Hort Innovation

Final Report

Supply Chain Quality Improvement - Technologies and Practices to Reduce Bruising

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Delivery partner:

Department of Agriculture and Fisheries - Queensland

Project code:

AV15009

Project:

Supply Chain Quality Improvement - Technologies and Practices to Reduce Bruising AV15009

Disclaimer:

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Content

Summary

Flesh bruising is a major postharvest quality concern for the Australian avocado industry. It is responsible for around half of all internal defects detected at retail level. Preceding Hort Innovation projects 'AV10019' and 'AV12009' established clearly that flesh bruising is caused, and primarily expresses, in the supply chain post-ripener; i.e., in fruit that have commenced the softening process. Opportunity exists to improve fruit quality at retail by identifying and adopting measures that lessen or, ideally, eliminate flesh bruising. Doing so will ultimately lead to improved consumer satisfaction and bolster demand in the face of a domestically, and seemingly internationally, looming market over-supply.

The current project sought to clarify the relative contributions of inherent fruit characteristics and external environmental conditions and management practices to bruise susceptibility. This was realised by thoroughly reviewing the current literature and in undertaking a directed series of experiments to investigate final fruit quality in response to prescribed simulated (i.e., lab-based) and actual (i.e., real world) supply chain conditions. Additionally, the project reviewed and tested technologies that could potentially be used by shoppers and retail staff to determine fruit firmness (viz., ripeness) stage without the undesirable consequence of physically damaging handling (i.e., squeezing). The tests included a prototype Avocado Decision Aid Tool recently dubbed the 'Readycado'. This prototype had been devised and developed in the course of preceding project 'AV12009'. In-store consumer testing suggested that this device could be well-received by shoppers. Knowledge generated by the project was shared with other R, D & E workers (e.g., projects 'AV15010' and 'AV15011') via Hort Innovation co-ordinated 'Avocado Supply Chain Quality Improvement Program – Project Reference Group Meetings' and with industry stakeholders, including growers, packers, ripeners, retailers, consumers and AAL.

Research showed that final fruit quality in response to early-stage postharvest handling is highly variable and strongly dependent on fruit source. One of four through the supply chain experiments conducted in the course of this project revealed increased bruise susceptibility in response to both delayed postharvest cooling and impact injury at packing. However, these factors did not affect bruise susceptibility in the other supply chain experiments.

Pre-harvest factors leading to differences in fruit robustness were evidently important contributors to both bruise susceptibility and body rot expression upon ripening. A high ratio of nitrogen to calcium (N/Ca) in the fruit was linked to high incidence and severity of body rots, but not bruise susceptibility. Impact injury at packing caused greater body rot expression upon ripening in fruit with a sub-optimal mineral nutrient balance (i.e., high N/Ca ratio), despite no attendant flesh bruising. An opportunity for future work is to understand the mechanisms underlying impact triggered disease expression.

Four technologies suitable for avocado ripeness assessment were identified and evaluated on the basis of reliability, cost, robustness and utility; i.e., ease of operation and maintenance. All were able to discriminate between different avocado stages of ripeness for both 'Hass' and 'Shepard' fruit. The devices included a FruitFirm meter (TR Turoni, Forli, Italy), a bench top Sinclair IQ™ Firmness Tester (SIQFT; Sinclair International Ltd, supplied by J Tech Systems, Albury, Australia), a Digital Firmness Meter, and a prototype decision aid tool dubbed the 'Readycado' which is based on a force sensing resistor.

The learnings summarized above were captured for dissemination in outputs that included a series of four literature reviews:

1. Factors influencing bruise susceptibility in avocado fruit;
2. Relationship between impact injury, flesh bruising and postharvest disease;
3. Best practice towards preventing avocado flesh bruising at retail; and,
4. Alternative technologies for non-destructive assessment of avocado ripeness.

The findings from the supply chain experiments and the testing of technologies for avocado

ripeness assessment were written up as detailed research reports.

Regular Avocado Supply Chain Quality Improvement Program Reference Group meetings hosted by Hort Innovation promoted knowledge transfer between the three concomitant supply chain improvement projects, 'AV15009', 'AV15010' and 'AV15011'. Communication of project findings with industry stakeholders was achieved through a workshop held at Brisbane Markets in May 2018, project updates presented at the Crows Nest, Coolum, Childers and Mareeba regional grower meetings hosted by Avocados Australia Limited (AAL) during May - June 2018, a Youtube video, and five articles published in *Talking Avocados*. A scientific paper in *Postharvest Biology and Technology* and posters presented at TropAg2017 in Brisbane and Avocado Brainstorming 2018 in South Africa shared project findings with the broader scientific, technical and industry community.

The key project recommendations in terms of practical application by, or practice change for, industry are:

1. Pack and cool fruit promptly after harvest; viz., to 5-12°C within 24 hours;
2. Avoid impact damage during harvest and packing; and,
3. Regularly monitor avocado fruit quality at retail to gauge effectiveness of bruise-reduction measures implemented as a result of this and other recent supply chain quality improvement projects.

Recommendations for future research include:

1. Identify pre-harvest factors that influence 'fruit robustness', especially in terms of bruise susceptibility and associated increased disease incidence and/or severity;
2. Develop predictably reliable techniques and practices for consistently achieving low fruit N/Ca ratio without sacrificing yield; and,
3. Progress development of a novel avocado decision aid tool and/or one or more adaptations of existing technologies for in-store fruit ripeness assessment by staff and/or shoppers.

Keywords

Anthracnose; avocado; bruising; *Colletotrichum*; defect; disease; firmness; fruit; injury; postharvest; quality; rot; supply chain; temperature.

Introduction

Flesh bruising is a major postharvest quality concern for the Australian avocado industry. It is responsible for around half of all internal defects detected at the retail level (Tyas, 2016). Bruising that affects >10% of avocado flesh causes consumer dissatisfaction and negatively affects repeat purchasing decisions (Gamble et al., 2010). A goal of the Australian avocado industry is that by 2021, over 90% of avocados received by consumers should meet or exceed expectations of quality (Hort Innovation, 2017). In 2015, the figure was 80% (Tyas, 2016), indicating real need for further improvement. A key driver for improvement is a looming market over-supply due to forecast rapid and massive increases in domestic production in Australia and overseas. Continued growth in consumer demand is critical to maintain an economically sustainable industry for Australian growers.

Previous Hort Innovation projects 'AV10019' and 'AV12009' established clearly that flesh bruising is caused, and primarily expresses, in the supply chain post-ripener in fruit that have commenced softening. Accordingly, adopting measures to reduce avocado fruit squeezing by shoppers would help greatly to lessen the incidence and severity of flesh bruising in avocado fruit at the point and time of consumption. To this end, a first iteration prototype avocado Decision Aid Tool (DAT) was developed to assist avocado fruit shoppers in making their selection decision from the retail display. However, a number of alternative technologies exist that could potentially be used to non-destructively assess avocado fruit firmness. Better knowledge of the relative 'pros and cons' of these technologies is required to guide further development in this area.

It is generally understood that susceptibility to flesh bruising is associated with inherent fruit characteristics as pre-determined genetically and modified by external environmental conditions and management practices. For example, Project 'AV10019' indicated that low temperature handling at retail level can effectively reduce the severity of flesh bruising. Also, early as opposed to advanced fruit maturity and fruit softening can increase the risk of flesh bruising. Both internal and external fruit quality or 'robustness'-determining factors are potentially manageable to both retailers' and consumers' advantage.

In addition to flesh bruising, mechanical injury is also believed to cause increased postharvest disease expression in avocado fruit. Observations in the course of preceding work (Hofman, 2005; Project 'AV10019') suggested that physical damage as impacts to green mature fruit and as may occur during harvest and/or on pack lines can increase the incidence and severity of body rots as the fruit ripen. This proposition was tested and affirmed in purpose-dedicated pilot trials conducted at The University of Queensland in 2016 and 2017. Rots are the second most common internal defect reported in avocado fruit after flesh bruising (Tyas, 2016). Given the profoundly unsightly and concomitant nature of both defects, it is imperative to gain better understanding of this poorly recognized relationship between physical damage and disease.

The current project aimed to address the abovementioned issues by:

1. Developing and testing alternative technologies that would reduce handling by retailers and/or consumers, including tools for identifying ripeness;
2. Documenting best practice to prevent fruit bruising at retail for implementation in retail education via AV15011;
3. Reviewing scientific evidence to identify any relationship between disease and flesh bruising and/or identify gaps in research that would elucidate this;
4. Reviewing and documenting contributing factors to fruit susceptibility to bruising; and,
5. Quantifying susceptibility to bruising and body rots under differing supply chain conditions.

Methodology

Research activities were divided into five areas based on the project objectives listed above.

Alternative Technologies

Novel and emerging tools to assist retailers and consumers to handle and select ripening avocado fruit without causing flesh bruising were comprehensively reviewed in the first year of the project. The full range of potential approaches, as promulgated in the media and popular and scientific literature, were critically compared and contrasted with a view to lessen flesh bruising as caused by retailers and consumers.

In the second year, potential decision aid technologies were comparatively evaluated in terms of accuracy, utility, and acceptability for use at retail. Complimentary assessments were conducted for 'Hass' and 'Shepard' fruit. Simple linear regression was used to characterise relationships between subjective hand firmness ratings and objective fruit firmness measurements as obtained using each of the four devices listed below:

1. A prototype avocado Decision Aid Tool (DAT) based on a force-sensing resistor. This device was conceived and developed as a prototype in project 'AV10019' and recently dubbed the 'Readycado'.
2. The Sinclair IQ™ Firmness Tester (SIQFT), based on a low mass impact sensor.
3. A non-commercial Digital Firmness Tester device refined by Macnish et al. (1997) which measures fruit deformation under load.
4. The recently-released FruitFirm Meter (T.R. Turoni, Italy) that measures deceleration of a low mass impact 'hammer'.

Best practice

A desk-top review of supply chain practices either known or likely to reduce flesh bruising in avocado fruit was undertaken in the first year. Information was presented in terms of pre-harvest, harvest and post-harvest stages of the supply chain. Emphasis was placed on identifying established, emerging and novel retail handling and display practices that potentially lessen flesh bruising. The review culminated in best practice recommendations for consideration by supply chain players.

Proposed amendments to the AAL online Best Practice Resource (BPR) were developed based on these recommendations. A table of comparison with the then current BPR advice was prepared for consideration.

This activity also interacted with and informed concomitant Projects 'AV15010 - Cool Chain Best Practice Adoption' and, more so, 'AV15011 - Retailer Point of Purchase Improvements'. Findings were communicated via updates provided at Hort Innovation 'Avocado Supply Chain Quality Improvement Program Reference Group Meetings' as well as via direct communication (e.g. discussion, email) between the projects' team members.

Disease and flesh bruising

Existing scientific evidence for a then putative undefined interaction between mechanical damage and postharvest disease incidence and severity in avocado fruit was reviewed in the project's first year. The review focused on three areas:

1. Physical, physiological and biochemical responses of avocado fruit to mechanical damage;
2. Factors governing anthracnose development in avocado fruit; and,
3. Potential mechanisms for impact-induced disease expression.

Gaps in research that would elucidate the relationship between impact injury and postharvest disease were highlighted.

Susceptibility to bruising

A review of literature was undertaken in the first year to define inherent fruit characteristics, as well as pre- and postharvest environmental conditions and management practices that can be manipulated to reduce the incidence and severity of flesh bruising. Following Hort Innovation projects 'AV10019' and 'AV12009', this activity focused on the general understanding that susceptibility to flesh bruising is associated with inherent fruit characteristics and postharvest management practices. Project 'AV10019', for example, suggested that low temperature management at retail level can reduce the severity of flesh bruising. Fruit immaturity and fruit softening were also determined to be predisposing factors. Overall, the review broadly canvassed pre- and postharvest factors including genotype (viz., cultivar) and phenotype (e.g., fruit maturity), environment (e.g., rainfall, temperature, humidity) and management (e.g., nutrition, tree health, packaging) that may impact on bruise susceptibility in fruits in general and in avocado in particular.

Supply chain monitoring and simulation

In the final year of the project and as a funded extension to the core project, four experiments were undertaken to quantify the relative contributions of fruit robustness, postharvest temperature management and mechanical injury prior to ripening on final fruit quality at retail. Fruit were assessed for flesh bruise susceptibility (viz., bruise volume in response to 1 Joule impact approximately equivalent to a 40 cm drop height for a 250 g fruit) and the occurrence of flesh bruising and body rots upon ripening, as well as dry matter and mineral nutrient composition at harvest.

Two simulation experiments involved harvesting 'Hass' fruit from a commercial orchard in South-east Queensland, transporting them to a laboratory within 4 hours of harvest and subjecting them to supply chain conditions. Two complimentary through the (real world) supply chain experiments involved monitoring 'Hass' fruit through chains from Central Queensland to Victoria and from Northern New South Wales to Victoria. These consignments were retrieved from wholesaler and ripener, respectively, and held in a laboratory at 20-22°C to emulate retail display prior to assessment for bruising, bruise susceptibility and body rots. Dry matter and fruit mineral nutrient composition of fruit from each orchard were also determined. Each experiment investigated six treatments comprised of 20 replicate fruit (Table 1).

Table 1. Summary of treatments investigated in supply chain experiments.

Experiment	Factors	Levels
Supply chain simulation 1	Drop height at packing	0, 30 or 60 cm
	Postharvest cooling	Cooling (5°C) or no cooling (20°C)
Supply chain simulation 2	Drop height at packing	0, 30 or 60 cm
	Postharvest cooling	Prompt or delayed*
Supply chain monitoring 1 *(Queensland to Victoria)*	Drop height at packing	0, 30 or 60 cm
	Fruit source	Orchard A or B
Supply chain monitoring 2 *(New South Wales to Victoria)*	Drop height at packing	0, 30 or 60 cm
	Postharvest cooling	Prompt or delayed*

* Prompt = cooled to 12°C on day of harvest. Delayed = held at ambient temperature for 48 h, followed by 48 h at 12°C.

Outputs

- Literature reviews:
  - Factors contributing to avocado fruit susceptibility to bruising (**Appendix A**)
  - Relationship between impact injury and postharvest disease expression in avocado (**Appendix B**)
  - Best practice recommendations towards preventing avocado flesh bruising at retail (**Appendix C**)
  - Alternative technologies to determine avocado ripening (**Appendix D**)

- Research reports:
  - Non-destructive avocado fruit firmness assessment using a commercial 'FruitFirm' meter (**Appendix E**)
  - Comparison of devices for 'non-destructive' firmness measurement of avocado fruit (**Appendix F**)
  - Supply chain effects on quality of 'Hass' avocado fruit upon ripening (**Appendix G**)

- Articles in *Talking Avocados* (Australian avocado industry's quarterly publication; readership >2300):
  - New Hort Innovation project to combat flesh bruising in avocado (**Summer 2017**)
  - Factors affecting avocado flesh bruising susceptibility (**Winter 2017 and online**) http://www.avocado.org.au/public-articles/tav28n2_bruising/
  - Best practice handling to reduce flesh bruising (**Summer 2018 and online**) http://www.avocado.org.au/public-articles/tav28n4_bruising/
  - Does impact injury at harvest increase body rots at retail? (**Autumn 2018 and online**) https://www.avocado.org.au/public-articles/tav29n1_bodyrots/
  - Reducing bruising in avocado – project update (**Winter 2018**)

- AV15009 Stakeholder Knowledge Sharing Workshop held at Brisbane Markets on 15 May 2018. This workshop provided an opportunity for industry supply chain stakeholders to nominate priority areas for future research into avocado fruit quality improvement. Sixteen attendees included representatives from Murray Brothers, Costa, Favco, Freshmax, Naturo Technologies, Hort Innovation, The University of Queensland (UQ) and Queensland Department of Agriculture and Fisheries (QDAF). An activity report on the workshop (including presentation slides) appears in **Appendix H**.

- Table of recommended updates for AAL online 'Best Practice Resource' based on findings from the literature reviews (**Appendix I**).

- Project update presented at AAL regional grower meetings (Figure 1b; refer to **Appendix J** for presentation slides):
  - Crows Nest, Qld (1 May 2018; 64 attendees)
  - Coolum, Qld (2 May 2018; 49 attendees)
  - Mareeba, Qld (31 May 2018; 73 attendees)
  - Childers, Qld (7 June 2018; 62 attendees)

- Conference poster presentations:
  - Shopper and consumer contribution to mesocarp bruising in avocado (*Persea americana* M.) cv. 'Hass' fruit and a prototype decision aid tool for in-store firmness assessment (**Appendix K**)

    TropAg2017, Brisbane, 20-22 November 2017. Conference attendance: 720 delegates from 46 countries. Book of poster abstracts available online at https://tropagconference.org/wp-content/uploads/2018/01/TropAg2017-Book-of-poster-abstracts-FINAL.pdf
  - Technologies and practices to reduce bruising in avocado fruit (**Appendix L**)

    Avocado Brainstorming 2018, Tzaneen, South Africa, 28 May – 1 June 2018. Conference attendance: ~ 80 delegates from 11 countries. Activity report appears in **Appendix M**.

- Youtube video 'Better handling of avocados through the supply chain to reduce bruising' https://youtu.be/D4yTzSX1pzE (draft version only; under internal review).

- Public demonstration of the 'Readycado' prototype DAT for fruit firmness assessment on People's Day (15 August 2018) at the Royal Queensland Show (Figure 1a).

- Milestone reports 102-105 submitted to Hort Innovation between January 2017 and May 2018 providing regular updates on progress with project activities.

- Final report (this report) submitted to Hort Innovation in October 2018.

Figure 1. (A) Project leader Daryl Joyce (centre) and team member Sohail Mazhar (right) demonstrate the prototype Avocado Decision Aid Tool to Queensland's Minister for Agricultural Industry Development and Fisheries the Hon Mark Furner (left) at the Royal Queensland Show on 15 August 2018; and, (B) project team member Melinda Perkins presents an AV15009 project update to industry stakeholders at the AAL Sunshine Coast Regional Meeting held at Coolum on 2 May 2018.

Outcomes

Suitable technologies for non-destructive avocado firmness assessment identified

Sixteen technologies ranging from relatively more conventional impact recording devices to novel carbon nanotube-based sensors were reviewed (**Appendix D**). To date, only 10 of these technologies have been tested on avocados and with varying degrees of success. It was concluded that most reliable prediction of avocado ripeness will be achieved with devices that directly measure fruit firmness. Moreover, for in-store use by retail staff and shoppers, the ideal technology would need to be relatively low-cost, robust, and simple to operate with minimal physical interaction and technical maintenance requirements.

Laboratory experiments comparing the four 'best bet' devices as described in the Methodology section found that all were able to discriminate between different avocado stages of ripeness from 1 (rubbery) to 5 (soft-ripe) for both 'Hass' and 'Shepard' fruit (**Appendix F**). However, around half of the 'Shepard' fruit assessed at soft-ripe stage developed bruising in response to measurement with the FruitFirm Meter and the SIQFT. Hence, these two devices might not be considered truly 'non-destructive' for 'Shepard' fruit firmness assessment. Further testing is needed to confirm this finding. In contrast, none of these devices caused bruising in 'Hass' fruit.

Tests conducted with the DAT and FruitFirm Meter established that measurements at the equatorial fruit region were more consistent than those made at the stem-end, neck or base. Subsequently, the handheld FruitFirm Meter was (re-)configured into a prototype bench-top version for in-store use (Figure 2). This design allows for a fruit to simply be placed into a cradle which brings the equatorial region of the fruit in contact with the measuring tip of the FruitFirm meter. The operator then presses a button to take a measurement and the result is digitally displayed within 1-2 seconds. It is envisaged that, beyond AV15009, the configuration might be further refined into an attractive user-friendly interface for testing in-store with shoppers.

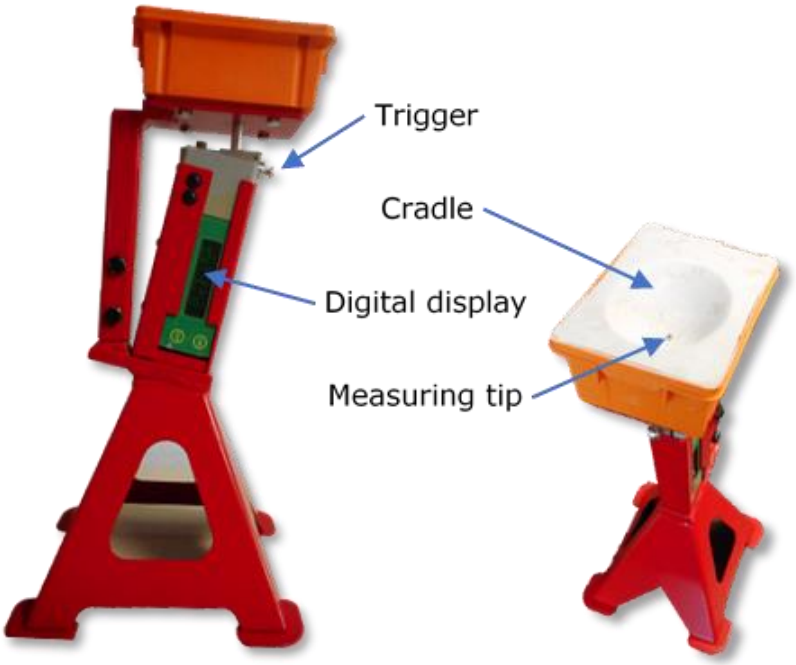

Figure 2. Prototype bench-top configuration of FruitFirm Meter for avocado fruit firmness assessment.

Documented best practice to reduce flesh bruising

The literature review titled, 'Best practice recommendations towards preventing avocado flesh bruising at retail' (**Appendix C**) found sufficient evidence to recommend the following practices to reduce flesh bruising:

1. 'Hass' avocado fruit be harvested above 23% dry matter, which is the current industry recommendation.
2. Fruit be passed through the supply chain in as short a time as possible.
3. Drop heights be kept below 10 cm for fruit at the rubbery to softening ripeness stages.
4. Fruit be handled carefully without dropping or excessive squeezing from firm-ripe stage onwards.
5. Ripened 'Hass' avocado fruit be maintained at 5°C.

These recommendations were communicated to AAL via a face-to-face meeting between John Tyas (AAL), Daryl Joyce (QDAF) and Melinda Perkins (UQ) on 5 May 2017. Several unconfirmed pre-harvest and post-harvest factors likely to reduce bruising at the retail level were also identified in the review. However, there was insufficient supporting evidence for these to be included in the list of recommendations. Among these unconfirmed factors was the appropriate postharvest temperature management of unripe fruit, which is anecdotally believed to greatly influence bruise susceptibility at retail. It has been determined that prompt cooling of fruit after harvest limits early ripening and softening of fruit. It has also been determined that fruit become more susceptible to bruising as they ripen. However, the extent to which temperature management of unripe fruit affects bruise susceptibility at retail was unknown at the time of the review. A project extension was subsequently approved to investigate this issue through a series of supply chain experiments (see below).

Confirmed relationship between impact injury and postharvest disease

Both supply chain simulations (**Appendix G**) confirmed that impact injury incurred prior to packing promotes body rots in 'Hass' avocados upon ripening (Figure 3). A drop height of 30 cm caused body rots to occur at the impact site in at least 7 out of 10 fruit. Lesion area at the impact site almost doubled (Simulation 1) or tripled (Simulation 2) as drop height increased from 30 cm to 60 cm. Fungal isolates obtained from the lesions were identified as *Colletotrichum* spp., confirming the initial belief that this pathogen is responsible for impact-induced body rots.

Findings from the 'actual' supply chain experiments were less conclusive. Increased body rot incidence in response to impact injury was observed in fruit from one orchard in Central Queensland, but not from the other. No relationship between impact and disease was observed in fruit from NSW. The variable response may relate to differences in disease pressure between orchards or the intrinsic robustness of the fruit.

The literature review (**Appendix B**) found that whilst there has been much investigation of the pathogen most commonly responsible for body rots in avocado, *Colletotrichum gloeosporioides* (species complex), little is known of the impact-induced physiological and biochemical changes that occur in avocado or how they may trigger disease development. This lack of insight and inconsistent results from the supply chain experiments point to a need to better understand the underlying causes of impact-induced disease expression in avocado. Nevertheless, limiting drop heights to less than 30 cm prior to packing is likely to reduce body rot expression upon ripening in fruit that are predisposed to the disease.

