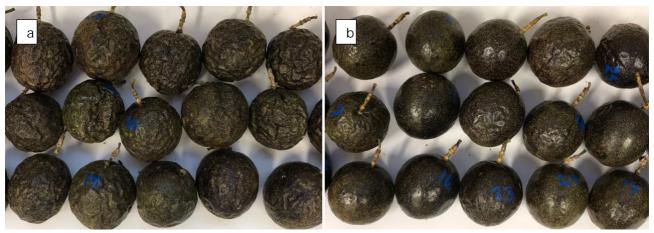


Figure 10 Percentage of Sweetheart and Misty Gem passionfruit with shrivel scores 0 (none), 1, 2, 3 or 4 (severe) folloat &C and 3 days under ambient conditions. Fruit were left untreated or dipaged in Castle



Figurel 1. Condition of Misty Gem passionfruit after &Cday days at ambient conditions. Fruit were left untreated (a) or dipped in Castle wax (b).



Figurel 2 Condition of Sweetheart passionfruit after & days days at ambient conditions. Fruit were left untreated (a) o dipped in Castle wax (b).

While formal taste testing was not poissibte halved samples were detected in the waxed fruit.

Conclusions

While the iquidsea WG wax proved very effective at reducing water loss, this product had a number negative effects. The thickness of the product made it more difficult to apply and resulting fruit was dull. Although shrivel was greatly reduced, this dways the paper arance of large, sunken areas. Moreover, off flavours were detected in some fruit, suggesting that internal fermentation may hoccurred.

In contrasto, the Liquidseal Bio APId Castle Chemicals producted more modest effects or moistuloss and shrivel. How broath of these products exact apply and resulted in an enhanced, glossy appearance of the fibroith product were nost effective when applied to Misty Gem, providing a significant delay in quality loss after final how five to ambient conditions.

Note that only small volumes of fruit were treated to the fruit were sourced from wholesale rather than direct from farms. This work should be repeated using freshly harvested passion fruit verify the resurcessults suggest that there could be quality be appellistis of the properties of the could be described by the could be desc

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>""-#-&\$ (1#<* (+1\$4#9 (4#, &#"2&#-&()"2#\$%(\$#(. &-(8�())1"23-*1\$#""2)*90\$1"2#-&9(12)#-&))#\$%(2#JCC8# 0&-#0&-)"2#0&-#4&(-6#K'''"-5128#\$"#\$%&#JCALMAN#K*)\$-(+1(2#: "-\$1'*+\$*-�\$(\$1)\$1')#: (25, ""7/#-&))#\$%(2# A#12#P#K*)\$-(+1(2#%"*)&%"+5)#, *4#0())1"23-*1\$/#; 1\$%#&('%#0*-'%()&#'"90-1)128#(-"*25#BCC8#"3#3-*1\$6#

: "; &. &-/#\$%&#. "+* 9&#" 3#O())1" 23-*1\$#0-"5*'\$1" 2#%()#, &&2#)\$&(51+4#12'-&()128#". &-#\$%&#+()\$#31. &(-)# H90-".128#<*(4|\$4#)#7&4#\$"#12'-&()128#5&9(25#()#; &+#()#)\$(,1+1)128#"-#12'-&()128#0-1'&)6#

Q"-&". &-/#190-". &5#0")\$%(-. &)\$#)\$"-(8&#\$&'%21<*&)#'"*+5#%&+0#; 1\$%#(2"\$%&-#1))*('128#\$%&# 125*)\$-4#R#. (-1(, 1+1\$4#12#)*00+46#\$=\$&25128#)\$"-(8&#+13&#"3#0())1"23-*1\$#, 4#&. &2#J#\$"#B#; &&7)#'"*+5#%&+0# (. "15#". &-)*00+4#12#\$%	(-7&\$/#\$%&-&, 4#12'-&()128#-&\$*-2)6#Q"-&#)\$(, +�-1'&)#'"*+5#(+)"#%&+0#\$"# 12'-&()&#-&\$(1#)(+&)T#""2)*9&-)#(-(-#9"-/&+4#\$"#12'+*5�())1"23-*1\$#"2#\$%&1-#)%"00128#+1)\$#13# \$%&4#72"; #(00-"=19(\$&+4#%"; #9*'%#\$%&1-*1\$#; 1+#"")\$6#