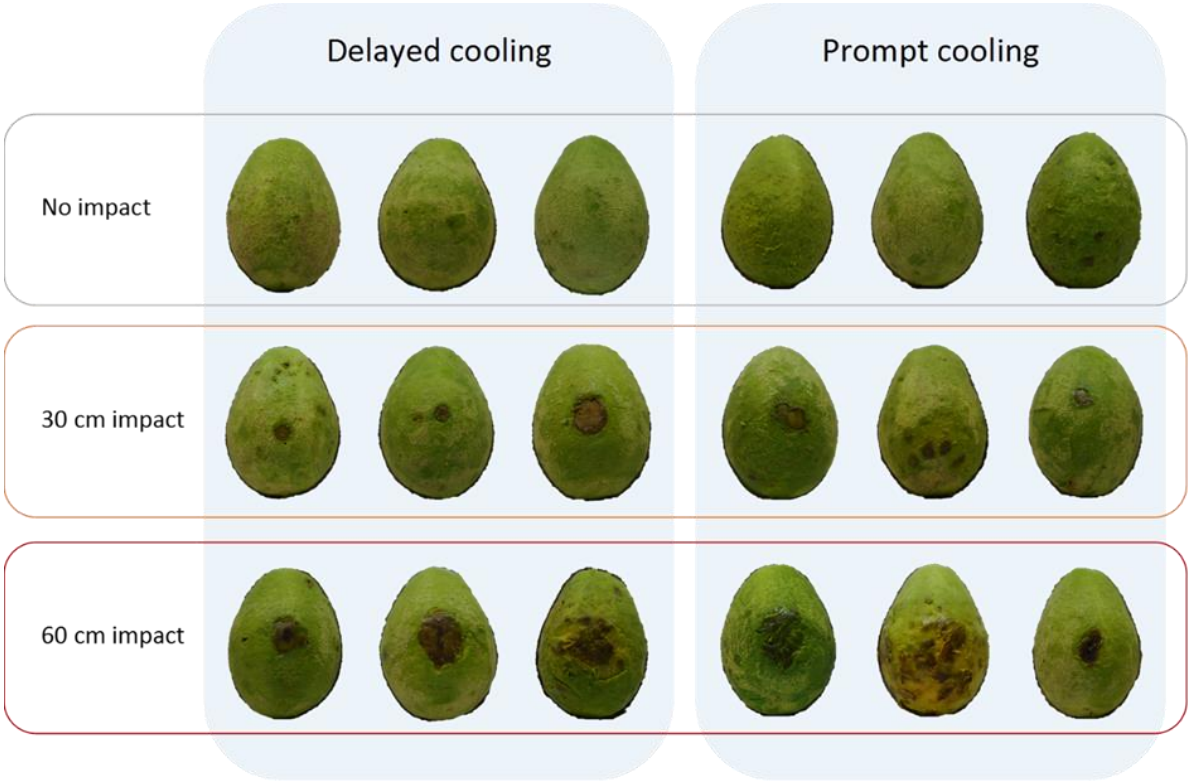

Figure 3. Body rot expression in 'Hass' avocado fruit 1 d after reaching firm-ripe stage. Fruit were harvested from a commercial orchard in South-east Queensland on 17 and 20 August 2018 and subjected to drop heights of 0, 30 or 60 cm on 21 August 2018. Fruit from the first harvest were held at ambient conditions for 48 h followed by 48 h at 12°C (delayed cooling). Fruit from the second harvest were cooled to 12°C on the day of harvest (prompt cooling).

New knowledge of pre-harvest versus postharvest influences on final fruit quality

Findings of the supply chain experiments (as summarized in Table 2) provide a better understanding of some factors affecting final fruit quality. Pre-harvest factors greatly influenced final fruit quality, in some cases more so than early-stage postharvest handling practices (**Appendix G**). Marked differences in body rot incidence and severity were observed between fruit from two orchards in Central Queensland (Figure 4), despite being harvested on the same day, packed on the same line into the same trays and subjected to the same supply chain conditions. All fruit from Orchard A were severely affected with body rots, as compared with 0% of non-impacted fruit and 15% of impacted fruit from Orchard B. Differing fruit robustness and/or disease pressure arising from pre-harvest factors can be the only explanation for such a variable response. Fruit from Orchard A had higher N/Ca and lower (Ca + Mg)/K ratios, both of which have previously been linked to poor fruit quality.

Delayed as opposed to prompt cooling caused body rot incidence to increase from 35 to 95% in non-impacted fruit from the NSW to Victoria supply chain monitoring experiment. However, no difference was observed when the same cooling treatments were applied to fruit from South-east Queensland in Simulation 2. Conversely, impact at harvest caused increased body rot incidence in fruit from Simulation 2, but had no effect upon the NSW fruit. These inconsistencies suggest the involvement of other interacting and potentially over-riding factors. Differing inherent 'fruit robustness' is one likely candidate, as the SEQ fruit had an N/Ca ratio approximately twice that of the NSW fruit. Differences in fruit temperature between packing and retail is another, as the NSW fruit received inadequate cooling during these stages.

Table 2. Summary of findings from supply chain experiments showing increased (up arrow) or no (equal sign) effect of delayed cooling and impact at packing on bruise susceptibility and body rot severity in 'Hass' avocado.

Experiment	Delayed cooling		Impact at packing	
	Bruise susceptibility	Body rot severity	Bruise susceptibility	Body rot severity
Simulation 1	=	=	=	↑
Simulation 2	↑	=	↑	↑
Supply chain 1 (Qld to Vic)	nd	nd	nd	=
Supply chain 2 (NSW to Vic)	=	↑	nd	=

nd = not determined

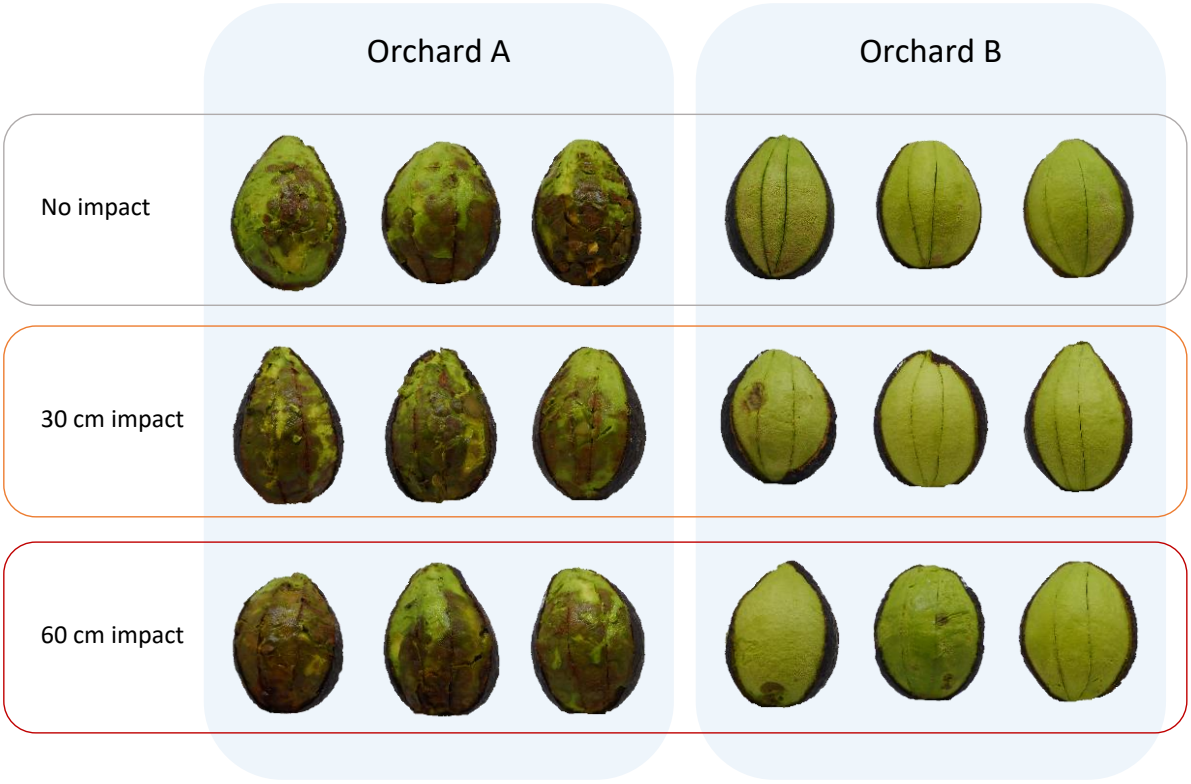

Figure 4. Body rot expression in 'Hass' avocado fruit at soft-ripe stage. Fruit were harvested on 24 July 2018 from two orchards in Central Queensland and exposed to differing drop heights at time of packing.

With respect to bruise susceptibility, results were also inconsistent. Simulation 2 showed that bruise susceptibility increased with increasing drop height and when postharvest cooling was delayed. However, no treatment effects were found in the other three experiments. A comparison of overall bruise susceptibility between experiments suggested that fruit source has a highly significant ($P<0.001$) influence – susceptibility to bruising was either 18, 22 or 30 $mm^3.mJ^{-1}$, depending on the orchard from which the fruit were harvested. Although fruit 'robustness' is a likely contributing factor, these fruit had been subjected to differing supply chain conditions and thus the relative contributions of pre-harvest and postharvest factors to bruise susceptibility could not be determined. Furthermore, differences in bruise susceptibility between orchards appeared to be unrelated to dry matter or flesh mineral nutrient composition. The findings highlight the complexity of bruise susceptibility in avocado fruit. Models to predict bruise susceptibility cannot be developed and applied to effect until the contributing factors are better

understood. A well-known advertising slogan 'oils ain't oils' clearly has parallels to avocado fruit off the tree too.

Better informed R, D & E and industry players

A major focus of the project has been the collation, analysis and (especially) dissemination of information regarding avocado flesh bruising. A multi-faceted industry communications strategy was used which included a half-day 'knowledge sharing' workshop held at Brisbane Markets in May 2018 (**Appendix H**), a series of technical articles in Talking Avocados, project updates presented at four AAL regional grower meetings in Queensland (Appendix J), and one-on-one communication with AAL as well as growers, packers and wholesalers.

Communication with other R, D & E providers (including the project teams of 'AV15010' and 'AV15011') was achieved via updates provided at Program Reference Group meetings coordinated by Hort Innovation and hosted by DAF, poster presentations at TropAg2017 (**Appendix K**) and 2018 Avocado Brainstorming Workshop (Appendix L), and a scientific publication in peer-reviewed international journal *Postharvest Biology and Technology*. Further scientific publications are anticipated to arise from the literature reviews and research reports in due course. The review of impact injury and postharvest disease expression in avocado (**Appendix B**) was submitted to *Scientia Horticulturae* in June 2018 and manuscripts are currently being prepared for the others.

Monitoring and evaluation

Overall, the project was highly successful in collating existing knowledge on flesh bruising in avocado, identifying critical gaps in the research and generating new knowledge in these areas. Project performance in terms of impact, effectiveness, appropriateness, efficiency and legacy (in accordance with the project M & E plan) is discussed below.

Impact

Findings from the literature reviews had an immediate impact, prompting a request from industry to investigate important, but poorly understood, factors involved in flesh bruising. A project variation was consequently contracted, allowing some additional research focused activities (viz., the supply chain experiments) to be undertaken during the 2018 season.

From inception, the project was expected to have future impact on activities and behaviors of supply chain stakeholders and shoppers. Widespread practice change is yet to be realised for the project recommendations of reducing fruit exposure to impacts from harvest onwards, limiting fruit squeezing at retail, maintaining a postharvest temperature of 5°C where possible and passing fruit quickly through the supply chain. As outlined in the project's M & E plan, it may take 5 years for the full impact of improvements to become apparent. Hence, changes in behavior and fruit quality at retail should be measured beyond the time frame of the current project.

Effectiveness

All project activities were achieved and, in some instances, exceeded. Extra deliverables included the AV15009 Stakeholder Knowledge Sharing Workshop, a Youtube video, two additional *Talking Avocados* articles, representation at the Avocado Brainstorming Workshop in South Africa, a poster presentation at TropAg2017, and project updates provided at the 2018 AAL regional grower meetings in Queensland. All activities have led to achievement of the target end-of-project outcome of 'more informed R, D & E and industry players'.

A more defined outcome was anticipated with respect to the development and testing of a prototype and potential variant DATs for avocado fruit firmness. However, early in 2018 the key collaborating industry partner Pacific Data Systems (PDS) withdrew from active engagement in the project based on their changing 'business model'. That is, PDS determined that it was no longer in a business position to support development and testing of prototype in-store fruit firmness testing / determination devices. In this light, technical consultant Brett Jahnke was instead commissioned to re-configure a commercially available handheld device into a bench-top model for demonstrating 'proof of concept'. While refinement is needed in preparation for the consumer-testing phase, initial lab testing of this device (Figure 2) has been highly promising.

An appropriate industry partner might ideally be sought to progress development of suitable alternative technologies like those identified in this project and the relevant preceding project. Public interest is rife in this regard. An article in *The Weekly Times* (2018) stated, "there should be a Nobel Prize in it for the successful inventor [of] a device that measures ripeness without damaging the fruit".

Appropriateness

Intended beneficiaries of the project include avocado supply chain players (i.e., growers, packers, ripeners, retailers, and consumers) and other R, D & E workers. Positive feedback received in the course of 'AV15009' suggested that the project's activities appropriately met the needs of these groups. For example, all participants of the 'AV15009' Stakeholder Knowledge Sharing Workshop, of whom most were ripeners or wholesalers, rated the workshop as useful and felt that they had played a participatory role and learnt new things (Figure 5). Comments included, "Very interesting and interactive", "good source of information", "I enjoyed it", "Very well run" and "Overall interesting and kept moving". However, the workshop received one criticism for its lack of participants from other sectors of the supply chain; viz., growers and packers. Therein lies inherent future potential for

expanded dissemination of the findings from this project.

Opportunities to communicate project findings to growers and packers came in early 2018 at the AAL regional grower meetings. Updates on all three Hort Innovation Avocado Supply Chain Improvement projects (i.e., 'AV15009', 'AV15010', and 'AV15011') were provided at these meetings. Detailed feedback from participants is presented in the final reports of 'AV15010' and 'AV15011'. In summary, participants of the regional grower meetings were "satisfied with the content of the program, found the information useful, and learned something new".

Industry awareness generated by the reviews provided the impetus for extending the project to accommodate the supply chain experiments.

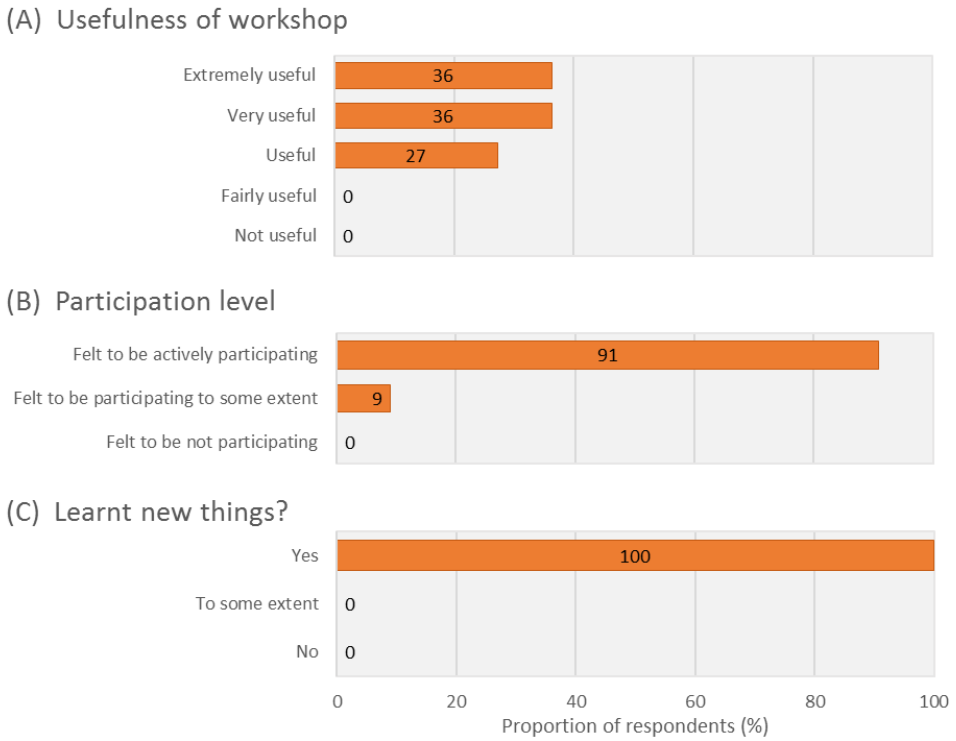

Figure 5. Participant feedback on the 'AV15009' Stakeholder Knowledge Sharing Workshop held at Brisbane Markets on 15 May 2018 (*n* = 11).

Efficiency

Engagement of experienced project team members with complementary areas of expertise across the areas of postharvest physiology, plant pathology, supply chain management, and food science ensured efficient delivery of project outputs and outcomes. The project also benefited from the extensive industry networks that had been developed by senior team members over decades of involvement in avocado research. Ready access to the established protocols and physical resources of two major agricultural research organisations in Australia, DAF and UQ, allowed for effective planning, execution and delivery of project activities.

'Piggy-backing' off the AAL regional grower meetings was an efficient use of resources. It allowed project findings to be communicated to a wide audience of growers at minimal cost to the project. However, presentations were admittedly limited to the Queensland meetings, as they had not been originally budgeted for in the project. Future R & E projects might ideally factor in capacity or means for nation-wide representation at grower meetings to make the most of this important opportunity for researcher-grower interaction.

Legacy

In the short to medium to long term and as originally conceived for this essentially 'take stock' project (P. Lorimer, pers. comm.), its outputs and outcomes will inform and no doubt enhance future R, D & E impact. For example, the overriding importance of poorly defined and understood 'fruit robustness' to final fruit quality determination as touched on in this project, is expected to be a highly rewarding future research focus. R, D & E into contributions of pre-harvest factors to flesh bruising, postharvest disease, overall fruit shelf life and, ultimately, organoleptic quality to consumers is particularly needed. Parallel investigation of the basic biology of avocado fruit quality, biochemistry and physiology will assist development of high impact solutions for the industry. Supply chains that master 'fruit robustness' in this context are likely to be the most sustainable ones as supply increasingly outstrips demand in an evidently looming 'post peak avocado' world. Interestingly, this matter was 'touched on' at the 'Avocado Brainstorming 2018' in South Africa, but realization seems to have only 'just dawned'.

In the medium to long term, adoption of best practice recommendations from this project (see below) is expected to increase as industry stakeholders continue to access information like the Youtube video, the online AAL BPR and/or via the retail training packages such as developed in project 'AV15011'. Changes in postharvest handling practices to lessen flesh bruising and any attendant decay will ultimately result in delivery of better quality fruit to the consumer. Increased customer satisfaction will bolster demand for avocado fruit and have a long term positive effect on industry sustainability and profitability, including in the face of lower cost production overseas; e.g. Mexico.

Recommendations

Confirmed recommendations in terms of practical application to industry include:

1. **Pack and cool fruit promptly after harvest**

   The practice of prompt packing and cooling of fruit is widely accepted, but is not consistently practiced. In this project, delayed cooling had inconsistent results on both bruise susceptibility and body rot expression. In cases where a response was detected, bruise susceptibility almost doubled and body rot incidence almost tripled when cooling was delayed. For these reasons, growers and packers should make a concerted effort to ensure fruit are cooled within 24 h of harvest.

2. **Avoid impact damage during harvest and packing**

   According to findings of project 'AV15010', avocados are sometimes exposed to substantial mechanical impact during harvest and packing. As hard, unripe fruit generally do not bruise, this has caused little concern to growers and packers in the past. However, new evidence from project 'AV15009' suggests that impact at packing can increase body rot expression and bruise susceptibility once fruit ripen. For instance, a 60 cm drop height at packing caused a four-fold increase in the area of fruit affected by body rots in Simulation 2. Bruise susceptibility almost doubled in response to a 30 cm drop height, as compared with no impact (Simulation 2). Hence, avoiding impact damage during harvest and packing is recommended to reduce the risk of bruising and body rots developing in fruit at retail.

3. **Monitor avocado fruit quality at retail to estimate project impacts**

   The extensive monitoring of avocado fruit quality at Australian retail stores conducted by Tyas (2016) between 2008 and 2015 allowed the industry to gauge its performance against minimum benchmarks for maturity, ripeness and internal quality. It is imperative that retail monitoring continue so to provide a measurable indicator of the effect of practice change arising from this and other recent supply chain quality improvement projects. Future monitoring should follow the same protocols applied across a similar number of stores and locations to ensure comparability with previously generated data sets.

Recommendations for future research include:

1. **Identify pre-harvest factors that influence 'fruit robustness'**

   It is generally accepted that so-called 'fruit robustness' influences final fruit quality. The concerning revelation of this project is just how large the influences on body rot expression and bruise susceptibility can be in relation to some postharvest practices, such as impact at packing and delayed cooling after harvest. Hence, production of 'robust fruit' needs to become a priority if industry sustainability and profitability is to be maintained into the future. But just what constitutes a 'robust' fruit? It is debatable that growers already have the know-how to grow a robust fruit. In fact, there are few clearly defined measurable parameters for robustness.

   Achieving the right balance of mineral nutrients in fruit, particularly a low N/Ca ratio, has consistently been associated with fewer body rots upon ripening. However, other different and as yet undetermined pre-harvest factors appear to govern bruise susceptibility in softening fruit. Research is needed to identify pre-harvest genetic x management x environment factors that consistently underpin fruit robustness and, ultimately, fruit quality at retail. Such knowledge could lead to development of quality-centric 'best practice' orchard management protocols as well as quality monitoring tools

for growers.

2. Develop a reliable means of achieving low fruit N/Ca without sacrificing yield

N/Ca ratio in avocado and other fruits is increasingly being recognized as one key predictor of postharvest disease susceptibility. The present project's findings have reaffirmed this view in that Central Queensland fruit from Orchard B and NSW fruit both had low N/Ca ratios of ~20 and exhibited little or no body rot when promptly cooled after harvest. In contrast, much higher body rot incidence (≥80%) and N/Ca ratios (~40) were observed in Central Queensland fruit from Orchard A and South-east Queensland fruit.

Despite considerable investigation, production of fruit with consistently low N/Ca continues to be a challenge. Plant Ca uptake and its distribution to fruit are notoriously difficult to manipulate. Increased Ca fertilization is generally ineffective for increasing fruit Ca concentration. In this light, strategies that reduce foliar competition for Ca during the critical stage of early fruit development and/or which reduce N distribution to the fruit without compromising yield may potentially realise more control in establishing more favorable N/Ca ratios.

3. Progress development of a DAT for in-store fruit ripeness assessment

The technologies identified and tested in this project have proven to be capable of distinguishing serial stages of ripeness on the basis of fruit firmness. Their further refinement is needed, such as to incorporate one or more of the technologies into a low cost user-friendly configuration suitable for in-store testing and use by retailers and shoppers. The time is seemingly opportune for this activity to proceed in the light of immense public interest in the topic. However, an industry collaborator with the required technical expertise and resources to develop such a device is critical. The company originally engaged to assist DAF in the development of the prototype avocado DAT have no current interest in the tool. Nonetheless, opportunity exists for collaborators to investigate and develop options for further testing and potential commercialisation.

Refereed scientific publications

Mazhar, M., Joyce, D., Hofman, P., Vua, N., 2018. Factors contributing to increased bruise expression in avocado (*Persea americana* M.) cv. 'Hass' fruit. *Postharvest Biology and Technology* **143**, 58–67.

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

Hofman, P.J., 2005. Skin damage to Hass avocados can cause quality problems down the track. *Talking Avocados* **16**(2), 24-26.

Hort Innovation (2017). Avocado strategic investment plan 2017-2021.

Hort Innovation measure damage shoppers can do checking avocado ripeness, 2018. In: *The Weekly Times*. https://www.weeklytimesnow.com.au/country-living/back-paddock/hort-innovation-measure-damage-shoppers-can-do-checking-avocado-ripeness/news-story/8f4a4c00123907320080293 4c96743c6?csp=b66d9dd1ad77498f675715f997bd7d5d. Accessed 24 September 2018.

Macnish, A.J., Joyce, D.C., Shorter, A.J., 1997. A simple non-destructive method for laboratory evaluation of fruit firmness. *Aust. J. Exp. Agric.* **37**, 709-713.

Tyas, J., 2016. Avocado industry fruit quality benchmarking. Final report AV11015. Horticulture Innovation Australia, Sydney.

Intellectual property, commercialisation and confidentiality

Horticulture Innovation and the Queensland Government (acting through its Department of Agriculture and Fisheries, DAF) are joint owners as tenants-in-common of Background intellectual property (BIP) with HIA taking a security interest of 1%.

No commercial-ready IP was generated in the course of the project; however the knowledge, experience and outputs may be used to develop commercial best practice resources, for example a fruit firmness tool.

Four literature review documents and three research reports will remain confidential until fully progressed through standard publications' processes.

Acknowledgements

The project team would like to thank the growers, packers, ripeners and wholesalers who provided invaluable advice and resources during the supply chain experiments. John Tyas and the team at AAL are especially gratefully acknowledged for their assistance in promoting the project and communicating its findings via *Talking Avocados* and the regional grower meetings.

The team greatly appreciates the guidance and support provided by members of the project steering committee, Peter Hofman (QDAF), Corrine Jasper (Hort Innovation), Cormac te Kloot (Costa Group), Philippa Lorimer (Hort Innovation) and John Tyas (AAL), as well as the members of the Supply Chain Quality Improvement Program Reference Group.

Also thanked are Lisa Dwyer (Brismark) for help with organising the AV15009 Stakeholder Knowledge Sharing Workshop, Ken Pegg and Roger Mitchell (QDAF) for their diagnosis of avocado postharvest pathogens, John Lopresti (AgriBio) for access to laboratory resources during the Melbourne component of the supply chain experiments, Tony Cooke (QDAF) for assisting with fruit quality assessments, Yiru Chen (QDAF) for post-production refinement of the Youtube video, Peter Isherwood (UQ) for conducting fruit mineral nutrient analyses, and UQ postgraduate students Abdullah Al Hosni, Khamla Mott and Aljay Valida for help with harvesting fruit.

Appendices

Literature reviews:

Appendix A. Factors contributing to avocado fruit susceptibility to bruising (confidential)

Appendix B. Relationship between impact injury and postharvest disease expression in avocado (confidential)

Appendix C. Best practice recommendations towards preventing avocado flesh bruising at retail (confidential)

Appendix D. Alternative technologies to determine avocado ripening (confidential)

Research reports:

Appendix E. Non-destructive avocado fruit firmness assessment using a commercial 'FruitFirm' meter (confidential)

Appendix F. Comparison of devices for 'non-destructive' firmness measurement of avocado fruit (confidential)

Appendix G. Supply chain effects on quality of 'Hass' avocado fruit upon ripening (confidential)

Industry communications:

Appendix H. Activity report for AV15009 Stakeholder Knowledge Sharing Workshop

Appendix I. Table of recommended updates for AAL online 'Best Practice Resource'

Appendix J. AV15009 project update presented at 2018 AAL regional grower meetings

Conferences:

Appendix K. TropAg2017 poster

Appendix L. Avocado Brainstorming 2018 poster

Appendix M. Activity report for Avocado Brainstorming 2018

Avocado Supply Chain Quality Improvement

Technologies & Practices to Reduce Bruising

Hort Innovation Project Reference: AV15009

Activity Report

Stakeholder Knowledge Sharing Workshop, 15 May 2018, Brisbane Markets

Muhammad Mazhar, Melinda Perkins, Daryl Joyce, Noel Ainsworth, Lindy Coates and Peter Hofman

Contents

Project Objectives

- Develop a project monitoring and evaluation plan using program logic.
- Develop and test alternative technologies that would reduce handling by retailers / consumers, including tools for identifying ripeness.
- Document best practice to prevent fruit bruising at retail for implementation in retail education via AV15011.
- Review scientific evidence to identify any relationship between disease and flesh bruising and / or identifying gaps in research that would elucidate this.
- Review and document contributing factors to fruit susceptibility to bruising.

Project Partners

- Hort Innovation (HI)
- Avocados Australia Limited (AAL)
- Brisbane Markets Limited, Rocklea (Brismark)
- Murray Bros, Brisbane Markets, Rocklea (MB)
- Commercial avocado supply chain stakeholders
- Queensland Department of Agriculture & Fisheries (QDAF)
- The University of Queensland, Gatton (UQ)

Workshop Objectives

- Sharing the recent developments of HI project AV15009 with the industry stakeholders.
- Collecting views of the avocado industry stakeholders on future R, D, and E priorities from particular perspective of reducing mesocarp bruising and rots potentially caused due to the handling practices of supply chain stakeholders.

Acknowledgements

This report has been produced based on the workshop conducted for the project 'Supply Chain Quality Improvement - Technologies & Practices to Reduce Bruising; Grant Number AV15009'. This project has been funded by Hort Innovation, using the avocado 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. The Queensland Government co-funded the project through the Department of Agriculture and Fisheries. The project team is thankful to industry stakeholders and co-workers at The University of Queensland, and the Queensland Department of Agriculture and Fisheries for their support and assistance. The support of Ms Lisa Dwyer of Brismark in making arrangements of the workshop and the support of Ms Corrine Jasper for participation in the workshop is especially appreciated.

Workshop Program

Convenor / Chair: Dr Daryl Joyce, Project Leader, QDAF / UQ

Time	Activity	Facilitator/s
8:15 AM	Arrival & registration Workshop organizers, facilitators, and participants arrive at the venue	C/- Brismark
8:30 AM	Welcome Welcome to organizers, facilitators, and participants of the workshop Importance of high quality avocado fruit for wholesalers, retailers and consumers will be emphasised	Lisa Dwyer, Brismark
8:45 AM	Introduction of participants Organizers, facilitators and participants of the workshop introduce themselves	All participants ('round robin')
9:00 AM	Workshop scope Overview of project AV15009 scope and of the workshop purpose	Daryl Joyce, QDAF/UQ
9:15 AM	Industry perspective An industry perspective on avocado supply chain R,D&E needs in Australia Murray Bros. collaboration / support will be noted	Stephen Edwards, MB
9:30 AM	Pre- and post-harvest management to reduce bruising Update on maintaining avocado fruit quality through the supply chain Emphasis on recommended practices during harvesting and postharvest handling	Melinda Perkins, UQ
9:50 AM	Extension strategy for research dissemination Overview of this and related avocado supply chain project strategies for dissemination by QDAF of findings to stakeholders	Noel Ainsworth, QDAF
10:10 AM	Association between poor fruit handling practices and rots Elucidation in the context of physical damage of an association between fruit rots and handling practices for avocado fruit	Lindy Coates, QDAF
10:30 AM	*Morning Tea and networking*	C/- QDAF
11:00 AM	Concurrent HI funded avocado supply chain projects	Supported by Sohail Mazhar
11:10 AM	Identification of future R,D,& E needs Participants in groups identify, list and prioritise future avocado supply chain R,D,&E needs from 'paddock to plate'.	Participant groups
11:55 AM	Group summaries Groups' suggestions shared with all participants by a spokesperson from each group Information collected and collated by Sohail Mazhar and duly shared with AAL, HI and other interested parties	Supported by Sohail Mazhar
12:20 PM	Overall summary, concluding remarks HI perspectives on the project and the workshop shared with participants Thanks afforded to attendees	Corrine Jasper, Hort Innovation
12:30 PM	*Lunch and networking*	C/- QDAF

Workshop Participants

Count	Name	Affiliation
1	Mark Girle	Murray Brothers
2	Scott Paine	Murray Brothers
3	Stephen Edwards	Murray Brothers
4	Dominic Kanongara	Costa
5	Dan Turner	DBMCO
6	Kris Gosper	DBMCO / FreshMax
7	Hayden Clarke	FAVCO
8	Patrick Lorne	FAVCO
9	Glen Goker	Naturo
10	Corrine Jasper	Hort Innovation
11	Lisa Dwyer	Brismark
12	Peter Hofman	DAF
13	Lindy Coates	DAF
14	Yiru Chen	DAF
15	Daryl Joyce	UQ / DAF
16	Melinda Perkins	UQ
17	M Sohail Mazhar	UQ

Workshop Proceedings

The workshop proceedings started with arrival of participants at Fresh Centre at Brismark Rocklea. Ms Lisa Dwyer offered welcome to the organizers, facilitators, and participants of the workshop. She briefly discussed about importance of high quality avocado fruit for wholesalers, retailers and consumers; and advised the participants to effectively utilize the opportunity of learning at their door steps. Ms Lisa Dwyer advised the participants the housekeeping details and handed over the program to the Chair / Project Leader AV15009, Professor Daryl Joyce.

Professor Daryl Joyce welcomed the workshop participants and offered the ‘round robin’ introduction of the participants with each other. Professor Daryl Joyce then presented the overview of project AV15009 and discussed the scope of the workshop.

Picture 1: Professor Daryl Joyce presenting the scope of project AV15009.

Mr Stephen Edwards verbally briefed the participants about the importance of the avocado industry in the fresh produce sector and highlighted the need of continuity of efforts to tackle the ever emerging fruit quality issues. Mr Stephen Edwards shared the role of his organizations (Murray Brothers) in extending support to the research departments in conducting several studies on fruit quality. He shared the experiences and learnings of past Hort Innovation projects where his organization had participated. He appreciated the efforts of the project team and assured that industry stakeholders will continue to support research initiatives for greater good of the avocado supply chain stakeholders.

Picture 2: Mr Stephen Edwards sharing the industry perspective on avocado quality.

Dr Melinda Perkins presented the research outputs on pre- and post- harvest management of avocado fruit to reduce the incidence of bruising. Dr Melinda Perkins particularly shared an update on findings of AV15009 relating to maintaining avocado

fruit quality through the supply chain and emphasized on recommended practices during harvesting and postharvest handling of avocado fruit.

Picture 3: Dr Melinda Perkins and Professor Daryl Joyce responding to the questions of the workshop participants.

Ms Yiru Chen, on behalf of Mr. Noel Ainsworth, presented the extension strategy of project AV15009. She described the various approaches, with examples from other avocado projects implemented by the same research group, used for delivery of research findings to multiple layers of the stakeholders.

Picture 4: Ms. Yiru Chen presenting the extension strategy of project AV15009.

Dr Lindy Coates presented the research findings of AV15009 on association between poor fruit handling practices during harvesting and post-harvest stages and rots development at the site of impacts happened to the fruit at any stage in the supply chain.

Picture 5: Dr Lindy Coates presenting research work on association between poor fruit handling practices and rots.

After the technical session of sharing updates of AV15009 with industry stakeholders; Professor Daryl Joyce and Dr Sohail Mazhar shared the avocado resource material developed by concurrent HI projects on avocado supply chain management - being implemented by Applied Horticultural Research (AHR) - with the workshop participants. The participants were encouraged to take along copies of the resource material and use these and reference guides. The guides included 1) Australian avocado supply chain best practice guide, 2) Avocado fruit quality problem solver & Australian avocado supply chain checklists, and 3) Avocado stages of ripeness. Additional copies of the resource material were provided to Brismark administration for sharing with interested stakeholders who could not participate in this workshop.

Dr Sohail Mazhar also demonstrated the use of 'non-destructive' firmness measurement devices being tested by the project team of AV15009. The devices on the display included Force sensor Decision Aid Tool (DAT), Fruitfirm Meter (FFM), and Near Infra-red handheld device. Dr Sohail Mazhar shared with the workshop participants the current status of research on these devices and the expected timeline for sharing the conclusion of the on-going research experimentation.

Picture 6: Dr Sohail Mazhar sharing the avocado quality resource material produced by a concurrent Hort Innovation project and the 'non-destructive' firmness measurement devices being tested by the project AV15009.

The workshop participants were distributed in three groups for brainstorming on identification of future R, D, and E needs of the avocado industry in Australia. Each group was assigned one topic of each of R, D, and E for brainstorming and reporting back to the participants of other groups for their reflections and feedback. The group's constitution is provided in Table 1.

Table 1: Groups constituted for brainstorming on future R, D, and E needs of the avocado industry in Australia

Group 1: Research	Group 2: Development	Group 3: Extension
Stephen Edwards Dan Turner Corrine Jasper Daryl Joyce	Kris Gosper Scott Paine Patrick Lorne Peter Hofman Lindy Coates	Mark Girle Hayden Clarke Yiru Chen Melinda Perkins

The groups effectively utilised the time slot for brainstorming and produced many effective ideas for future R, D, and E needs of the avocado industry in Australia.

Picture 7: Brainstorming of small groups for determining future R, D, and E needs of the avocado industry in Australia.

The groups presented their ideas to the whole group of workshop participants for mutual agreement on the proposed ideas and if any of the workshop participants would have added any other related ideas to those presented at the forum. The consolidated ideas for each of the future R, D, and E needs of Australian avocado industry were recorded for future reference.

Picture 8: Workshop participants sharing the output of brainstorming of small groups for determining future R, D, and E needs of the avocado industry in Australia.

At conclusion of the workshop, Ms Corrine Jasper shared her views on conducting the workshop of AV15009. Ms Corrine Jasper encouraged industry stakeholders to keep in contact with the research community for getting right advice on their issues. Also, Ms Corrine Jasper advised industry stakeholders to record their desired future

researchable ideas on the online portfolio of Hort Innovation. She shared the Hort Innovation process of identification of new ideas for future research and development and implementation of new projects.

Picture 8: Ms Corrine Jasper sharing her views about the workshop and encouraging industry stakeholders to take ownership of future R, D, and E.

The workshop participants were requested to complete a feedback form with their experience of participation in today's activity.

Way Forward

The R, D, and E ideas conceived in the workshop will be shaped into concept notes for consideration by HI and other similar funding agencies. Also, where possible, part of these ideas will be covered in the existing or future projects of this research group. The research group will continue to work 'together' with avocado industry stakeholders for development of sustainable avocado supply chain solutions.

Suggested changes to the AAL Best Practice Resource based on current knowledge of practices that reduce bruising in avocado.

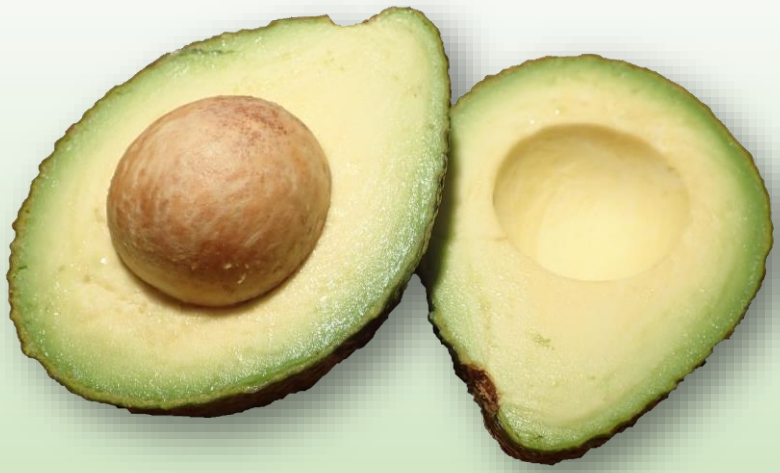
Section in BPR	Current BPR advice	Proposed BPR advice
Growing, Harvesting, Harvesting Grower Information, Pickers	Ensuring the pickers understand they should not drop the fruit more than 30cm.	Ensuring the pickers understand they should not drop the fruit more than 15cm.*
Growing, Harvesting, Harvesting Grower Information, Undamaged and Unblemished	Be sure to reject any fruit which has been dropped more than 30cm.	Be sure to reject any fruit which has been dropped more than 15cm.*
Growing, Harvesting, Harvesting Picker Information	Be gentle! Empty your picking bags gently as avocados can bruise easily. Fruit dropped more than 30cm should be thrown out.	Be gentle! Empty your picking bags gently as avocados can bruise easily. Fruit dropped more than 15cm should be thrown out.*
Growing, Harvesting, Avocado Harvesting Pickers Poster	Don't drop me over 30 cm.	Don't drop me over 15 cm.*
Growing, Harvesting, Avocado Harvesting Growers and Managers poster	Reject any fruit which has been dropped more than 30cm. Ensure pickers understand they should not drop the fruit more than 30cm.	Reject any fruit which has been dropped more than 15cm.* Ensure pickers understand they should not drop the fruit more than 15cm.*
Growing, Harvesting, Don't Drop Harvest Sticker	Don't drop me over 30 cm.	Don't drop me over 15 cm.*
Wholesale, Avocado Handling Wholesale Poster	Avocados bruise easily so minimise drop heights: • Rubbery to softening fruit: less than 10cm • Firm ripe to soft ripe fruit: less than 3cm	Avocados bruise easily so minimise drop heights: • Rubbery to softening fruit: less than 10cm • Firm ripe to soft ripe fruit: no dropping at all
Wholesale, Defect Identification, Bruising	Rubbery to softening fruit should not be dropped from heights more than 10cm. Firm-ripe to soft-ripe fruit should not be dropped from a height more than 3cm.	Rubbery to softening fruit should not be dropped from heights more than 10cm. Firm-ripe to soft-ripe fruit should not be dropped at all.
Retail, Avocado Retailer Training Manual	Once avocados start to soften, they are extremely susceptible to bruising. Always minimise drop heights and treat avocados like eggs: • Rubbery to softening fruit - less than 10cm • Firm ripe to soft ripe fruit - less than 3cm	Once avocados start to soften, they are extremely susceptible to bruising. Always minimise drop heights and treat avocados like eggs: • Rubbery to softening fruit - less than 10cm • Firm ripe to soft ripe fruit – no dropping at all
Retail, Avocado Handling Retail Poster	Avocados bruise easily so minimise drop heights:	Avocados bruise easily so minimise drop heights:

	• Rubbery to softening fruit: less than 10cm • Firm ripe to soft ripe fruit: less than 3cm	• Rubbery to softening fruit: less than 10cm • Firm ripe to soft ripe fruit: no dropping at all
Retail, Defect Identification, Bruising	Rubbery to softening fruit should not be dropped from heights more than 10cm. Firm-ripe to soft-ripe fruit should not be dropped from a height more than 3cm.	Rubbery to softening fruit should not be dropped from heights more than 10cm. Firm-ripe to soft-ripe fruit should not be dropped at all.

** Proposed change relates not to bruising, but to the increased risk of body rots upon ripening that occurs when hard green mature fruit are subjected to drop heights of 30 cm or more. A drop height of 15 cm does not increase the risk of body rots upon ripening.*

AV15009

Technologies and Practices to Reduce Bruising



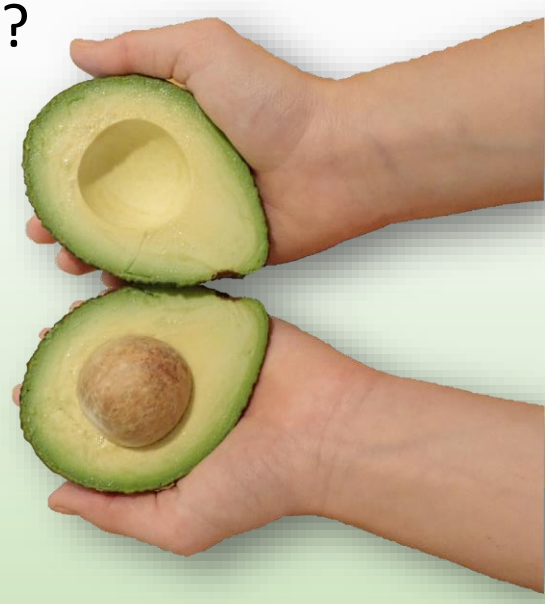
Industry update

Avocados Australia Regional Meeting

Sunshine Coast, Queensland, 2 May 2018

Overview of presentation

- Background
- Project scope
- What is flesh bruising and how is it measured?
- What contributes to flesh bruising in avocado?
- Does impact injury also promote body rots?
- What can be done to reduce bruising?
- Spreading the message
- Where to next?
- Concluding remarks



Background

- Flesh bruising is responsible for around half of all avocado internal defects detected at the retail level[1]
- Defects affecting more than 10% of the flesh can negatively affect consumers' repeat purchasing[2]
- Handling by retailers and shoppers is the main cause of flesh bruising at retail[3]
- Post-purchase handling by consumers causes further bruising[3]

Bruising in 'Hass' fruit handled once by each of 20 different shoppers

1. Tyas, J. (2016). Avocado industry fruit quality benchmarking. Final report AV11015. Horticulture Innovation Australia, Sydney.
2. Harker, F.R.,et al. 2007. Australian consumers' perceptions and preferences for 'Hass' Avocado. Final report AV06025. Horticulture Australia Ltd, Sydney.
3. Joyce, D.C., M.S. Mazhar, and P.J. Hofman (2015). Understanding and managing avocado flesh bruising. Final report AV12009. Horticulture Australia Limited, Sydney, Australia.

Background

- 97% of Australian avocado consumers admit to squeezing fruit to test ripeness[1]
- Shoppers handle 3 times more avocados than they buy[2]
- Awareness of shoppers regarding their contribution to bruising seems to be increasing…

Five years ago…

42% of shoppers agreed that "bad" avocados have been handled or touched too much[1]

Now…

92% of shoppers know that squeezing avocados too hard causes bruising[3]

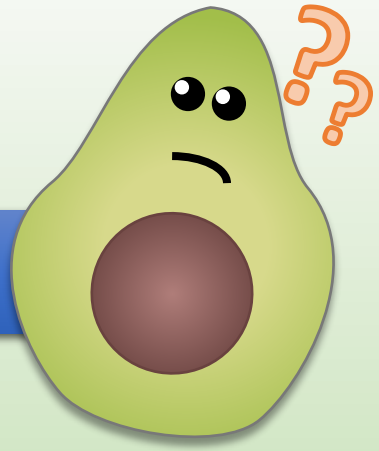
1. Jones, T. (2014). Project avocado education QN. Final report AV12035. Horticulture Australia Limited, Sydney.
2. Joyce, D.C., M.S. Mazhar, and P.J. Hofman (2015). Understanding and managing avocado flesh bruising. Final report AV12009. Horticulture Australia Limited, Sydney, Australia.
3. Quantum Market Research (2017). Avocado buyer segmentation. JN17051. Hort Innovation, Sydney.

Background

But inconsistent quality remains an issue…

- Around 1 in 5 avocados at retail level do not meet consumer expectations for quality[1]
- 45% of avocado shoppers at least sometimes felt dissatisfied with the quality once they had cut into an avocado at home[2]

What is the solution?



1. Tyas, J. (2016). Avocado industry fruit quality benchmarking. Final report AV11015. Horticulture Innovation Australia, Sydney.
2. Quantum Market Research (2017). Avocado buyer segmentation. JN17051. Hort Innovation, Sydney.