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- >('7(8128/#(\$9")0%&-1'#9(2(8&9&2\$#(25#3-*1\$#'"(\$128)#9(4#, &#(, +&#\$"#"33&-#9(24#, &2&31\$)#12#\$&-9)#
 "3#)+"; 128#-10&2128/#-&5*'128#9"1)\$*-&#+"))/#(25#-&\$(12128#<*(+1\$46#
- K#)*, V\$-"01' (#3-*1\$/#0())1"23-*1\$#(-&#(+)"#' %1+428#)&2)1\$1. &6#> (-\$1(++4#-10-*1\$#(-&#-&'"99&25&5#\$"#, &#)\$"-&5#(\$#LVACWX/#; %1+*++4#-10-*1\$#9 (4#, &#)\$"-&5#()#+"; #()#PWX6#: "; &. &-/#(''"-5128#\$"#>-"36#YS#>(*+#)"9&#. (-1&\$1&)#%(. &#"2+4#91219 (+#' %1+128#)&2)1\$1. 1\$4/#(++"; 128#\$%&9#\$"#, &#)\$"-&5#()#+"; #()#BWX6#Z&)01\$&#\$%1)/#K*)\$-(+1(2#-&\$(1+&-)#-&<*1-&#(++0())1"23-*1\$#\$"#, &#)*00+1&5#(\$#NVAJWX6#
- ! (51\$1"2(++4#0())1"23-*1\$#%(. &#, &&2#(++"; &5#\$"#-10&2#; %1+&#(\$\$('%&5#\$"#\$%&#. 12&6#\$\$%4+&2�-"5*'&5# 5*-128#-10&2128#'(*)&)#\$%-*1\$#\$"#2(\$*-(++4#(,)'1)&/#)"#1\$#'(2#, &#&()1+4#01'7&5#*0#3-"9#\$%-"*256# : "; &. &-/#13#3-*1\$#(-&#+&3\$#"2#\$%-"*25#3"-#9"-&#\$%(2#(#3&; #%"*-)#\$%&4#9(4#, 	"-&+4#\$"#)*33&-#)*2, *-2#"-#5&. &+"0#-"\$)6#|2#)"9&#""*2\$-1&)#0())1"23-*1\$#(-&#%(-. &)\$&5#0(-\$1(++4#-10&#, 4#'+1001286#!%1)#

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K#2&; #0-''?&'\$#' ''2\$-('\$&5#\$''#K00+1&5#: ''-\$1' *+\$*-(#Y&)&(-'%#; 1++#%&+0#8-''; &-)#E(25#''\$%&-)#12#\$%&#)*00+4#'%(12F#*25&-)\$(25#(25#(5''0\$#, &)\$#0-('\$1'�'')\$%(-.&)\$#9(2(8&9&2\$#3''-#0())1''23-*1\$6##

K'''-5128#\$"#0-"'?&'\$#+&(5&-#Z-#[&224#\$79(2/#\; &#; (2\$#\$"#\$125#"*\$#; %(\$#&9&-8128#2&; #\$&'%21<*&)# (25#\$&'%2"+"81&)#(-&#(. (1+(, +&#\$%(\$#' "*+5#, &#*)&5#, 4#\$%&#K*)\$-(+1(2#125*)\$-46]###

\! %-)\$#)\$&O#; 1+#, &#\$"#""25*'\$#(#\$%"-"*8%#5&)7\$"O#-&.1&; #"3#O")\$%(-.&)\$#, &)\$#O-('\$1'"-#O())1"23-*1\$6]##

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8*15"-#K*)\$-(+1(2#0())1"23-*1\$#8-"; &-)6#! %&#O+(2#)#\$"#O-12\$#"*\$#%(-5#' "01&)#()#; &++#()#9(7&#\$%&#
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S[#]!&2246&79 (2' (%-6'"96(*#"-#Q^*CaCL#BNa#JNP6#