Scope of project AV15009

Objectives:

- To qualify influences and interactions that cause and contribute to flesh bruising
- To qualify, develop and promote tools and technologies for reducing flesh bruising at retail

Activity areas:

- Review contributing factors to fruit **susceptibility to bruising** to identify gaps in research
- Review relationships between **disease and flesh bruising** to identify gaps in research
- Document **best practice** to prevent fruit bruising at retail for implementation in retail education
- Develop and test **alternative technologies** that reduce handling by retailers / consumers

AV15009 project team

Daryl Joyce (QDAF)
Project Leader

Project Team Members

Noel Ainsworth (QDAF)

Lindy Coates (QDAF)

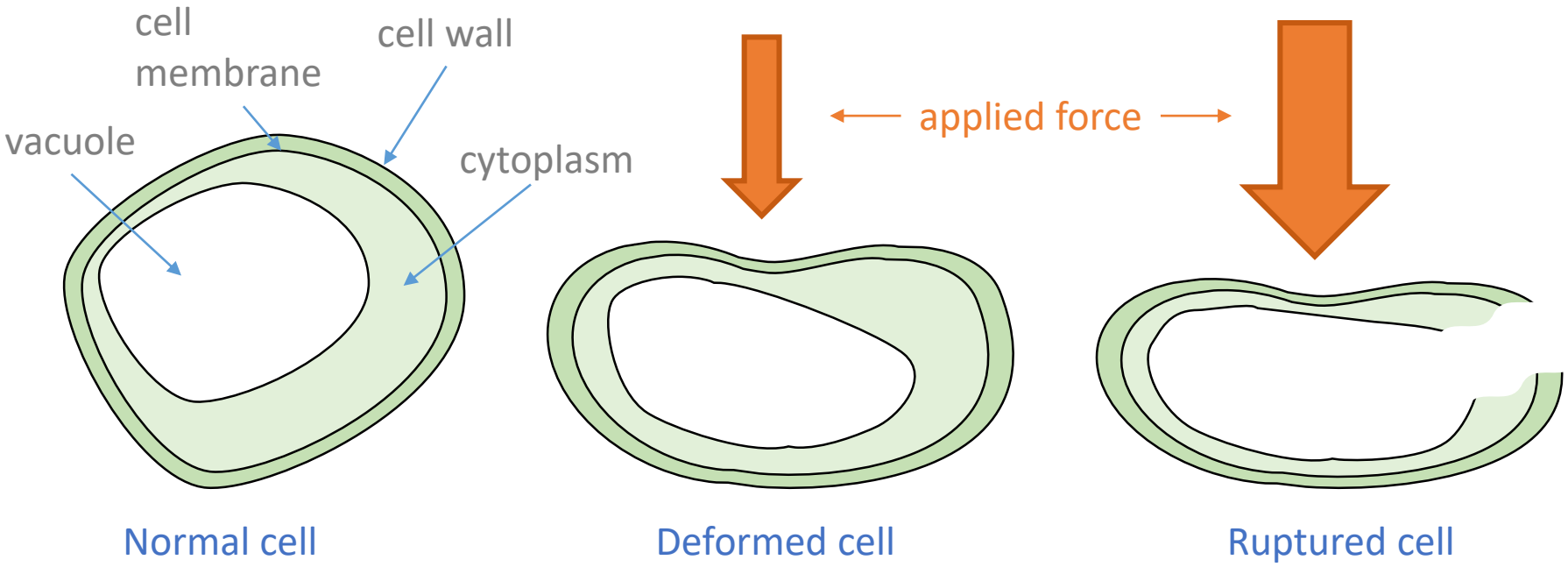
Peter Hofman (QDAF)

Sohail Mazhar (UQ)

Melinda Perkins (UQ)

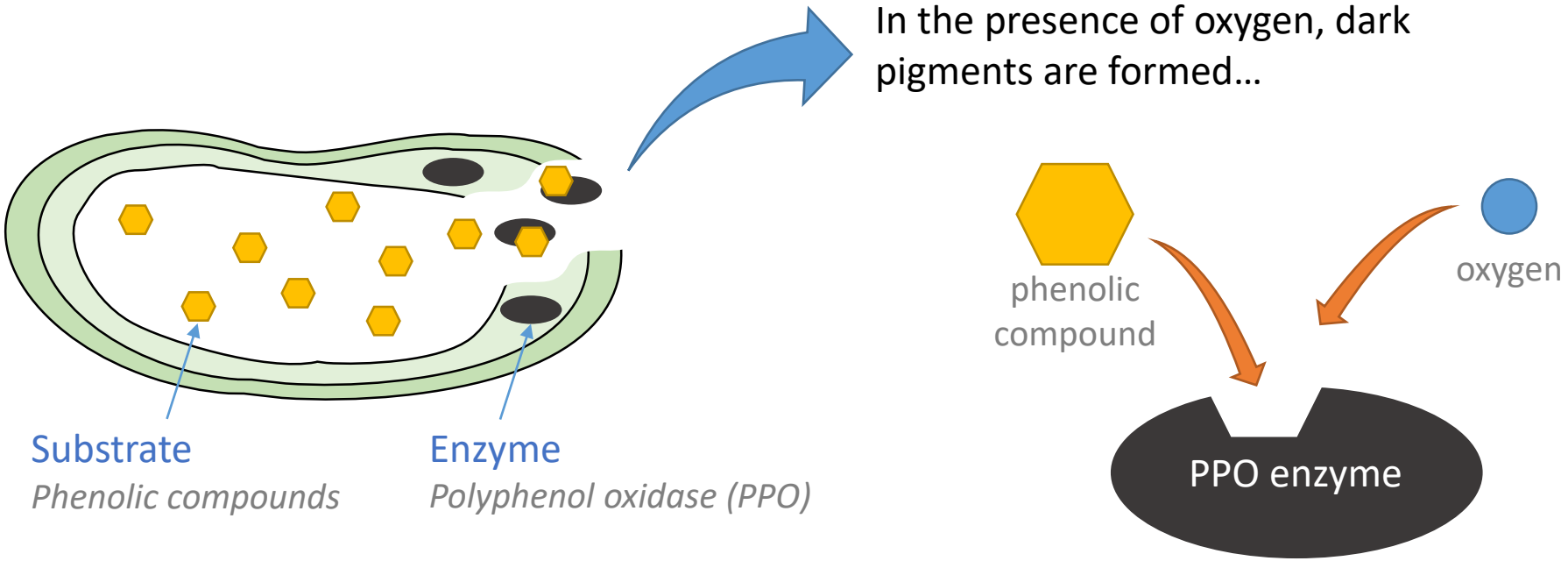
What is flesh bruising?

The bruising process at a cellular level…



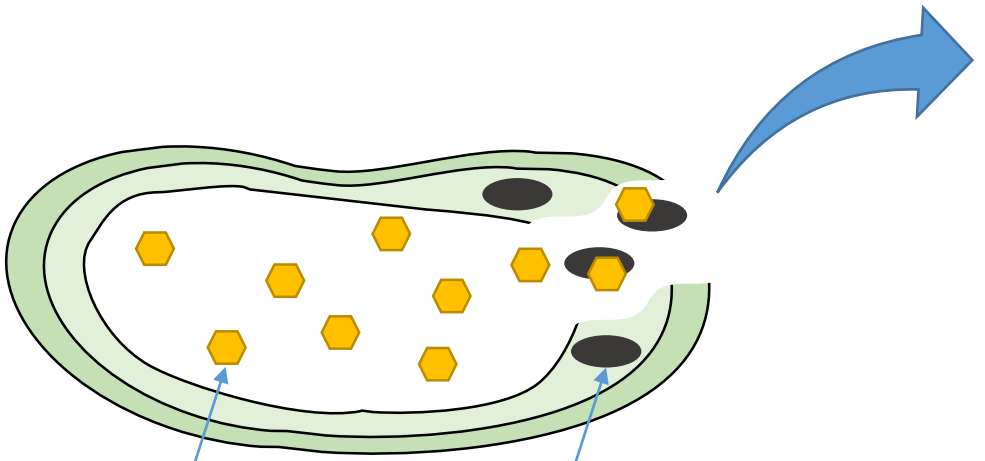
What is flesh bruising?

Cell damage brings together browning enzymes and their substrates…



What is flesh bruising?

Cell damage brings together browning enzymes and their substrates…



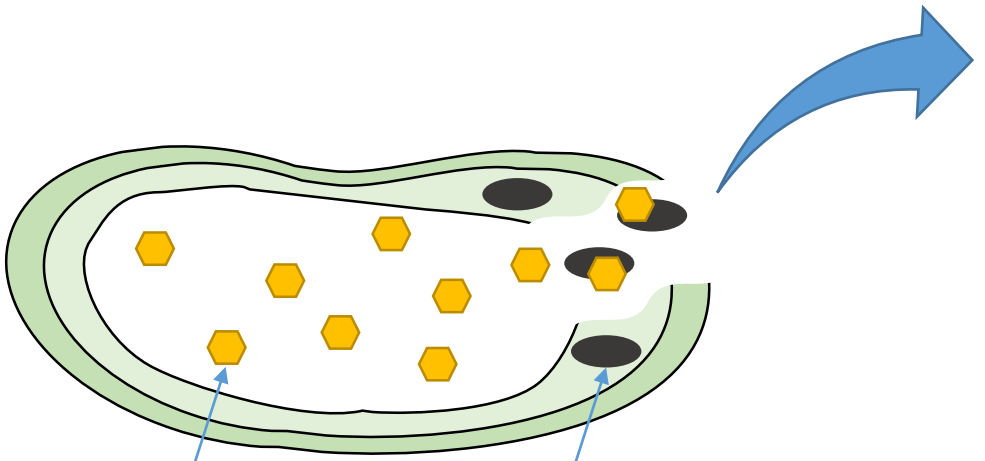
In the presence of oxygen, dark pigments are formed…

Substrate
Phenolic compounds

Enzyme
Polyphenol oxidase (PPO)

What is flesh bruising?

Cell damage brings together browning enzymes and their substrates…



In the presence of oxygen, dark pigments are formed…

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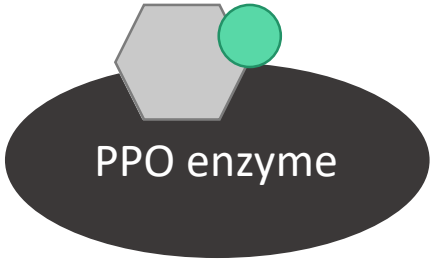
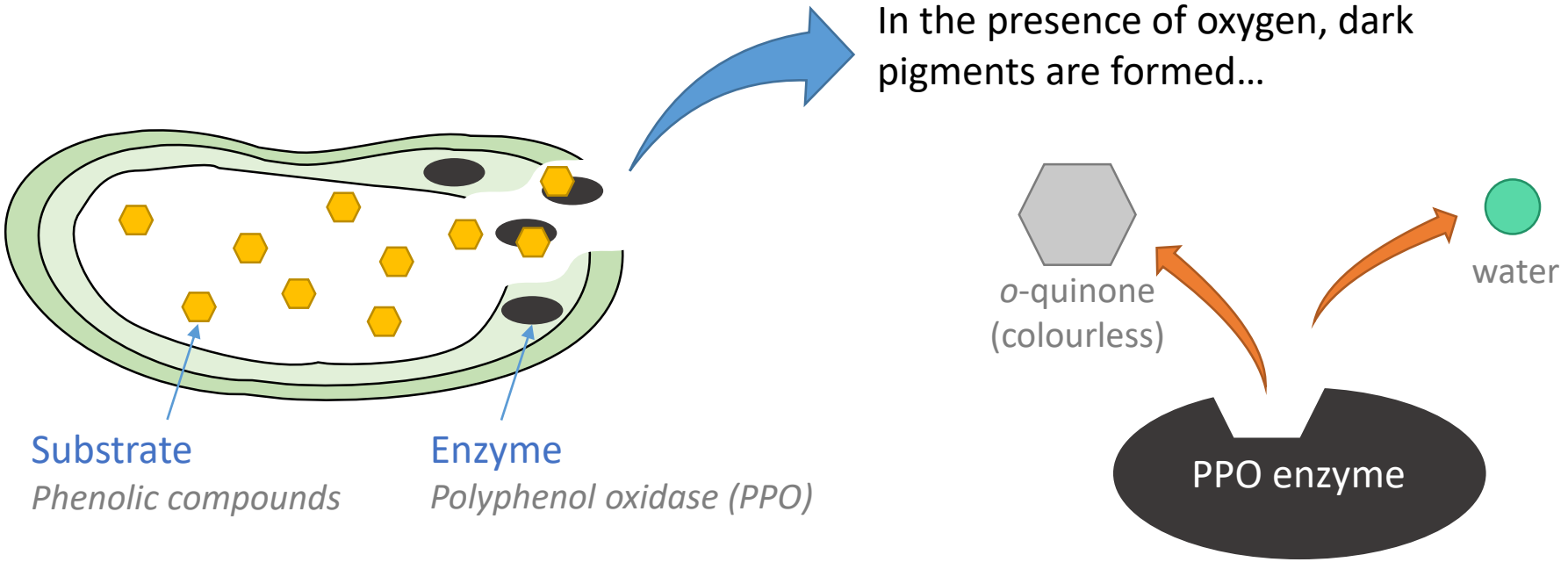


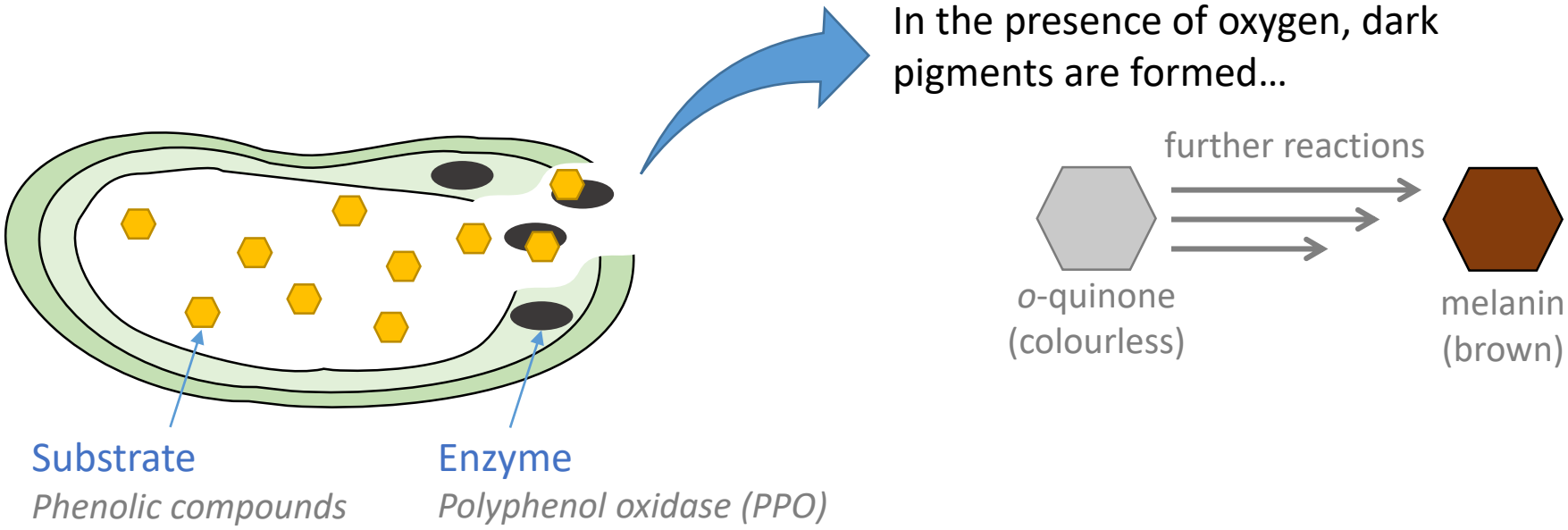
What is flesh bruising?

Cell damage brings together browning enzymes and their substrates…



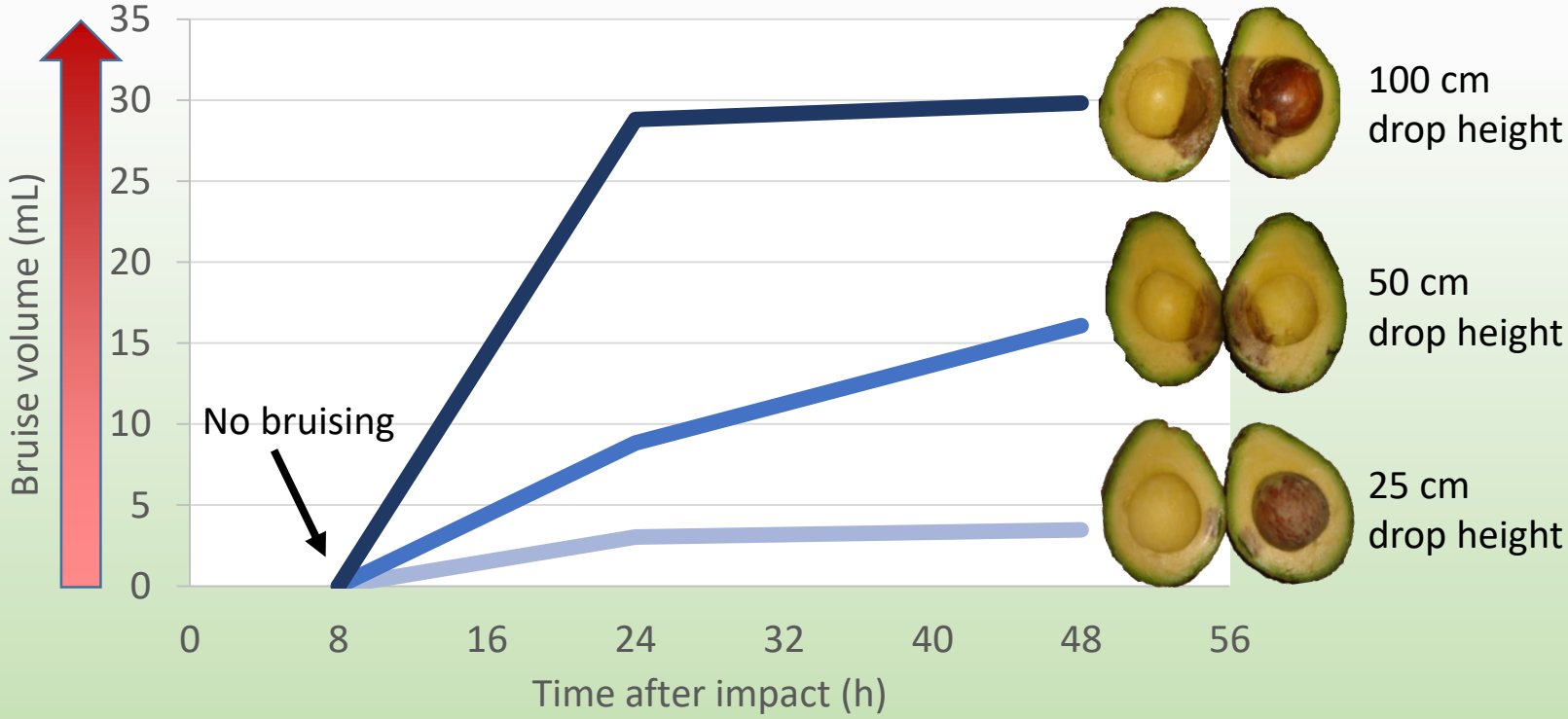
What is flesh bruising?

Cell damage brings together browning enzymes and their substrates…



What is flesh bruising?

- Rate of browning also depends on temperature and pH
- At 20°C, visible bruising can take 24 hours to develop



How is flesh bruising measured?

Bruise incidence

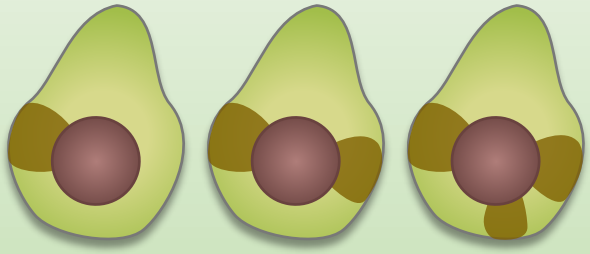
- Number of bruised fruit in a given sample (e.g. tray) of fruit

  Often expressed as a percentage of the total number of fruit

3 out of 10 = 30% incidence

OR…

- Number of bruises on an individual fruit



How is flesh bruising measured?

Bruise severity

- Volume or area of bruised flesh in individual fruit
- May be converted to a percentage of the total fruit flesh volume or area of cut surface
- 10% bruise area is generally considered unacceptable to consumers

5% 10% 15%

How is flesh bruising measured?

Bruise intensity

- Relative darkness of a bruise

  Can be scored visually (e.g. light brown to black) or measured with a colour meter

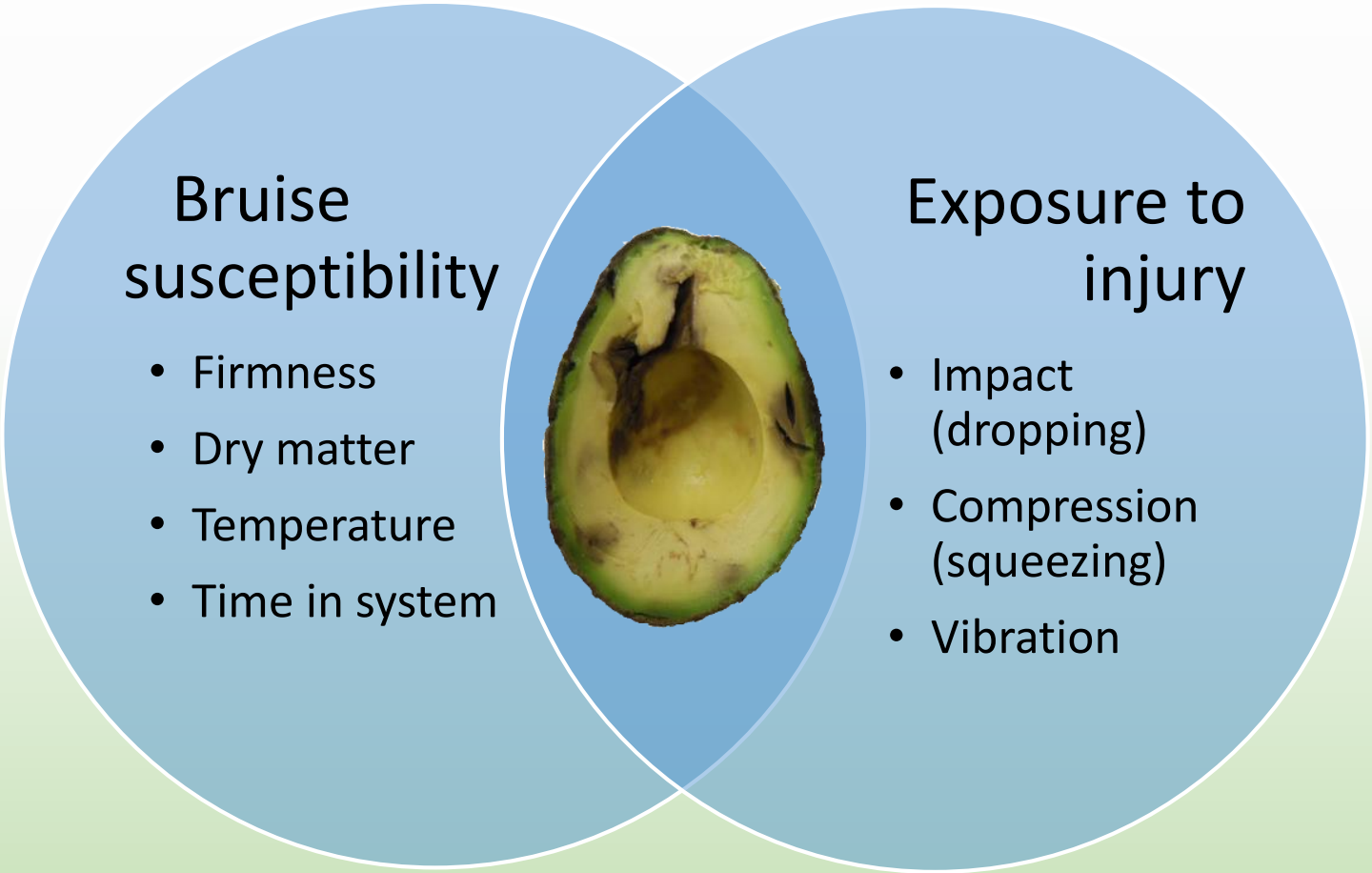
Bruise susceptibility

- Degree of ease or difficulty by which a fruit bruises

  Expressed as ratio of bruise volume to impact energy

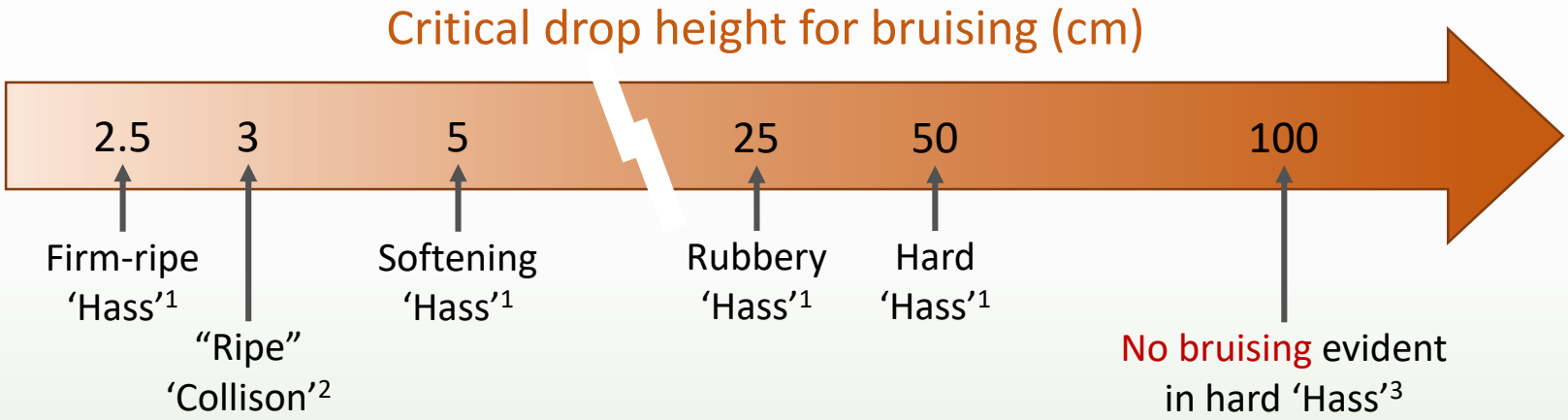
Using a colour meter to measure bruise intensity

What contributes to flesh bruising in avocado?



What contributes to flesh bruising in avocado?

- Firmness



- Dry matter

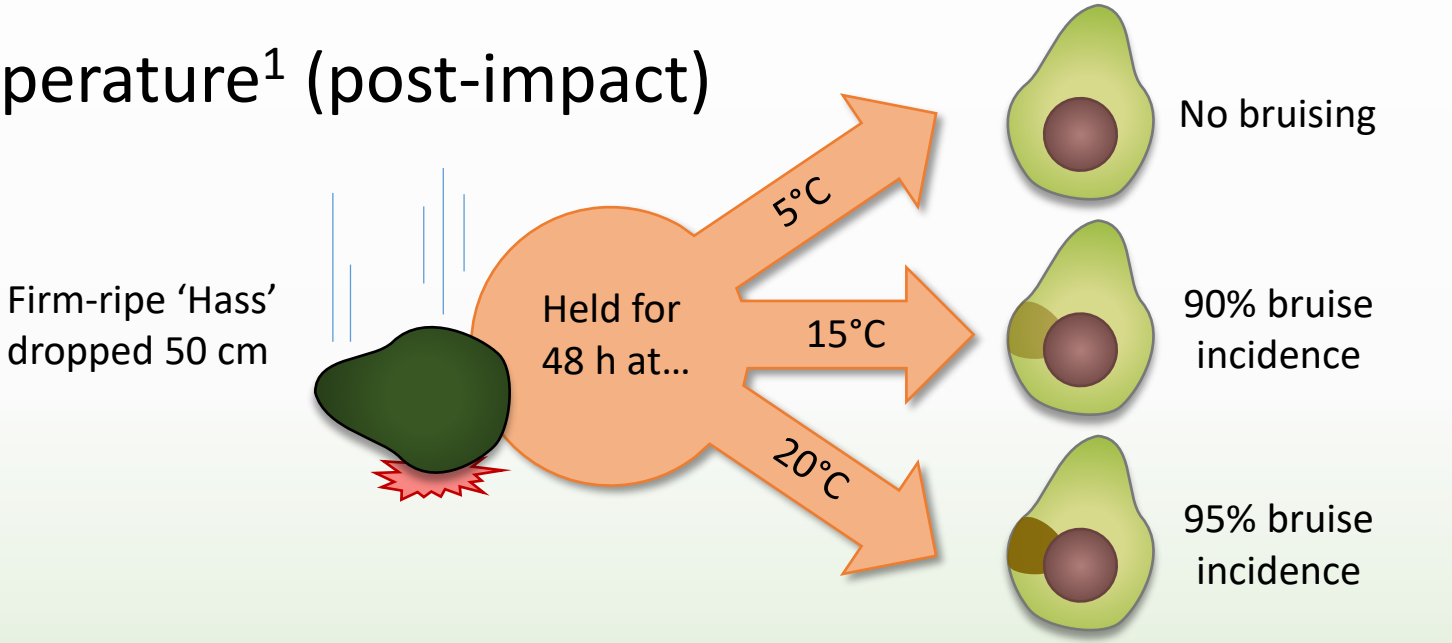
  ↑ dry matter = ↓ bruise susceptibility in firm-ripe 'Hass' avocados subjected to a 50 cm drop height[4]

  Bruise volume progressively decreased as dry matter increased from 22 to 33%

1. Ledger, S.N., Barker, L.R., 1995. Black avocados - the inside story, Australian Avocado Growers Federation Conference - The Way Ahead, pp. 71-77.
2. Baryeh, E.A., 2000. Strength properties of avocado pear. Journal of Agricultural Engineering Research 76, 389-397.
3. Mazhar, M., et al. (2015). Non-destructive 1H-MRI assessment of flesh bruising in avocado (*Persea americana* M.) cv. Hass. Postharvest Biology and Technology 100, 33-40.
4. Joyce, D.C., et al., 2015. Reducing flesh bruising and skin spotting in 'Hass' avocado. Final report AV10019. Horticulture Australia Ltd, Sydney.

What contributes to flesh bruising in avocado?

- Temperature[1] (post-impact)



20°C > 15°C for bruise intensity

- Time in system[1]

  Storage at 5°C for 1 to 5 weeks prior to ripening increased bruise susceptibility of firm-ripe 'Hass' fruit *(vs fruit not stored)*

  ↑ storage duration = ↑ bruise volume

1. Joyce, D.C., et al., 2015. Reducing flesh bruising and skin spotting in 'Hass' avocado. Final report AV10019. Horticulture Australia Ltd, Sydney.

What contributes to flesh bruising in avocado?

Other factors likely to be involved

- Pre-harvest water stress

  Increases PPO activity in avocado fruit at "eating ripeness"[1]

- High turgor pressure at harvest

  Causes greater lenticel damage in avocado fruit[2]

  Linked to increased bruise susceptibility in apple and pear[3]

- Mineral nutrient balance

  Calcium is important for cell wall strength and membrane stability

  Low calcium and/or high nitrogen in avocado fruit → poor quality

  ↑ body rots[4,5], vascular browning[6,7] and mesocarp discolouration[4,6]

  ↓ firmness after storage[8] and time to ripening[4]

1. Bower, J.P., et al., 1989. Effect of pre- and post-harvest water stress on the potential for fruit quality defects in avocado (*Persea americana* Mill.). South African Journal of Plant and Soil 6, 219-222.
2. Everett, K.R., et al., 2008. Avocado lenticel damage: The cause and the effect on fruit quality. Postharvest Biology and Technology 48, 383-390.
3. Garcia, J.L., et al., 1995. Factors influencing mechanical properties and bruise susceptibility of apples and pears. Journal of Agricultural Engineering Research 61, 11-17.
4. Hofman, P.J., et al., 2002. Tree yield and fruit minerals concentrations influence 'Hass' avocado fruit quality. Scientia Horticulturae 92, 113-123.
5. Everett, K.R., et al., 2007. Calcium, fungicide sprays and canopy density influence postharvest rots of avocado. Australasian Plant Pathology 36, 22-31.
6. Marques, J.R., et al., 2003. Rootstocks influence 'Hass' avocado fruit quality and fruit minerals. Journal of Horticultural Science & Biotechnology 78, 673-679.
7. Thorp, T., et al., 1997. Survey of fruit mineral concentrations and postharvest quality of New Zealand-grown 'Hass' avocado (*Persea americana* Mill.). NZ J Crop Hort Sci 25, 251-260.
8. Defilippi, B.G., et al., 2015. Preharvest factors influencing 'Hass' avocado (*Persea americana* Mill.) quality during long term storage. Acta Horticulturae 1071, 137-141.

What contributes to flesh bruising in avocado?

Other factors likely to be involved

- Cultivar

  'Fuerte' > 'Lerman' for total phenolic content and PPO activity[1,2]

  'Hass' > 'Shepard' for peel phenolic concentrations and diversity[3]

- Rootstock

  'Velvick' > 'Duke 6', 'Duke7' or 'Reed' for fruit calcium concentration and quality, when grafted with 'Hass' scion[4-6]

1. Golan, A., et al., 1977. Relationship between polyphenols and browning in avocado mesocarp. Comparison between the Fuerte and Lerman cultivars. Journal of Agricultural and Food Chemistry 25, 1253-1260.
2. Kahn, V., 1975. Polyphenol oxidase activity and browning of three avocado varieties. Journal of the Science of Food and Agriculture 26, 1319-1324.
3. Kosinska, A., et al., 2012. Phenolic compound profiles and antioxidant capacity of *Persea americana* Mill. peels and seeds of two varieties. Journal of Agricultural and Food Chemistry 60, 4613-4619.
4. Coates, L.M., et al., 2011. Effects of rootstock on avocado fruit quality – assessment of postharvest disease, major cations and biochemical traits. Proceedings of the 7th World Avocado Congress, 2011. Cairns, QLD, Australia, 206-214.
5. Marques, J.R., et al., 2003. Rootstocks influence 'Hass' avocado fruit quality and fruit minerals. Journal of Horticultural Science & Biotechnology 78, 673-679.
6. Willingham, S.L., et al., 2006. Effects of rootstock and nitrogen fertiliser on postharvest anthracnose development in Hass avocado. Australasian Plant Pathology 35, 619-629.

Does impact injury also promote body rots?

- Freshly harvested fruit generally do not bruise if dropped
- But… *they appear to be more prone to body rots upon ripening!*
- 30 cm drop height at harvest caused ↑ body rots at soft-ripe stage *(versus no impact at harvest)*
- Response was consistent for ‘Hass’ fruit harvested from two orchards in different seasons

Impact from 30 cm drop height

No impact

What can be done to reduce bruising?

- Improve fruit robustness
  - Harvest when dry matter is above 23%
  - Pass fruit through the supply chain as quickly as possible
  - Hold ripened fruit at 5°C
  - Ensure that trees receive adequate water
  - Avoid harvesting fruit when wet
  - Select cultivars that produce fruit with low browning potential
  - Select rootstock cultivars that promote Ca accumulation in fruit

More evidence needed

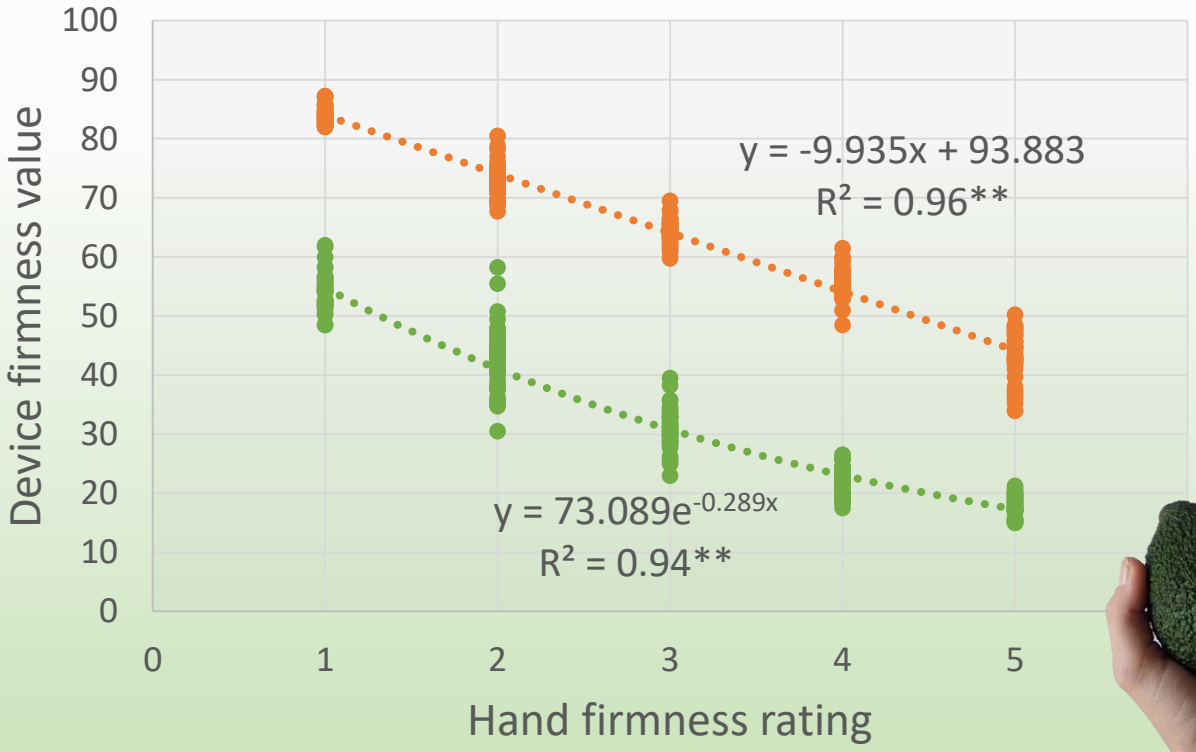
What can be done to reduce bruising?

- Limit exposure to injury
  - Keep drop heights below 15 cm for hard green mature fruit *(to reduce body rots upon ripening)*
  - Keep drop heights below 10 cm for softening fruit
  - Handle fruit carefully without dropping or excessive squeezing from firm-ripe stage onwards
  - Train retail staff in appropriate handling techniques
  - Arrange retail displays into ripeness categories
  - Provide point of sale information on fruit selection for ripeness
  - Provide shoppers with 'pre-pack' options
  - Inform consumers of appropriate in-home handling and storage techniques

More evidence needed

What can be done to reduce bruising?

- Non-bruising devices for in-store firmness assessment



** P < 0.01

Spreading the message

- Articles in *Talking Avocados*
  - New Hort Innovation project to combat flesh bruising in avocado
    Summer 2017 edition
  - Factors affecting avocado flesh bruising susceptibility
    Winter 2017 edition, http://www.avocado.org.au/public-articles/tav28n2_bruising/
  - Best practice handling to reduce flesh bruising
    Summer 2018 edition, http://www.avocado.org.au/public-articles/tav28n4_bruising/
  - Does impact injury at harvest increase body rots at retail?
    Autumn 2018 edition
- Meetings and workshop
  - Avocados Australia 2018 Regional Meetings - Queensland
    Crows Nest, Sunshine Coast, Childers & Mareeba (1 May – 7 June)
  - AV15009 Stakeholder Knowledge Sharing Workshop
    Brisbane Markets (15 May 2018)

Spreading the message

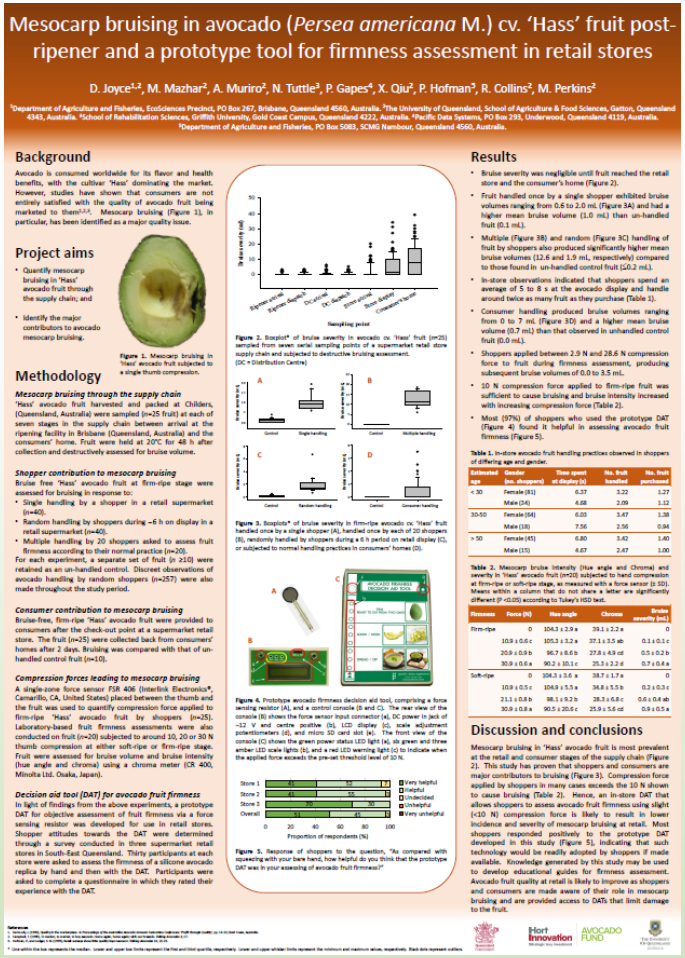
- Poster presentation at TropAg2017 Conference

  *Shopper and consumer contribution to mesocarp bruising in avocado (*Persea americana *M.) cv. 'Hass' fruit and a prototype decision aid tool for in-store firmness assessment*

  - Brisbane, 20-22 November
  - Conference attendance: 720 delegates from 46 countries

- YouTube video

  In production, due for release mid-2018



Mesocarp bruising in avocado (*Persea americana* M.) cv. 'Hass' fruit post-ripener and a prototype tool for firmness assessment in retail stores

D. Joyce[1,2], M. Mazhar[2], A. Muriro[2], N. Tuttle[3], P. Gapes[4], X. Qiu[2], P. Hofman[2], R. Collins[2], M. Perkins[2]

[1]Department of Agriculture and Fisheries, EcoSciences Precinct, PO Box 267, Brisbane, Queensland 4560, Australia. [2]The University of Queensland, School of Agriculture & Food Sciences, Gatton, Queensland 4343, Australia. [3]School of Rehabilitation Sciences, Griffith University, Gold Coast Campus, Queensland 4222, Australia. [4]Pacific Data Systems, PO Box 293, Underwood, Queensland 4119, Australia. [5]Department of Agriculture and Fisheries, PO Box 5083, SCMG Nambour, Queensland 4560, Australia.

Background

Project aims

Methodology

Results

Discussion and conclusions

Where to next?

- Current project (June – October 2018)
  - Monitor fruit quality through two prominent supply chains

    Queensland → Victoria *Western Australia → Victoria*

  - Simulate supply chain conditions in the laboratory

    best practice vs poor practice → final fruit quality

Where to next?

- Concept note submitted to Hort Innovation for future research into:
  - Orchard management practices for effects on bruise susceptibility and postharvest disease expression in ripe fruit at retail level
  - Development of decision aid tools to optimize orchard management and fruit robustness from farm to consumer

There is currently no published research on avocado bruise susceptibility in response to tree vigour, crop load and nutrition!

Concluding remarks

Based on current knowledge, there are changes in harvesting and handling practices that can be made now to reduce flesh bruising

- Harvest above 23% dry matter and when fruit are not wet
- Minimise drop heights – handle ripe fruit "like eggs"
- Maintain fruit temperature of 5°C (except when ripening)
- Pass fruit through the supply chain as quickly as possible

But…

There are many other factors likely to affect flesh bruising at retail

We need to confirm and quantify their contribution…

…and estimate the economic consequences to industry!

Acknowledgements

AV15009 is funded by Hort Innovation, using the Hort Innovation Avocado research and development levy, co-investment from the Queensland Department of Agriculture and Fisheries, the University of Queensland, Avocados Australia Ltd and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

The Project Team also wishes to acknowledge the contributions made by Murray Brothers, Farmgate 1411, Redbank Plantation, Brett Jahnke and technical staff and students of the UQ School of Agriculture and Food Sciences.

Mesocarp bruising in avocado (*Persea americana* M.) cv. 'Hass' fruit post-ripener and a prototype tool for firmness assessment in retail stores

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Background

Avocado is consumed worldwide for its flavor and health benefits, with the cultivar 'Hass' dominating the market. However, studies have shown that consumers are not entirely satisfied with the quality of avocado fruit being marketed to them[1,2,3]. Mesocarp bruising (Figure 1), in particular, has been identified as a major quality issue.

Project aims

- Quantify mesocarp bruising in 'Hass' avocado fruit through the supply chain; and
- Identify the major contributors to avocado mesocarp bruising.

Figure 1. Mesocarp bruising in 'Hass' avocado fruit subjected to a single thumb compression.

Methodology

Mesocarp bruising through the supply chain

'Hass' avocado fruit harvested and packed at Childers, (Queensland, Australia) were sampled (*n*=25 fruit) at each of seven stages in the supply chain between arrival at the ripening facility in Brisbane (Queensland, Australia) and the consumers' home. Fruit were held at 20°C for 48 h after collection and destructively assessed for bruise volume.

Shopper contribution to mesocarp bruising

Bruise free 'Hass' avocado fruit at firm-ripe stage were assessed for bruising in response to:

- Single handling by a shopper in a retail supermarket (*n*=40).
- Random handling by shoppers during ~6 h on display in a retail supermarket (*n*=40).
- Multiple handling by 20 shoppers asked to assess fruit firmness according to their normal practice (*n*=20).

For each experiment, a separate set of fruit (*n* ≥10) were retained as an un-handled control. Discreet observations of avocado handling by random shoppers (*n*=257) were also made throughout the study period.

Consumer contribution to mesocarp bruising

Bruise-free, firm-ripe 'Hass' avocado fruit were provided to consumers after the check-out point at a supermarket retail store. The fruit (*n*=25) were collected back from consumers' homes after 2 days. Bruising was compared with that of un-handled control fruit (*n*=10).

Compression forces leading to mesocarp bruising

A single-zone force sensor FSR 406 (Interlink Electronics®, Camarillo, CA, United States) placed between the thumb and the fruit was used to quantify compression force applied to firm-ripe 'Hass' avocado fruit by shoppers (*n*=25). Laboratory-based fruit firmness assessments were also conducted on fruit (*n*=20) subjected to around 10, 20 or 30 N thumb compression at either soft-ripe or firm-ripe stage. Fruit were assessed for bruise volume and bruise intensity (hue angle and chroma) using a chroma meter (CR 400, Minolta Ltd. Osaka, Japan).

Decision aid tool (DAT) for avocado fruit firmness

In light of findings from the above experiments, a prototype DAT for objective assessment of fruit firmness via a force sensing resistor was developed for use in retail stores. Shopper attitudes towards the DAT were determined through a survey conducted in three supermarket retail stores in South-East Queensland. Thirty participants at each store were asked to assess the firmness of a silicone avocado replica by hand and then with the DAT. Participants were asked to complete a questionnaire in which they rated their experience with the DAT.

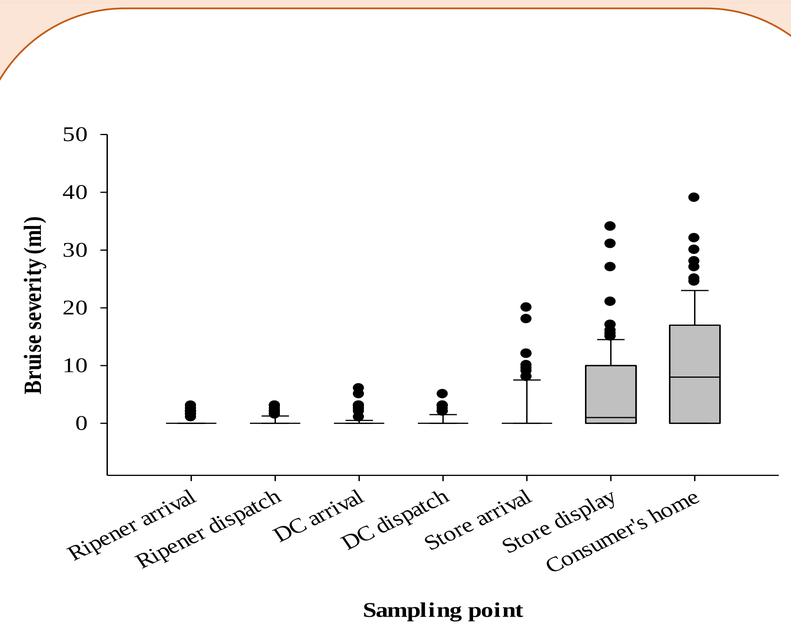

Figure 2. Boxplot* of bruise severity in avocado cv. 'Hass' fruit (*n*=25) sampled from seven serial sampling points of a supermarket retail store supply chain and subjected to destructive bruising assessment. (DC = Distribution Centre)

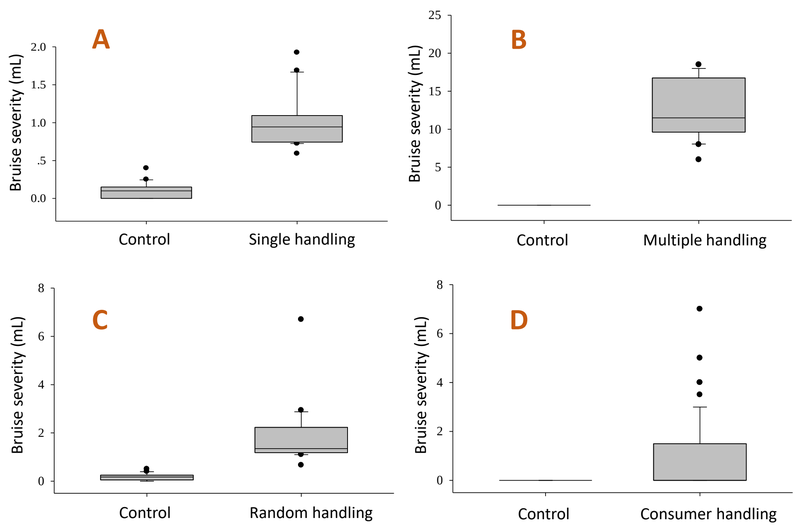

Figure 3. Boxplots* of bruise severity in firm-ripe avocado cv. 'Hass' fruit handled once by a single shopper (A), handled once by each of 20 shoppers (B), randomly handled by shoppers during a 6 h period on retail display (C), or subjected to normal handling practices in consumers' homes (D).

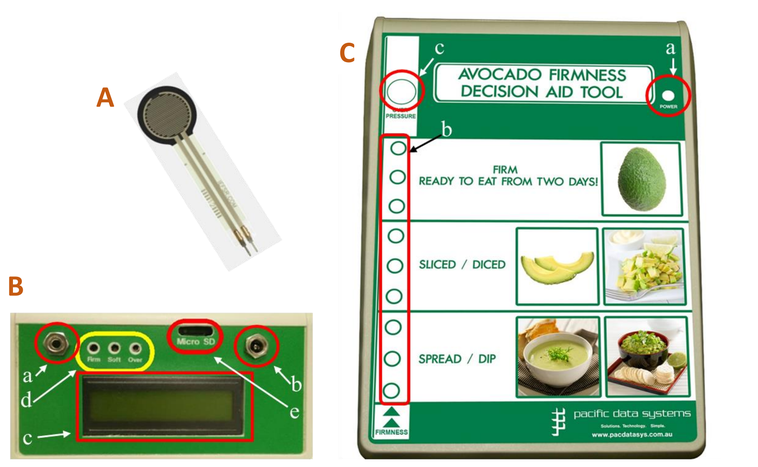

Figure 4. Prototype avocado firmness decision aid tool, comprising a force sensing resistor (A), and a control console (B and C). The rear view of the console (B) shows the force sensor input connector (a), DC power in jack of ~12 V and centre positive (b), LCD display (c), scale adjustment potentiometers (d), and micro SD card slot (e). The front view of the console (C) shows the green power status LED light (a), six green and three amber LED scale lights (b), and a red LED warning light (c) to indicate when the applied force exceeds the pre-set threshold level of 10 N.