>@ABCCD#(25#>@ANCCJ#%(. &#, &&2#3*25&5#, 4#: "-\$#122". (\$1"2/#*)128#\$%�())1"23-*1\$#-&)&(-' %#(25#5&. &+"09&2\$#-&. 4#(25#' "2\$-1, *\$1"2)#3-"9#\$%&#K*)\$-(-1(2#b". &-29&2\$6#: "-\$#122". (\$1"2#)#\$%-"; &-\frac{1}{2}*5**. &+"09&2\$#' "-0"-(\$1"2#3"-#K*)\$-(-1(2#%"-\$1'*+\$*-&61#





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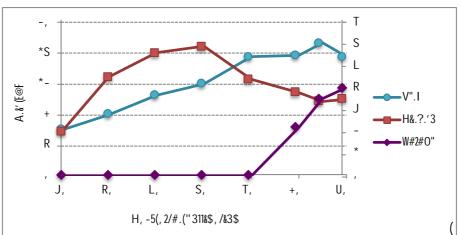
! ""#\$%%'()(*(+,-(,./&01#(23.(4,55&3\$(6&\$#(7,8,9&\$#(

4,55&3\$2.: &/(,\$%(#/;-1#\$#(

!"#\$%&'(!)*+,,-(./(&0""%1'23("%4.%5.16(7#/'89"4%/'(:%/'(7"9&'.&%(;#"(79//.#1;"0.')(1.36)))))

4,55&3\$2.: \(\lambda'\).\(\delta''\)#\$&\$8(

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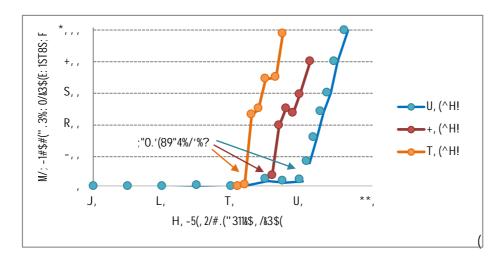
<88: .#(=\(\frac{2}{2}\); , \$8#5(\(\bar{8}\)(@(A.\(\bar{8}')\)B(C\(\bar{8}\), /, D1#(, 0\(\bar{8}\)\)W/-(EC!\(\bar{8}\)(7#, 5: .#\(\bar{8}\)(, 5(0\(\bar{8}\))\)(, 0\(\bar{8}\)F(, \$\(\bar{8}\)(": ."1#(0313: .\(\bar{8}\)#G#13" 7#\$/(32()", 55\(\bar{8}\)32):\(\bar{8}\)(\(\bar{8}\); \(\bar{8}\)(\(\bar{8}\); \(\bar{8}\)H, /, (\(\bar{8}\)#\)(2.37(I;\(\bar{8}\)37\)(#/(,\(\bar{8}\)H/, I\)(=\)JK\(\bar{8}\)</p>

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;2#5%"/('#(/8%?('8%."(7%'92/e('0"1(&9""#'/(: .''%"e(91?('".66%"(".7%1.16(#;(E.5.;"0.'<=#(70'('8./(.1(7%"/7%&'.4%e(9(/.162%(LE6(&9"'#1(#;(59">(79//.#1;"0.'(729&%?(.1(9(L,,,>)(&##2("##>(5#02?(6%1%"9'%(,<*77>(5.'8.1(*,(8#0"/e(#"(2%//(.;('8%("##>(59/(;02(#;(#'8%"(7"#?0&'/<

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+#/; 3%5(32(.#%: 0&\$8(#/; -1#\$#(

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! #'9//.0>(7%">916919'%(./(0/%?(.1(>913(?.;;%"%1'(&#>>%"&.92(%'832%1%(/&94%16%"/•<["916.16();"#>(/>922(/9&8%'/('89'(&91(:%(70'(.1'#(9(&9"'#1•('#(29"6%(;.2'%"/(.1/'922%?(#4%"('8%(&#??("##>(4%1'/(91?(%4%1(7".1'%?(29:%2/(91?(79?/(;#"(79&E96.16<)

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