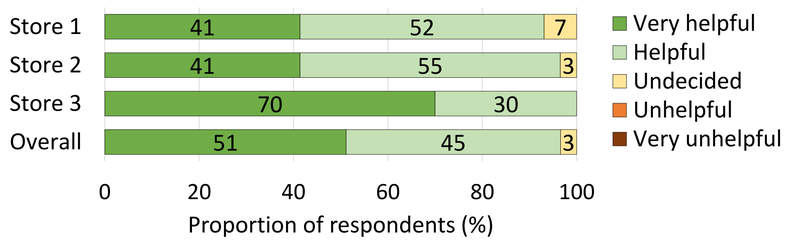

Figure 5. Response of shoppers to the question, "As compared with squeezing with your bare hand, how helpful do you think that the prototype DAT was in your assessing of avocado fruit firmness?"

Results

- Bruise severity was negligible until fruit reached the retail store and the consumer's home (Figure 2).
- Fruit handled once by a single shopper exhibited bruise volumes ranging from 0.6 to 2.0 mL (Figure 3A) and had a higher mean bruise volume (1.0 mL) than un-handled fruit (0.1 mL).
- Multiple (Figure 3B) and random (Figure 3C) handling of fruit by shoppers also produced significantly higher mean bruise volumes (12.6 and 1.9 mL, respectively) compared to those found in un-handled control fruit (≤0.2 mL).
- In-store observations indicated that shoppers spend an average of 5 to 8 s at the avocado display and handle around twice as many fruit as they purchase (Table 1).
- Consumer handling produced bruise volumes ranging from 0 to 7 mL (Figure 3D) and a higher mean bruise volume (0.7 mL) than that observed in unhandled control fruit (0.0 mL).
- Shoppers applied between 2.9 N and 28.6 N compression force to fruit during firmness assessment, producing subsequent bruise volumes of 0.0 to 3.5 mL.
- 10 N compression force applied to firm-ripe fruit was sufficient to cause bruising and bruise intensity increased with increasing compression force (Table 2).
- Most (97%) of shoppers who used the prototype DAT (Figure 4) found it helpful in assessing avocado fruit firmness (Figure 5).

Table 1. In-store avocado fruit handling practices observed in shoppers of differing age and gender.

Estimated age	Gender (no. shoppers)	Time spent at display (s)	No. fruit handled	No. fruit purchased
< 30	Female (81)	6.37	3.22	1.27
	Male (34)	4.68	2.09	1.12
30-50	Female (64)	6.03	3.47	1.38
	Male (18)	7.56	2.56	0.94
> 50	Female (45)	6.80	3.42	1.40
	Male (15)	4.67	2.47	1.00

Table 2. Mesocarp bruise intensity (Hue angle and Chroma) and severity in 'Hass' avocado fruit (*n*=20) subjected to hand compression at firm-ripe or soft-ripe stage, as measured with a force sensor (± SD). Means within a column that do not share a letter are significantly different (P <0.05) according to Tukey's HSD test.

Firmness	Force (N)	Hue angle	Chroma	Bruise severity (mL)
Firm-ripe	0	104.3 ± 2.9 a	39.1 ± 2.2 a	0
	10.9 ± 0.6 c	105.3 ± 3.2 a	37.1 ± 3.5 ab	0.1 ± 0.1 c
	20.9 ± 0.9 b	96.7 ± 8.6 b	27.8 ± 4.9 cd	0.5 ± 0.2 b
	30.9 ± 0.6 a	90.2 ± 10.1 c	25.3 ± 2.2 d	0.7 ± 0.4 a
Soft-ripe	0	104.3 ± 3.6 a	38.7 ± 1.7 a	0
	10.9 ± 0.5 c	104.9 ± 5.5 a	34.8 ± 5.5 b	0.2 ± 0.3 c
	21.1 ± 0.8 b	98.1 ± 9.2 b	28.3 ± 6.8 c	0.6 ± 0.4 ab
	30.9 ± 0.8 a	90.5 ± 20.6 c	25.9 ± 5.6 cd	0.9 ± 0.5 a

Discussion and conclusions

Mesocarp bruising in 'Hass' avocado fruit is most prevalent at the retail and consumer stages of the supply chain (Figure 2). This study has proven that shoppers and consumers are major contributors to bruising (Figure 3). Compression force applied by shoppers in many cases exceeds the 10 N shown to cause bruising (Table 2). Hence, an in-store DAT that allows shoppers to assess avocado fruit firmness using slight (<10 N) compression force is likely to result in lower incidence and severity of mesocarp bruising at retail. Most shoppers responded positively to the prototype DAT developed in this study (Figure 5), indicating that such technology would be readily adopted by shoppers if made available. Knowledge generated by this study may be used to develop educational guides for firmness assessment. Avocado fruit quality at retail is likely to improve as shoppers and consumers are made aware of their role in mesocarp bruising and are provided access to DATs that limit damage to the fruit.

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* Line within the box represents the median. Lower and upper box limits represent the first and third quartile, respectively. Lower and upper whisker limits represent the minimum and maximum values, respectively. Black dots represent outliers.

Queensland Government
Hort Innovation Strategic levy investment
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Technologies and Practices to Reduce Flesh Bruising in Avocado Fruit

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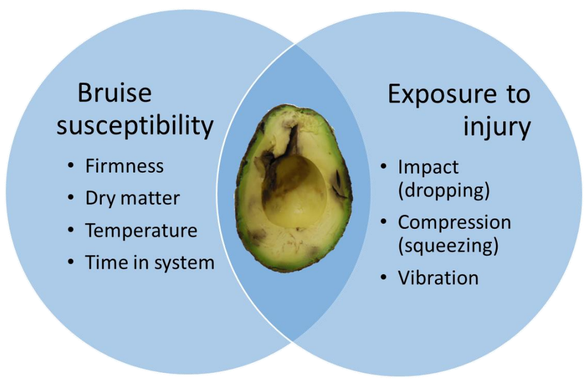
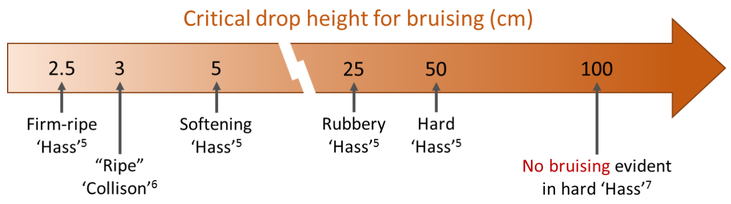
Background

- Flesh bruising is responsible for around half of all avocado internal defects detected at the retail level[1]
- Internal defects affecting more than 10% of the flesh can negatively affect consumers' repeat purchasing[2]
- Handling by retailers and shoppers is the main cause of flesh bruising at retail[3]
- Post-purchase handling by consumers causes further bruising[3]
- 97% of Australian avocado consumers admit to squeezing fruit to test ripeness[4]
- Shoppers handle 3 times more avocados than they buy[3]

What contributes to flesh bruising in avocado?



Firmness



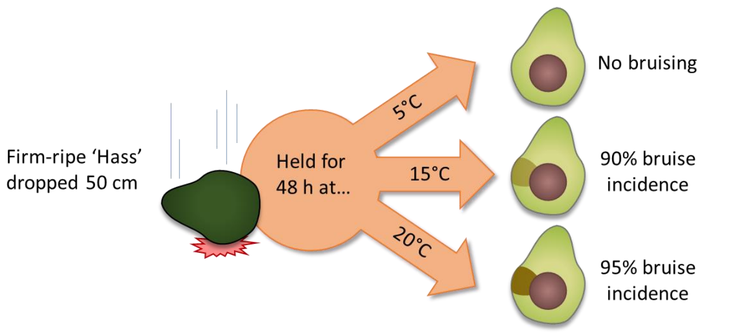
Dry matter

- For firm-ripe 'Hass' avocados subjected to a 50 cm drop height:

  ↑ dry matter = ↓ bruise susceptibility[8]

- Bruise volume progressively decreased as dry matter increased from 22 to 33%[8]

Temperature (post-impact)[8]



20°C > 15°C for bruise intensity

Time in system

- Storage at 5°C for 1 to 5 weeks prior to ripening increased bruise susceptibility of firm-ripe 'Hass' fruit[8] *(vs fruit not stored)*

  ↑ storage duration = ↑ bruise volume[8]

Bruising in 'Hass' fruit handled once by each of 20 different shoppers.

Does impact injury also promote body rots?

- Freshly harvested fruit generally do not bruise if dropped[7]
- **But… they appear to be more prone to body rots upon ripening!**
- 30 cm drop height at harvest caused ↑ body rots at soft-ripe stage *(vs no impact at harvest)*
- Response was consistent for 'Hass' fruit harvested from two orchards in different seasons

Impact from 30 cm drop height

No impact

Other likely contributors to flesh bruising

Pre-harvest water stress

- Increases PPO activity in avocado fruit at "eating ripeness"[9]

High turgor pressure at harvest

- Causes greater lenticel damage in avocado fruit[10]
- Linked to increased bruise susceptibility in apple and pear[11]

Mineral nutrient balance

- Calcium is important for cell wall strength and membrane stability[12]
- Low calcium (Ca), high nitrogen (N) and/or low N:Ca ratio in avocado fruit → poor quality in terms of:
  - ↑ *body rots*[13,14]
  - ↑ *vascular browning*[15,16]
  - ↑ *mesocarp discolouration*[13,15]
  - ↓ *firmness after storage*[17]
  - ↓ *time to ripening*[13]

Cultivar

- 'Fuerte' > 'Lerman'
  for total phenolic content and PPO activity[18,19]
- 'Hass' > 'Shepard'
  for peel phenolic concentrations and diversity[20]

Rootstock

- 'Velvick' > 'Duke 6', 'Duke7' or 'Reed' for fruit Ca concentration and quality, when grafted with 'Hass' scion[15,21,22]

What can be done to reduce flesh bruising?

Improve fruit robustness

- Harvest when dry matter is above 23%
- Pass fruit through the supply chain as quickly as possible
- Hold ripened fruit at 5°C
- Ensure that trees receive adequate water
- Avoid harvesting fruit when wet
- Select cultivars that produce fruit with low browning potential
- Select rootstock cultivars that promote Ca accumulation in fruit

More evidence needed

Limit exposure to injury

- Keep drop heights below 15 cm for hard green mature fruit *(to reduce body rots upon ripening)*
- Keep drop heights below 10 cm for softening fruit
- Handle fruit carefully without dropping or excessive squeezing from firm-ripe stage onwards
- Train retail staff in appropriate handling techniques
- Arrange retail displays into ripeness categories
- Provide point of sale information on fruit selection for ripeness
- Provide shoppers with 'pre-pack' options
- Inform consumers of appropriate in-home handling and storage techniques

More evidence needed

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REPORT ON THE 'AVOCADO BRAINSTORMING 2018' CONFERENCE HELD IN TZANEEN, SOUTH AFRICA 28 MAY TO 1 JUNE 2018

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PROGRAMME

Monday 28 May

7:45 am – 12:30 pm	Optional field trip to **Allesbeste Nursery and high density (trellised) plantings** hosted by Andre and Zander Ernst
12:30 pm	Lunch
2:30 pm – 4:30 pm	**Providing for the consumer: Health, safety, flavour**
	Co-chairs: Nikki Ford, Lise Korsten & David Obenland
4:30 pm	High tea
6:00 pm	**New technology to improve avocado production**
	Co-chairs: Nicki Taylor & Mark Buhl
8:15 pm	Dinner

Tuesday 29 May

8:30 am	**Challenges to productivity: diseases**
	Co-chairs: Randy Ploetz and Kerry Everett
11:00 am	**Challenges to productivity: how the tree regulates return bloom and crop load**
	Co-chairs: Harley Smith, Rodrigo Iturrieta & Vered Irihimovitch
1:00 pm	Lunch
4:00 pm	**Poster session 1**
6:00 pm	**Where theory meets practice**
	Co-chairs: Francisco Mena & Ben Faber
8:15 pm	Dinner

Wednesday 30 May

Field day hosted by Westfalia Estates

7:15 am	Depart for field day
7:30 am	African welcome at packing shed, breakfast at Ramalea guesthouse
9:30 am	Avocado rootstock screening tour: visit to 'killing fields', 30 years of rootstock selection. Westfalia heritage tour: Dr Hans Merensky Conservation Heritage, visit to clone of original 'Hass' tree, cultivar display
12:30 pm	Lunch
1:00 pm	Depart for Soekmekaar
2:00 pm	Avocado cultivar and rootstock field trials: 6 different cultivars being tested on 5 different rootstocks, and Gem® and Hass being tested on 11 different rootstocks. Gem® being tested under shade netting, pros and cons.
5: 15 pm	Braaivleis (BBQ) at Westfalia

Thursday 31May

8:30 am	**Challenges to productivity: genetics, genomics and biotechnology**
	Co-chairs: Aurelliano Bombareley & Iñaki Hormaza
11:00 am	**Meeting the challenges of the future**
	Co-chairs: Mary Lu Arpaia, Zelda Van Rooyen & Tim Spann
1:00 pm	Lunch
4:00 pm	**Poster session 2**
6:00 pm	Tying the loose pieces together – planning for the future
	Co-chairs: Jose Chaparro & Nigel Wolstenholme
8:15 pm	Dinner

Friday 1 June

8:00 am – 1:00 pm	Optional field trip to **Nick and Nelius Human's net structure (20% and 40% shade) with Maluma, Hass and Carmen Hass,** then visit **ZZ2 orchards at Mooketsi to inspect compost tea, compost making and orchards.** Lunch provided by ZZ2.

ALLESBESTE NURSERY AND ORCHARDS

The day started with a briefing delivered at the hotel and then proceeded with a trip to some of their orchards and their nursery. Allesbeste's operations commenced in 1927 with citrus and timber but greening disease wiped out the citrus. The nursery was established in 1980 and has developed one of only two avocado cloning techniques used around the world today. Micro management, continual improvement and sharing information are central to their business philosophy. They believe that through sharing information and interacting with others they will learn and improve their own understanding. An example of this approach is demonstrated by the 'Maluma®' conference they organise each year. The Ernst family hold the variety rights for the Maluma® variety which they are actively promoting around the world. They share the philosophy promoted by the late Jan Toerien (former researcher and general manager of Westfalia) who believed that researchers should be integrated with producers and have constant interaction.

Avocados in the Tzaneen region

ALLESBESTE NURSERY

The visit was hosted by owners Andre and Zander Ernst and manager Abram de Villiers.

They have an avocado nursery accreditation scheme in South Africa (same intended purpose as Australia's ANVAS nursery scheme) and Allesbeste has always achieved a five star (top) rating.

Maintaining a disease-free nursery – a copper sulphate footbath for everyone entering.

Potting mix and electrical conductivity

After using various potting mixes over the years Allesbeste now uses 'coir-peat' (also known as 'coco-peat') which is made entirely from coconut husk and is imported, already fumigated, from Sri Lanka. Apart from some slow release fertiliser ('Multicote 8' slow release fertiliser with 8 months longevity, or 'Osmocote mini' which has smaller granules) nothing else is used in the potting mix.

They use a grade that is 70:30 coarse:fine coir fibres. It has 20 – 25% porosity with an average pH of 5.5. Great importance is placed on regular monitoring of the electrical conductivity of the potting mix at different stages of the tree production process, it mustn't be too high or too low. The ideal range is 1.3 to 1.8 mS/cm.

Left: Filling potting bags with 'coco-peat' which is now the only ingredient of the potting mix apart from slow release fertiliser. Right: Successfully germinated seed are planted in these micro pots. Note the raised concrete benches for disease prevention.

Producing clonal trees

Allesbeste employs 50 people in their nursery. They no longer produce grafted seedling trees, only clonal trees. 400,000 avocado seed are planted each year to yield about 200,000 clonal trees (thus 50% yield overall). Trees sell for the equivalent of USD10 each.

Avocado seed is sterilised in a water bath at 50°C for 30 minutes then planted in trays to germinate. Preferred air temperature is 27°C. After about 12 to 15 days each seed is inspected and when root growth has developed sufficiently it is transferred to a planter pot.

Seedlings are 'whip' grafted using a two-bud piece of grafting wood of the variety which will be the future rootstock (e.g. 'Dusa®') and the plants treated with anti-transpirant. The best graft 'takes' and root development are achieved when grafting is done 21 days after roots develop on the original seedlings. A plant with two stems (one from each of the two buds) develops so that two trees can be produced from the one seedling. Once the grafts have taken and grown sufficiently plants are graded for uniformity then placed into a totally dark etiolation chamber. Etiolation brings the plants back to juvenility. Once sufficiently etiolated the plants are brought out of the chamber into a light room at 26°C and 55% humidity. The etiolated stems of the clonal rootstocks are nicked with a sharp blade and the cut treated with a drop of 0.7% IBA solution (carried in methylated spirits) to encourage root development. A micro-pot is threaded down the stem to cover this hormone treated area of the stem and filled with potting mix. The micro-pot is held in place with a stiff wire. After the plant has greened up again and established roots (usually about 20 days after the root primordia appear within the micro-pot) the clonal rootstock is whip grafted to the intended scion variety (e.g. Hass) and wrapped with PVC tape (not parafilm). Scion material is kept in a damp cloth held at 7°C. They achieve 95% take on the first graft attempt and 65 – 80% on the second attempt for those that failed the first time.

Plants are kept under misters using ozone treated water and sprayed weekly with fungicide. When sufficiently established they are severed from the mother seedling plant, the PVC tape cut off, plants staked and painted with white acrylic paint against sunburn and hardened off. The seedlings can then be recycled i.e. put back into the production line to be grafted again etc.

Trees are either kept in these micro-pots for transport to 'satellite' nurseries or re-potted into 7 L bags and grown out till ready for planting in the orchard. If they are to be re-potted each plantlet is removed from its micro pot and the root system examined. If it is not sufficiently advanced it is returned to its micro pot and given longer to develop. If the temperature is too low roots won't develop all the way around the former stem. The multiple air holes in the bottom third of the 7 litre bags are considered essential. CCA treated tree stakes are used and are colour coded with tape. Trunks are painted to protect them from sunburn.

Each planter bag has a label that identifies the specific tree (not just the variety) that the seed came from. This labelling continues throughout the production chain recording other information including the variety of the clonal root system, the scion variety, grafting dates, who grafted it etc. However, Allesbeste has its own IT department which is working on developing an electronic system to replace this manual system. It will use Radio Frequency Identification (RFID) tags (inserted in the trees) containing all this information and will be used to track the trees through the nursery and will

remain in the tree after planting out, the technology will be able to generate orchard maps and will be invaluable in identifying superior rootstocks etc.



Seedlings are grafted (left) to the intended rootstock e.g. Dusa® using a two-bud piece of scionwood so that two trees can be produced per seedling, then etiolated (middle, nursery manager Abram de Villiers showing the two stems) in a dark room before being treated with rooting hormone and a micro-pot threaded down the stem and filled with potting medium (right).

Optimum conditions for producing cloning trees are a warm, humid environment. Temperatures are not allowed to drop below 20°C. Heaters and humidifiers are used if necessary and ozone is used in the misters to help suppress disease. Salts in the coir can be a problem but the electrical conductivity is monitored regularly. Trees are hand watered with a shower-head rose on the hose pipe to ensure that every bag receives sufficient water. Nursery hygiene is very strict. The typical time needed to produce a clonal tree is 16 – 18 months but it has been achieved in 12 months. There are seven steps in the process so even with relatively small losses in each step the final result is about a 50% success factor overall.


Custom built grafting room (left). Clonal rootstock being grafted to the scion variety (right).

'Micro clones', the manual tags will soon be replaced by an RFID system.

The grafted trees are either dispatched as small trees to 'satellite' nurseries or potted up into 7 litre bags to gain more size.

Transport of trees and 'satellite' nurseries

If trees are to be sent long distances, including overseas (e.g. Philippines) by air-freight, they are not re-potted into 7 litre bags at Allesbeste but are sent as 'micro trees' in their micro-pots. Small plastic covers are placed over the mouth of each pot to prevent loss of potting media and moisture and the trees are stacked on their sides in cardboard boxes, 100 to a box. Because the trees are sealed in these boxes ethylene produced by the trees can build up and lead to leaf abscission so a sachet of an ethylene 'scrubber' is included in the box.

Transporting nursery stock as 'micro trees' results in huge savings in transport costs. In the distant destinations 'satellite' nurseries have been established where these trees are re-potted into bigger bags and grown out before being planted in the field. This has allowed the price to be kept the same at any location in South Africa (currently equivalent to USD10 each).

Zander Ernst showing the upright single leader growth habit of 'Maluma®' (planted at 5x2m) and the high flesh recovery of this variety. 'Maluma®', compared with 'Hass' requires extra care post-harvest to reach distant markets.

ALLESBESTE ORCHARD RESEARCH

In addition to their research on nursery practices Allesbeste also conduct their own orchard research which includes a focus on varieties and rootstocks, and planting density and canopy management. The list below outlines a history of the latter.

- 2006 - established a 4.5 ha high density trial with 'Maluma®' at 800 trees/ha.
- 2010 - established a trial growing 'Maluma®' at high altitude
- 2012 - established a 1 ha ultra-high density trial with 'Maluma®' at 2.5 x 2.5 m spacing "to see what it would do at this density".
- 2014 - expanded the ultra-high density trial to 4.8 ha testing 'Maluma®' on the rootstocks 'Duke 7', 'Dusa®' and 'Bounty'.
- 2015 - 1.2 ha trial established with 'Maluma®' on 28 different rootstocks growing on heavy soils with drip irrigation.
- 2016 - the first trellis trials established with 'Maluma®' (see discussion below).
- 2016 - started looking at 'precision farming' using Geographical Information System (GIS) using Real-Time Kinematic (RTK), drones etc.
- 2017 - 2 ha commercial trellis trial established with 'Maluma®'.

Allesbeste have 28 different varieties in three genetic blocks and have progressed 4 varieties to a semi-commercial stage. They are also experimenting with Low Volume spraying, PGRs, cover crops and mulches.

Rootstocks

Allesbeste Nursery currently produces 'Bounty®', 'Dusa®' and 'Duke 7' clonal trees. 'Bounty®' is now one their top three sellers. 'Duke 7' is preferred for cooler areas. However they are always

investigating potential new rootstocks and have a 2 year old trial containing 28 different lines. In these trials they record yield, calculate yield efficiency and estimate projected yields. These lines include the Birdwood selection 'BW78' which they have found good both as a seedling and a clonal rootstock. Allesbeste have their own rootstock selections (designated by 'AK' e.g. AK13).

'Maluma®' variety

Allesbeste claimed that under local conditions 'Maluma®' has a potential yield of 25 – 30 t/ha compared to 'Hass' which has a potential of 20 – 25 t/ha under the same conditions, and that it is more frost tolerant and has a better fruit size especially in hot areas where 'Hass' struggles for size. A block of 'Hass' (on 'Bounty®' rootstock) in a frosty area that was yielding only about 5 t/ha was top worked in 2015 to 'Maluma®' giving yields of 6 t/ha in 2017 and a projected 20-25 t/ha in 2018.

However it is interesting to note that Westfalia has decided not to grow 'Maluma®' due to its post-harvest challenges especially given their distant European export markets. Westfalia's research has shown that 'Maluma®' requires more care and attention to reach its destination in good condition. Apparently its respiration rate is very high so it is imperative to remove the field heat immediately after harvest and it needs to be in the packhouse, packed and forced air cooled within 6 hours of picking. Thereafter a very strict cool chain needs to be maintained. Other issues with Maluma®' include a high level of seed coat death as well as a greater incidence of 'grey pulp'.

Trellising trials with 'Maluma®'

Allesbeste says that 'Maluma®' has a more weeping growth habit compared with 'Hass', producing droopy secondary branches so it is slow to fill the inter-row and inter-tree spaces but this growth habit results in more shading within the tree. Trellising is being tried for these reasons. Andre Ernst is convinced that 'Maluma®' lends itself to trellising, as do some other upright varieties such as 'GEM®', 'Pinkerton' and 'Lamb Hass' but he said that it doesn't suit 'Hass'. Allesbeste believes that 'Hass' trees need to be regularly rejuvenated through pruning to generate new branches because fruit on old branches tends to be small.

Maluma®' doesn't appear to need PGRs to reduce growth however they want to experiment with soil applied PGRs. No PGRs are being used in these trellising trials.

The 'Maluma®' trees in the trellis trials are on 'Bounty®' rootstocks which result in less vigorous growth than on 'Dusa®'. Andre said that 'Maluma®' performs better on 'Bounty®', whereas 'Hass' does better on 'Dusa®'.

Zander Ernst said that trellised 'Maluma®' produces flowers on the trellised horizontal branches right back to the main trunk, whereas 'Hass' doesn't. He made the comment about having to 'micro-manage' the pruning and thought it may be possible to start training trees in the nursery to suit trellises. He wants to keep tree height at 2.1-2.4m. Rodrigo Iturrieta (University of California) explained the theory behind the trellising including the fact that trellising converts unproductive growth into fruiting shoots.

The trials were planted in Oct/Nov 2016 and they are testing both Tatura and vertical trellises. Planting densities are 1,250 (4 x 2m spacing) and 2,500 trees/ha (4 x 1m). Branches are trained horizontally along trellis wires and will develop flower buds all along the branch if they receive sufficient light. In the vertical trellises they are experimenting with different distances between

horizontal trellis wires, namely 150, 200 and 300mm; so far 300mm is best whereas 150mm is too close because the branches shade each other too much reducing flower numbers. An alternative strategy might be to prune off alternate branches each year if wires are spaced only 150mm apart. No PGRs are being used in these trials.

Trellising trials with 'Maluma®', vertical (left) and Tatura (right). Note the pronounced tree row mounds for drainage.

The trellises cost approximately USD4,000 – 4,700/ha to establish, the most expensive part being the wire. Labour costs in South Africa are currently only about USD1.80 per hour.

If the distance between horizontal wires in the vertical trellises (left) are too close then branches shade each other and result in less flowers. Branches are trained to wires in the Tatura trellis (right) to create an 'open vase' tree structure.

Other trials

We visited a non-trellised block planted in December 2014 which consisted of 'Maluma®' on 'Bounty®' and 'Duke 7' rootstocks at 5x2m spacing (1,000/ha). The trees had reached 4m in height (i.e. their maximum theoretical height based on the 80% of row spacing rule). They were irrigated with 2 x 40 L/hr sprinklers. The yields in this block were 8, 10 and 16 t/ha in years 2, 3 and 4 respectively. Typical yields of 'Maluma®' at maturity are about 25 t/ha. Fruit had a good size distribution with 65% in the 12 – 22 count trays (4 kg tray).

Next to this block of 'Maluma®' was a variety trial which included one with an incredibly high flesh recovery (see below). The comment was made that the rounder the fruit shape the easier it is to pack.

A new variety with an exceptionally high flesh recovery being tested in the Allesbeste variety trial

Terracing

Avocado growers in South Africa are now starting to plant on slopes greater than 15% now that a viable system of field terracing and layout has been established that allows safe tractor access.

A viable system of terracing slopes previously considered too steep for avocado that now allows safe tractor access

WESTFALIA FIELD DAY

The day began with a traditional African singing and dancing welcome by the packing shed team then breakfast on the lawn of the Ramalea Guest House and a presentation about Westfalia.

WESTFALIA AT TZANEEN

Introduction and history of Westfalia

Westfalia Estate was purchased in 1929 by Dr Hans Merensky, a successful geologist and prospector, and he set about re-building the farm, employing competent technical staff, establishing schools on the farm and investing generously in the community. Dr Merensky sponsored activities at several universities and created bursaries. To ensure further development he founded the Hans Merensky Trust to be guided by his will *"…to promote and assist in the development of the resources of South Africa and neighbouring territories – particularly such natural resources as soil, water, minerals, flora and fauna and welfare of the inhabitants; more specifically by research and demonstration and through the correlation and application of scientific knowledge …."*.

The first avocados were planted in 1930. The technical team, Westfalia Technological Services, was formed in the 1970s and included Jan Toerien, Joe Darvas and Dr Lindsey Milne. Amongst their achievements were the development of injection of phosphorous acid to manage root rot and the convening of the first World Avocado Congress. A more recent achievement was the selection and commercialisation of 'Dusa®' rootstock.

Westfalia now has the largest avocado 'footprint' in the world with operations in Chile, Peru, Colombia, Mexico, California and Portugal. They recently formed a partnership with Agricom in Chile. Westfalia also has large timber interests and grows and processes mangoes as well.

View of the Westfalia avocado orchard amphitheatre.

The packing shed at Westfalia Estates is situated north of Tzaneen at 700 m ASL and the orchards and forestry are situated above this up to 1,300 m ASL. Westfalia currently employs 2,700 people in South Africa. The company is vertically integrated and cares for its people and the environment.

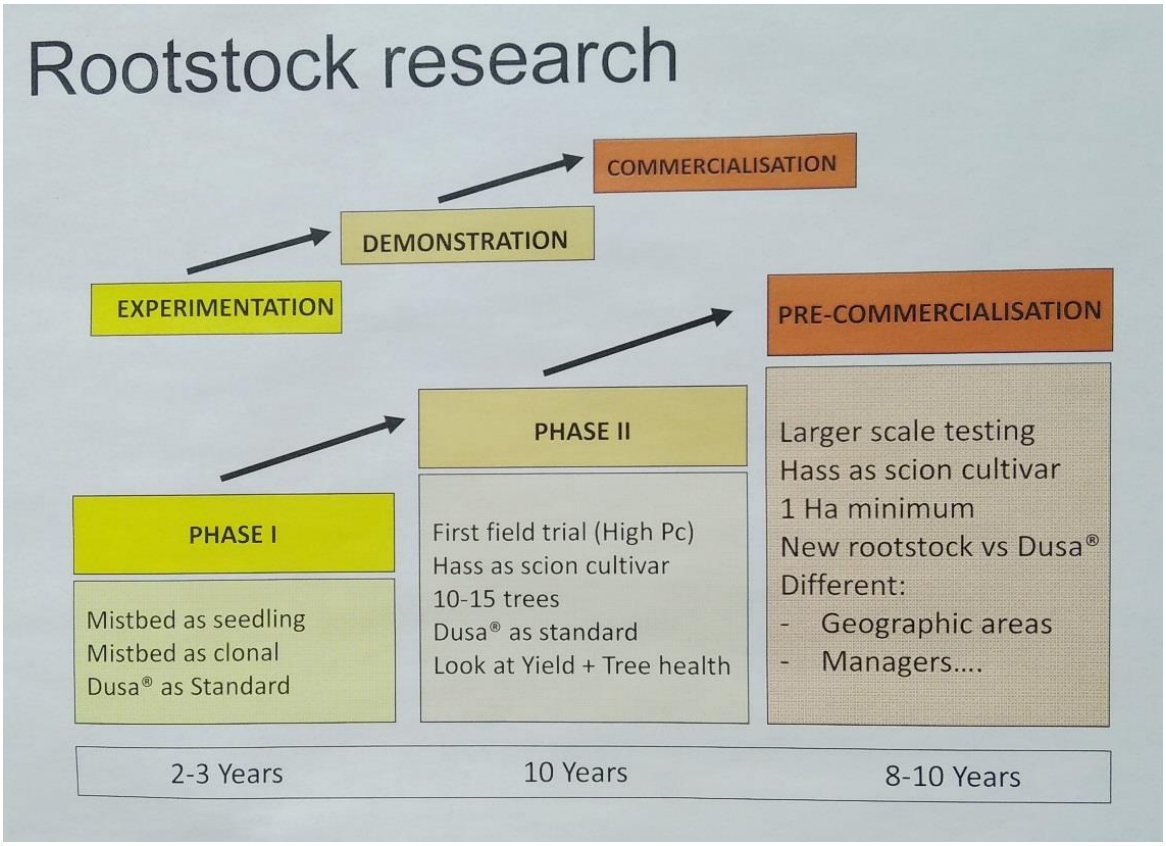
Westfalia has a large composting operation which was initiated to get rid of the oil waste from their guacamole plant. They also have an 'individual quick freeze' (IQF) plant for avocado halves.

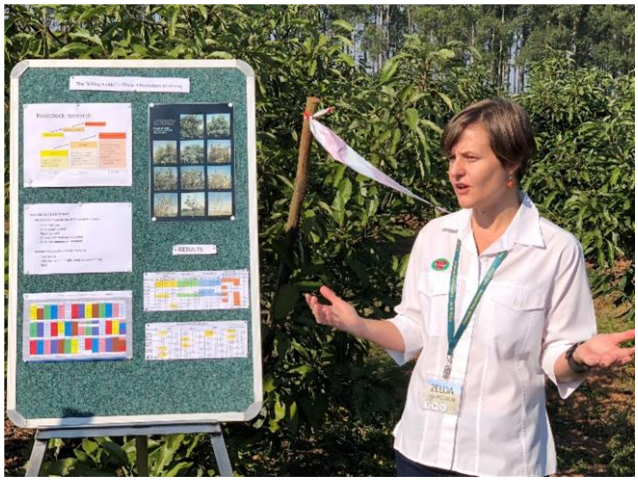
Rootstock selection and testing

Westfalia has several phases to its rootstock selection programme. **Phase I** (presented at the field day by Sylvie Kremer-Köhne and Wilna Stones) includes identification and initial screening of rootstocks. Standout rootstocks that have survived high root rot pressure in the field are identified where the others have succumbed. In order to recover material from surviving rootstocks they thin out the canopy and girdle above or at the graft to encourage the rootstock to shoot, these shoots are recovered and propagated. Westfalia also have a rootstock breeding programme (in the middle of an indigenous forest to avoid avocado pollen from other trees) that produces and screens about 10,000 seedlings a year. Parent trees in the breeding programme are girdled if necessary to make the trees flower in synchrony for the crosses. The pollen parent is not currently identified but in the future they might analyse the DNA to determine this. Phase I typically takes two to three years.

The promising seedlings are grown in a *Phytophthora cinnamomi* rich 'soup' in a mist bed. The survivors are cloned, grafted to 'Hass' and compared with 'Hass' on cloned 'Dusa®' rootstocks as the standard. Typically only 2 in 1,000 (0.2%) show any promise and are taken through to Phase II.

The objective of **Phase II** (presented by Zelda Van Rooyen), carried out in the 'killing fields', is conducted not only to further test their tolerance to root rot but also to see if they are productive. The tour visited the 'Groenkloof' research farm to see this phase of the work.





Left: Phase I (breeding and glasshouse screening) of the rootstock selection process. Right: Zelda Van Rooyen explaining Phase II (field testing), this particular plot was established in 2013.

Phase II is a field trial comparing 25 trees (5 reps of 5 trees with the middle 3 in each rep as the data trees) of each promising rootstock with 'Dusa®' as the standard. The scion used is always 'Hass'. The site of the trial is known to be a hot spot for root rot and 'Edranol' seedlings are scattered through the trial as a susceptible variety and source of disease inoculum. Root rot control treatments are applied for the first two years to get the trees established but not thereafter. Each trial is typically run for 10 years. So far the most tolerant rootstocks are also the most vigorous. In the process they are also on the lookout for dwarfing rootstocks.

Phase III (presented by Therese Brewer) is a pre-commercial stage which involves testing the selected rootstocks at several different locations with different managers to test the selections across a wider range of conditions. These locations include Tzaneen (1200mm annual rainfall), Mooketsi (warm and with 550mm annual rainfall) and Soekmekaar (cooler with 1200 mm annual rainfall). These trials are typically about 5 ha in size. In this phase they also look at fruit quality and post-harvest performance. Rootstock tolerance to salt has to be conducted overseas since Westfalia doesn't have a suitable site in South Africa. White root rot (*Rosellinia necatrix*) has recently been discovered in South Africa but it is currently not a major issue and the rootstocks are not being tested for this disease yet. In Spain where this disease is of more concern differences in susceptibility between rootstocks have been observed and this is their focus for its management (see below in the disease section of the conference notes).

The process to come up with a new commercial rootstock variety takes about 25 years.

Avocado production on the Westfalia home farm

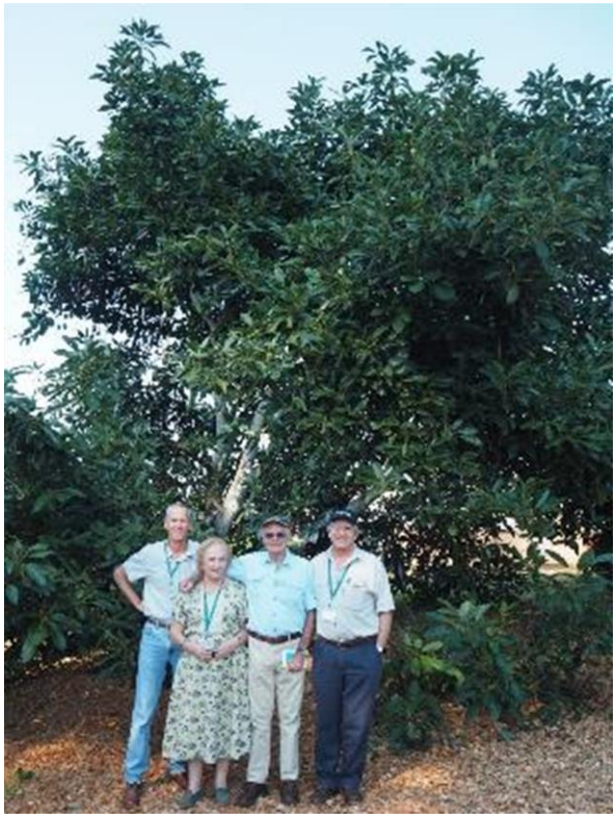
Some of the original avocado blocks still exist at Westfalia, these are planted on seedling rootstocks at high altitude on 10 x 10 m spacing and are not irrigated. The mix of varieties (including 'Fuerte') and altitudes at Westfalia allow a harvest season from February ('Fuerte') till October (late harvest 'Hass'). The average yields are in the 10 – 12 t/ha range with 15 – 18 t/ha where new technology is used and 35 – 40 t/ha from some old 'Fuerte' blocks. There is a big proportion of small fruit and some of this is used for specific markets in Europe and some for guacamole.

Spraying is done by hand held hoses, generally for anthracnose and Cercospora black spot and sometimes for the Taylorilygus insect which attacks just after fruitset. PGRs are difficult to spray with hand held hoses.

In high rainfall areas of Westfalia pruned branches are left under trees to contribute to the mulch.

Block 14 (left), the site of the very first experimentation with tree injection by Joe Darvas and (right) a demonstration of the history of development of tree injection.

We were shown Block 14 where the first experimentation was done with tree injection by Joe Darvas. Westfalia now has a team of 10 staff that carry out the injecting, they can inject 5.5 to 6.2 ha per day which may involve the use of 6,000 to 10,000 syringes. They aim to inject on warm, sunny days when tree transpiration is good. Syringes are collected the next day. They have graduated measuring poles to determine tree diameter for calculating phosphorous acid dose and two injection windows, February – April and October - November. There are some fruit residue issues with the October - November window because newly set fruit are on the tree and are actively growing and the European export market has very low MRLs for phosponate. The 'Avoguard' brand of phosphorous acid is used.



This 'Hass' tree, planted at Westfalia in 1991, was produced with wood from the original 'Hass' seedling in California. From left, Simon Newett, Gloria and Nigel Wolstenholme and Andre Ernst. Australia has a tree with the same credentials growing at DAF's Maroochy Research Facility in Nambour.

ORCHARD AT SOEKMEKAAR

After lunch we were taken to the Agrivet orchard, owned by Kosie Eloff's family and managed by his son Manie, about an hour's drive north of Westfalia Estate. The orchard is situated on the edge of an escarpment at about 1,200 m ASL and is 4°C cooler than Tzaneen but it rarely drops below 1°C, the maximum temperature reaches 35°C. It often experiences fog (hence its name of 'Soekmekaar' which means 'looking for each other' in Afrikaans) and has an annual rainfall of 1,200 mm. The total orchard area is 235 ha of avocados. The yields average 18 t/ha and they experience some biennial bearing. 'Duke 7' and 'Dusa®' rootstocks are used, 'Duke 7' is currently outperforming 'Dusa®' here but this is expected to change in the longer term. Leaf N levels range from 2.1 – 2.4%.

The farm has a joint venture with Westfalia which incorporates a number of trials including a variety trial, a phase III rootstock trial and a trial of the 'GEM®' variety growing under netting for protection from wind rub and hail which are issues at this site.

Variety and rootstock trials

Agrivet hosts a new scion variety trial (for Westfalia) where potential new varieties are compared against 'Hass', 'Lamb Hass', 'GEM®' and 'Harvest'.

'Hass': flowers here from mid-August till late September. Dry matter had reached 24% at the time of our visit (late May).

'Harvest': although it has a higher yield than 'Hass' it matures later and is susceptible to irregular bearing. Also, the fruit is very sensitive to cold weather with the vascular bundles freezing in response to frost, it is also sensitive to heat with fruit shedding during a heat wave of 40°C in the Eastern Cape Province. 'Harvest' was released at the same time as 'GEM®' but was not commercialised because of its alternate bearing.

Westfalia has a variety trial and a Phase III rootstock trial at the Agrivet farm

'GEM®': no problems with setting fruit at Soekmekaar and it is reported to be tolerant of hot conditions. Yield is 30% more than 'Hass'. Due to its upright growth habit and the fact that it flowers further down the shoot the fruit hangs inside the canopy and is thus better protected from sunburn. It is a late cultivar. Due to its upright growth habit the suitable spacing in this environment is 6 x 3m.

'Lamb Hass': claimed that profitability can be double that of 'Hass', expecting 30 t/ha on new plantings when they reach maturity. Late harvest but prone to alternate bearing and colours up before softening so confusing for consumers.

'Carmen®': a Hass-type that looks almost identical to 'Hass' and yields 20 to 30% higher. Flowers at least twice per year so has at least two crops per year. ZZ2 claim they can manage it so it only has one crop per year.

'Gem®' at Soekmekaar.

'Lamb Hass' at Soekmekaar.

'Harvest' at Soekmekaar.

'Hass' at Soekmekaar.

Agrivet has a Phase III rootstock trial for the Westfalia rootstock programme which includes six potential new rootstocks at 7 x 4m spacing planted in November 2014 on ridges in deep red soils. (there are 32 trees per rootstock at each site).

Asked about snap vs. snip picking, Westfalia said they snip pick if harvesting early in the season. They inject once per year at this site, this is done in between February and May once the summer leaf flush has hardened.

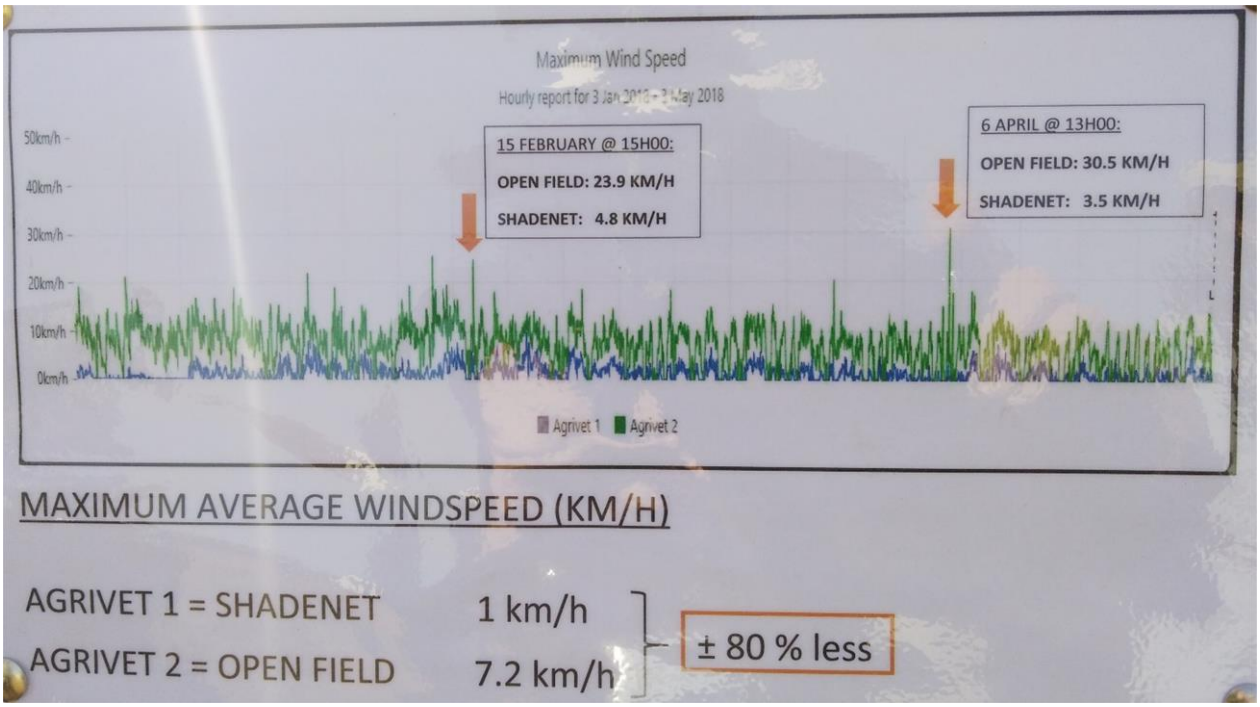
Pest management

Some evidence of red mite and algal spot was visible at this site. Apparently in Chile where red mite is an issue they have found that the castor oil plant is very susceptible to red mite. Consequently, they cultivate this plant to build up the numbers of natural insect predators then cut branches of this bush and scatter them through the avocado orchards as a source of beneficial insects.

Wind rub and algal spot are symptomatic of the climate at Soekmekaar where wind and fog are common.

Shade netting trial

The Soekmekaar region is quite windy and also experiences some hail so a 1.2 ha trial has been established where Gem® is being grown under 20% shade in order to produce more export-quality fruit. The trees are planted at 6 x 2 m and two different types of shade cloth weave are being tested. Black netting is more resistant to UV. After two years they have found that the trees are taller due to longer internodes (reaching for more light perhaps?), there is a much better fruit size distribution, 17% less wind rub damage and less sunburn. They are also recording a moderation in temperature and a difference in seasonality. Low bee activity is an issue within the netted area so at flowering time they lift the sides of the net and place beehives around the edges of the nets with their entrances facing the trees and provide sources of water.



Effect of shade-net on wind speed

Young orchard at Soekmekaar showing the prominent planting mounds and the red soil.

'Gem®' growing under shade net at Soekmekaar.
The hail release system in the net can be seen in the lower photograph.

FIELD VISIT TO AVOCADOS UNDER NETTING AT TZANEEN

We visited Nick and Nelius Human's 10 ha three year old trial with 'Maluma®', 'Carmen®', 'Harvest', and 'Hass' at 8 x 2.5m spacing (500 trees/ha) under netting near Tzaneen. All trees are on clonal 'Dusa®' rootstock. The family believes in very good land preparation for example they start growing sunhemp and velvet bean as cover crops one or two years prior to planting. Compost at 40 m^3/ha and charcoal, the latter believed by the growers to improve the water holding capacity and carbon content of the soil, are incorporated in the planting mound. Thereafter 20 m^3/ha of compost are applied per ha per year.

The shade structure was built 8m high and is testing 20% and 40% shade with or without a UV reflector thread in the fabric. Under 40% shade the trees grow much taller. They are unsure on the effect of the netting height on bee behaviour but next time would build it lower at 6 or 7 m which will be quicker to erect and less costly.

10 ha netting trial near Tzaneen. Basil is planted at row ends to feed bees.

The purpose of the shade netting is to protect the fruit from sunburn, hail and wind damage. The cost to install was R250,000 (equivalent to about AUD 25,000/ha) but the growers said that they re-couped the cost after three seasons. The effects of the netting include warmer temperatures at night, an earlier harvest date, less wind rub and larger fruit size (nothing smaller than a 14 count in a 4 kg tray). The growers said that the avocado trees are more vigorous under the netting.

It was mentioned that in Israel (where not much rain is received) that dust builds up on shade netting and as a result 15% shade becomes equivalent to 30% shade. Also it has been found in Israel that red shade cloth has resulted in the most vigorous tree growth but the worst quality fruit. At this site 'pearly white' is considered the best colour netting followed by blue.

Trees are drenched annually with Cultar® (paclobutrazol) just after harvest but before flowering to keep them smaller and they are also pruned straight after harvest. Each tree receives about 2 L of a diluted product, the equivalent of about 4 L of active ingredient is applied per ha.

Basil, the herb, is planted at the ends of the rows to feed and encourage the bees but it is cut when the avocados come into flower. More is being established. Some in the group of scientists felt that it should not be cut.

They have found that the 'Harvest' variety (a 'sister' of 'GEM®') can tolerate heat better (unlike Westfalia that has found that it is sensitive to extreme heat – see above), has an open spreading growth habit and it has a high propensity for alternate bearing (as discovered by Westfalia).

'Carmen®' generally has two main flowering periods per year but can flower at any time. They claim that it yields 20 to 30% more than 'Hass', perhaps as a result of the extra flowering.

Unfortunately last year the entire crop was stolen, 20 minibuses full of pickers turned up one night, broke through the security fence and harvested the entire crop.

Security is a big concern, all orchards visited were surrounded by electrified fences and razor wire.

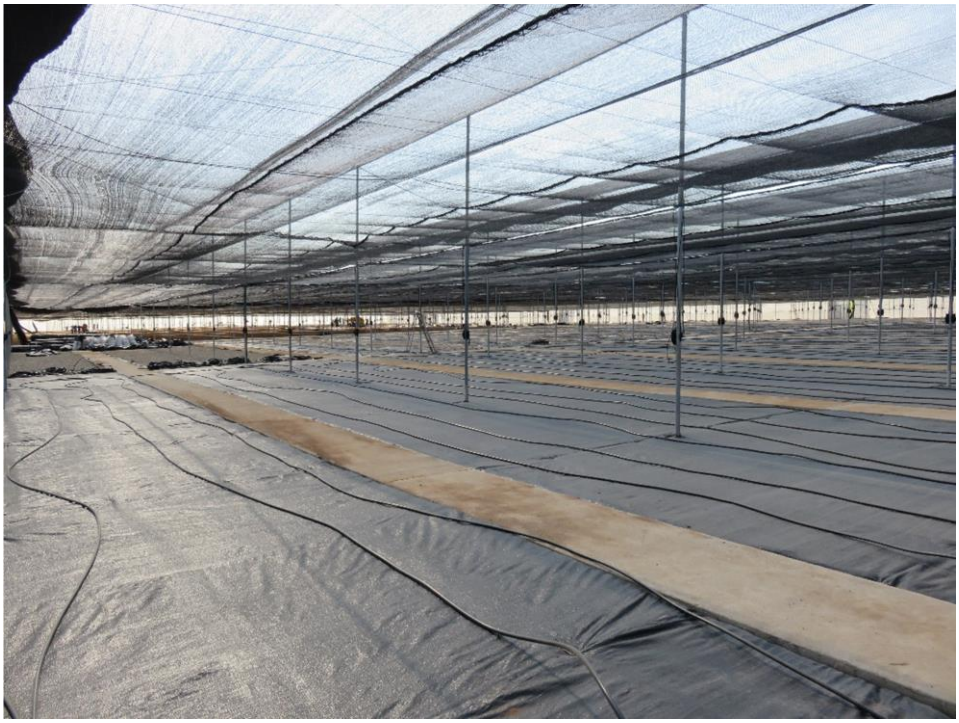
Sunblotch viroid is present in South Africa so they are concerned about spreading the disease when drilling holes for injection.

Growing under shade netting near Tzaneen, 'Maluma®' (left) showing its upright growth habit and 'Carmen®' (right) demonstrating its propensity for several major flowering events per year with mature fruit, half grown fruit and flowers present at the same time.

VISIT TO ZZ2 ESTATES AT MOOKETSI

Avocados

ZZ2 started growing avocados in 1981 (guided by Anton Hough and Udi Gafni) and currently have 1,000 ha of trees located at Mooketsi (700 m ASL with average rainfall of 450mm), Tzaneen (800 m ASL with average rainfall of 1200mm) and in the surrounding mountains (1600m ASL). They plan to expand to 2,300 ha of avocados and to achieve this are expanding their nursery, which was established in 2011, from producing 100,000 clonal trees this year to 250,000 trees next year in order to plant 200 to 300 ha of new orchard each year.



ZZ2 are expanding their nursery capacity in order to produce 250,000 clonal trees per year. This includes establishing this new 2.5 ha shade house.

We visited ZZ2's avocado operation at Mooketsi where they are 'pushing the boundaries' of growing avocados in a hot environment with some salinity issues. They have properties in the mountains where dams collect water that is piped as far as 30 km to Mooketsi and they are experimenting with new varieties, rootstocks, PGRs, canopy management techniques and more sustainable production practices which they refer to as 'nature farming'. They have a 130 different varieties in the ground (including 'Shepard') and a collection of 200 different rootstocks in the nursery some of which came from material collected in the Venda tribal area.

ZZ2 plans to have a horticulturist for every 300 to 400 ha of avocado orchard and a manager for every 100 ha. They are investing in precision agriculture including GPS for soil mapping and application of gypsum and lime. Drip irrigation is used with three drip lines per tree row. Nitrogen, boron and zinc are applied via fertigation. The average yield over the past 6 years (which included two seasons of hail) has been 19 t/ha, this past year they averaged 28 t/ha. All trees are planted on steep mounds about 800 mm high to get the water away quickly when they receive cyclonic rain.

They claim that putting trees on high mounds also makes them bear earlier and give higher yields. Irrigation decisions are based on monitoring soil moisture using soil probes and calculations from pan evaporation. Water use is monitored continuously with water meters. ZZ2 has its avocado blocks spread over a wide range of locations to minimise the risk of major losses from natural disasters such as hail and frost and this also helps even out the supply of fruit to the packshed through the season.

The range of tree spacing includes 6 x 2m for 'Maluma®' and 'Lamb Hass', 6 x 3m for 'Hass' at Mooketsi and 7 x 3m for 'Hass' at Tzaneen. They do have some on 10 x 5m which used to be 5 x 5m until every second row was removed. 'Maluma®' accumulates dry matter quicker. With the help of PGRs 'Hass' size is in the 16 – 20 count range here for a 4 kg carton (equivalent to a count range of 22 – 28 for a 5.5 kg tray). Keeping phosphonate residue levels low in the fruit is important for their export programme to Europe and they fly fruit samples to Germany for residue testing prior to despatching export orders.

ZZ2 also invest in research to develop more sustainable farming practices to match their 'nature farming' ('Natuurboerdery®') approach which is about trying, as far as possible, to farm in harmony with natural processes but still use modern methods. For example they have reduced the amount of inorganic fertiliser applied.

Tomatoes

ZZ2 are also major producers of tomatoes growing 200,000 tonnes of tomatoes in Limpopo Province on 2,000 ha in open fields and 200 ha under net, which supplies 50% of the South African market share. In other locations in South Africa, including Ceres in the Cape Province, they also grow onions, apples, pears, cherries, almonds and Medjool dates. They employ 9,500 staff and their goal is to be the benchmark of agriculture in South Africa.

With their tomato operation they have found that unless they follow the 'nature farming' approach, using practices such as longer rotations and applications of compost and compost tea, their yields drop and the crop becomes uneconomical. By using 'nature farming' they claim to have doubled the output of tomatoes per hectare. They employ a systems ecologist Leon and several researchers.

Compost

They make 50,000 m^3 of compost per year at Mooketsi (and 20,000 m^3 cubic metres in the Cape Province) using eucalyptus and pine tree sawdust, wood chips, gypsum, tomato waste, cattle manure purchased from tribesmen and chicken manure from broiler hen sheds. The compost made for tomatoes has a ratio of 40% wood: 60% manure whilst their compost for avocados has a ratio of 60% wood: 40% manure. It takes ZZ2 140 days to make the compost for tree crops, a more typical time to make compost is 180 – 220 days. Composting goes through thermophilic, mesophilic and curing stages. During the thermophilic stage the optimum conditions include a temperature of 55°C (it must not exceed 62°C) and a moisture level of 50-55%; watering and turning the material is carried out as necessary to maintain these conditions. They are trying to develop a compost that is strongly disease suppressive and follow the principles of healthy soils and soil microbiology promoted by the Soil Foodweb Institute. ZZ2 claim that they get a better root profile and depth from using compost. In the future they may harvest the heat, ammonia and carbon dioxide produced during the composting operation. Excess compost to their needs is sold for R520/m^3 (about AUD 52).


Compost operation at ZZ2

Compost tea

ZZ2 brew 650,000 litres of compost tea per year for use on their tomato fields. They produce two grades of compost tea, one is called 'EM' ('effective microbes') and is brewed under more controlled conditions where the ingredients are water, molasses, and yeast and lactic acid bacteria imported from Japan. It is fermented at a pH of less than 3 or 4. The other tea uses compost as the starter culture. The higher grade product (EM) has a shelf life of six months and is a useful carrier for other beneficials. For example they have a 35 ha herb garden where they grow plants such as lemon grass and wild garlic to add to the compost teas for different purposes.

Between 120 and 400 L/ha of the product is applied to a tomato crop over the life of the growing period and costs the equivalent of USD50/ha to produce and apply. The compost tea costs approximately USD 0.65/L to make and provides a low cost and low impact treatment. They claim that a lemon grass plus wild garlic spray is effective for white fly control.


The 'EM' compost tea is prepared under controlled conditions (left) whilst the other grade is less controlled (right).

Compost tea is also applied to avocados at 25 L/ha four times per year together with the application of mulch and fulvic acid and it is important to have mulch in place for the microbes to feed on. The practice has improved the structure of the soil. They claim that compost tea and 'EM' competes with the pathogens and dilutes their effect. The 'EM' is anaerobic and works well at depth in the soil. It can also be applied as a foliar spray after hailstorms - ZZ2 claims that it speeds up the formation of callouses on damaged tissue.

Adding 80 kg of macerated lantana bush to the 1,000 litre shuttle during the preparation of the compost tea makes a product that ZZ2 claims sufficiently suppresses pathological nematodes in their tomatoes so as not to require other forms of control. The low pH of the compost tea apparently neutralises any toxins in the product including lantadene A and lantadene B.

Canopy management

The approach is to try to keep the trees no higher than 4.5m and to balance the tree and crop.

- Year 1: Circular saw to remove some of the eastern side of the tree then spray the regrowth flush with PGRs.
    - Year 2 or 3: Circular saw to prune the top, or western side of the tree.
    - Year 3, 4 or 5: Circular saw to prune the side or top that hasn't been already pruned.
    - Each year one limb (sometimes more) is removed per tree, if possible the limb that has just borne a heavy crop.
    - Several times per year they go through the orchard to look for water shoots which they cut in half and this encourages them to branch and fruit.
    - They selectively apply PGRs about three times per year using a back-pack or hand held hose only to branches that need it, not the whole tree.

With this approach ZZ2 claim to get very little alternate bearing and maintain yields around 18 t/ha.

ZZ2 pioneered the use of drip irrigation in avocados South Africa and uses a "short back and sides" approach to canopy management.

Mechanically pruned Hass on 7 x 3m spacing.

Wouter Retief from ZZ2 with hand on the selected limb to be removed.

Example of tree after removal of selected limb.

Distant perspective of trees managed using the ZZ2 canopy management approach – 'short back-and-sides 'with 'windows' into the canopy for light penetration.

Pollination

ZZ2 bring in a lot of bees and believe that it pays off. However, they are investigating alternative pollinating insects such as their own stingless native bees. ‘Ettinger’, ‘Zutano’, ‘Galil’ and ‘Shepard’ are being tested as pollinisers.

Collection of potential avocado pollinators.

Pest management

They scout for stink bug and *Taylorilygus* sp and spray if necessary. *Taylorilygus* feeds on pollen then moves on to the fruitlets which they sting and cause to shed.

CONFERENCE PRESENTATIONS AND DISCUSSIONS

The following notes outline the main points raised and discussed.

PROVIDING FOR THE CONSUMER: SAFETY, FLAVOUR, HEALTH

Co-chairs: Nikki Ford, Lise Korsten & David Obenland

Avocado food safety – Lise Korsten

Lise Korsten (plant pathologist, University of Pretoria) spoke about food safety concerns such as outbreaks of *Listeria* and *Salmonella* and how to prevent them happening in avocado. She described the incident that occurred in Europe in 2011 that was originally blamed on Spanish tomatoes and melons but was actually caused by German sprouts. This incident was handled badly but raised the need for sound food safety programmes. Lise proposed the formation of a global network to share information, data and testing systems and to collaborate to solve these types of issues - a unified global avocado 'whole of supply chain' food safety initiative for whole and lightly processed fresh fruit. Should we establish a global food safety project and team to manage avocado industry reputation and risk?

Avocado fruit flavour – David Obenland

David Obenland (plant physiologist specialising in food quality, USDA) spoke about the attributes of avocado that contribute to, or detract from its flavour: food texture, the volatile aroma components that contribute to smell and the five properties that produce flavour, viz. sweet/sour/astringent/salt/umami (umami is the savoury component of flavour). He pointed out that different volatiles are released at different stages of chewing and these contribute to the taste. To measure flavour objectively he said that an 'electronic' tongue is being developed. Australian delegates believe that we need to really need to 'step up to the plate' in this area. David proposed more R&D into avocado fruit flavour in terms of organoleptic flavour perception.

Avocado health virtues – Nikki Ford

Nikki Ford (director of nutrition at California's Hass Avocado Board, HAB) explained that HAB is an agricultural promotion group established in 2002 to promote the consumption of Hass avocados in the United States. HAB conducts research, produces information resources and conducts marketing. Nikki outlined results from some of the **avocado health research**.

Cardiovascular, weight management, healthy living, type II diabetes virtues are generally recognised, including in the US Dietary Guidelines, but, nonetheless, need to be proven to legally make health claims. Researchable issues include: complexity of human biology, avocado handling education for users, characterisation of variability bio-actives and nutrition, and, unrealised opportunity for delivery of consistently high quality fruit.

- Consumers mainly eat avocados for their flavour and health benefits.
- One avocado per day raises good (HDL) cholesterol and lowers bad (LDL) cholesterol.
- One avocado per day did not increase body weight.
- Half an avocado per day in a hamburger reduces post-meal inflammation.

- In a survey avocado eaters weighed 7 ½ lbs less than non-eaters and had smaller waist measurements.
- Avocados reduced the desire to eat, i.e. they produced a higher level of satiety.
- Avocados act as 'nutrient boosters' to enhance the absorption of anti-oxidant carotenoids and improve the production of vitamin A.
- Avocado was 35 times more effective than a lutein supplement to improve macular pigment in the eye.
- Avocado consumption improves planning and working memory.
- Avocado consumption reduces the odds of developing precursors for diabetes and cardio vascular disease by 50%.
- Within 30 minutes of eating half an avocado blood insulin levels did not spike as high as after other foods.
- Avocados are a good source of fibre, vitamin K, folate, pantothenic acid and copper.

By line: "Avocados are healthy, flavourful and safe".

Things to think about going forward:

- The sustainability of production practices
- How you can incorporate the nutritional quality of avocados into your research

NEW TECHNOLOGY TO IMPROVE AVOCADO PRODUCTION

Co-chairs: Nicky Taylor & Mark Buhl

Block chain – Mark Buhl

Block chain was originally created to allow crypto currencies (such as Bitcoin') to be securely managed and traded online. It is described as *"a putative solution to handling an ocean of data in a secure, permanent and actionable way".* It involves assetisation, unitisation and flow.

Mark Buhl (DataHarvest, USA) gave an outline of **"Block chain"** and how "it will change everything". He promoted it as a solution for handling an ocean of data in a secure, permanent and collaborative way. Mark believes that a grower has two main assets – their trees and their data. The by-line on the DataHarvest website states: *"Our technology team stands ready to handle the pipeline of information that will flood our modern day farmers with data. Designing and supporting some of the world's largest data sets, we are ready to build the architecture for the data flow that enables the farms to harvest their second most valuable commodity; their data."* For growers they state: *"All aspects of oversight now can be easily recorded, preserved, and distributed to all accountable parties along the food chain. Farmers can begin to rely on electronic processes that document daily compliance and food safety issues while compiling data for the entire logistics and retail chain. Farmers can begin to go back to doing what they do best; farming!" and "Creating the passport to the world for your fresh food shipments. Phytosanitary Issues, government protocols, food safety, manifests, shipping documentation, customs clearance; all handled seamlessly with a documentation flow that reduces oversight and costs."*

Note: David Inderias has a start-up company with 'Block chain' in Brisbane.

Remote sensing - Nicky Taylor

Nicky Taylor explained that **remote sensing** was originally investigated in South Africa as a means to monitor irrigation efficiency. However, its potential for disease scouting, water management, canopy management, targeted spraying, efficient resource utilisation and for security has also been suggested. Nicky posed the question "What is the role of 'big data' in agriculture?" An example of a company that provides a remote sensing service to horticultural producers in the Cape Province in South Africa can be found at www.fruitlook.co.za. Liz Dann pointed out that remote sensing might be a very useful tool for early detection of trees infected with *Phellinus noxius*, thus being able to pull them out before the disease is spread to the next tree.

Note: there is work going on in this 'space' in Australia and HIA is assessing proposals to further develop precision agriculture in avocado.

Trellised and high density orchards – Zander Ernst

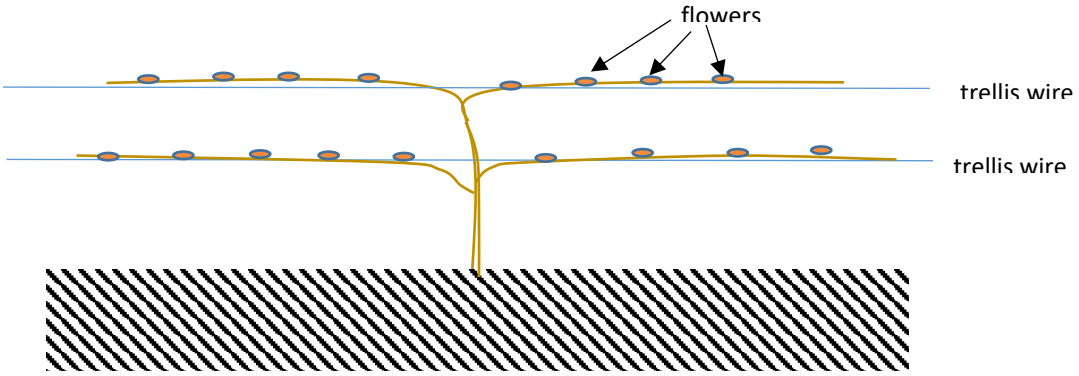
Zander Ernst (Allesbeste) believes that **high density orchards** enable **micro-management** enabling higher production per cubic metre of canopy volume and reducing irregular bearing. He believes that "trellising is the way of the future for the right varieties". Zander is experimenting with 'Maluma®' using a single leader and either vertical or Tatura trellises. After 3 years of research, Tatura has been found to be more productive than the vertical trellis but tree training for this system should start in the nursery. Zander also mentioned that these trellising systems have a big labour cost. He says that flowers develop along the horizontally trained branches and even develop on the main trunk but the increase in production has not yet reached the increase achieved in the level of flowering. 'Maluma®' is believed to have very different genetics from 'Hass'.

He states the advantages as follows:

- More efficient (directed) spraying
- Better spatial utilisation
- Increased flowering
- Increased fruitset
- Higher yields
- Higher fruit quality
- Lends itself to drip irrigation
- Labour costs for harvesting and spraying are less

The way forward:

- PGRs to be trialled
- Establish a full commercial Tatura trellis trial
- Determine the best timing for pruning that stimulates flower development and fruitset



Micro-propagation - Jayeni Hiti Bandaralage

Jayeni Hiti Bandaralage (UQ) spoke about the Neena Mitter team work to **propagate avocado using tissue culture**. Potential advantages include reducing time, labour, cost and land needs.

This work has been prompted by the need to produce greater numbers of avocado trees in a shorter time. They have found avocado to be highly recalcitrant woody tissue that makes it difficult to tissue culture. They have developed a successful system using 'Reed' avocado, getting 80 news plants from a single shoot and 500 from a single branch. Graft incompatibility hasn't been recorded with trees propagated using this method but sometimes incompatibility can develop later.

CHALLENGES TO PRODUCTIVITY: DISEASES

Co-chairs: Randy Ploetz and Kerry Everett

Bio-clay nanoparticles – Neena Mitter

Neena Mitter explained the development of **'BioClay'** as a possible alternative to developing new pesticides which typically cost $256m each to develop and register. 'Bioclay' consists of double stranded RNA interference (ds RNAi) from the pest or disease and when it is mixed with a carrier (the 'clay') and sprayed on the plant that needs to be protected from the pest or disease it disrupts the pest or disease. 'BioClay' allows for non-GM delivery of RNAi nanosheets. RNAi on its own is unstable and will only last about three days but by combining it with the 'clay' its effect can last for about 30 days. It is like 'vaccinating' the plant against the targeted pest or disease. New techniques allow it to be produced for a few dollars per gram and the rates needed are only about 1 gram per hectare.

Phosphonates – Liz Dann

Liz Dann gave an overview of **Phytophthora root rot**. It was first described in 1922 in Western Sumatra in cinnamon trees and just a few years later had spread to Puerto Rico where it was first discovered in avocado. It has a huge host range of over 3,500 different plant species and is a disease affecting any plant age from nursery to mature trees. In Australia it is estimated to cost in excess of $17m per year. A brief history of phytophthora control in Australia is as follows:

- Late 1970s – introduction of Aliette (fosetyl-Al)
- 1980s – discovery of phosphorous acid as a treatment
- 1987 – phosphorous acid becomes available to growers
- 1990s – correct timing of phosphorous acid application is established
- 1998 – introduction of root testing for phosphorous acid levels

It is still effective after 30 years with a dual mode of action - fungistatic and induced defence.

New work on the disease includes:

- The use of low volume sprays the use of surfactants (but with warnings of phytotoxicity and high residue levels in fruit).

- Experimenting with ammonium phosphonate as an alternative form.
- Differences in sensitivities amongst different isolates and associated different critical levels of phosphonate required.
- More work on timing of applications and associated fruit residue levels.
- Rootstock effects.
- Activation of defences.

Randy Ploetz pointed out that some rootstocks have thicker feeder roots than others. Does this make them more tolerant of Phytophthora root rot?

Tree health assessment – Liz Dann

Liz Dann (UQ pathologist) presented this session, speaking about the work of Surantha Salgadoe (UNE & UQ) that has established a high degree of correlation between tree canopy porosity with the degree of **Phytophthora root rot** in the tree. Surantha is developing an app for a mobile phone that rates trees for root rot based on canopy porosity from a photo taken by the phone. However, satellite images have proven more accurate for this purpose.

Rootstocks and their defence mechanisms - Noelani van den Berg

Noelani van den Berg (University of Pretoria) spoke about her work with a team of post graduate students on **Phytophthora root rot** and clonal rootstocks. 'Dusa®' was shown to actually have partial resistance to root rot (rather than tolerance), as there is quantitatively less *Phytophthora cinnamomi* in infected roots. 'Dusa®' has been shown to use the salicylic acid defence pathway initially to limit infection and then switch to the jasmonic acid pathway to limit spread. It was found that lignin and phenolics played no part in this resistance. Noelani hasn't included 'Bounty®' rootstock in her research yet but will do so in the future with collaboration from Allestbeste who control this rootstock.

Ben Faber mentioned that when Phytophthora root rot was addressed in California, zinc deficiency symptoms disappeared because the new healthy roots were able to source it.

Laurel wilt and Fusarium die back - Randy Ploetz

Randy Ploetz gave an update on **Laurel wilt**. This disease is caused by a fungus called *Raffaelea lauricola* which is intentionally spread and 'farmed' by an ambrosia beetle called *Xyleborus glabratus* which is a very efficient vector of the fungus. Other beetles may also vector the fungus. The ambrosia beetle bores into the tree trunk and inoculates the wood with the fungus to grow fungus 'gardens' and lays its eggs alongside. When the eggs hatch the larvae feed on this fungus 'garden'. When the tree is inoculated by the insect it reacts in an allergic way (akin to an anaphylactic shock in humans) producing plugs in the xylem called 'tyloses' within 21 days of inoculation and these block up the xylem vessels stopping the passage of water resulting in rapid wilt and death of the tree.

A molecular diagnostic test for Laurel wilt has now been developed.

Management practices are as follows:

- Sanitation 1 – remove affected trees as soon as possible and burn them so they can't be transported to other areas to spread the disease (it is thought that a major way that the disease has been rapidly spread over hundreds of kilometres is that people have carted infected wood as firewood).
- Sanitation 2 - remove affected trees as soon as possible to prevent root to root contact with neighbouring trees as there is systemic movement of the pathogen by root grafting.
- Cultural methods – establish trenches around affected trees to prevent root to root contact, or practice root pruning (e.g. deep ripping) around affected trees.
- Resistance – West Indian race avocado trees are the most susceptible e.g. 'Simmonds' so don't grow them.
- Chemical – triazoles (which can act as fungicides as well as PGRs) may work but researchers are not expecting chemicals to work due to how the disease affects the tree – firstly the disease is within the trunk and branches and secondly the xylem blocks up soon after infection removing the only means of getting a chemical to where it is needed. Fungicides are not a sustainable solution.

Interestingly, one grower in USA says that Laurel wilt is not a problem to him because he monitors tree health closely and removes and destroys affected trees promptly if they show symptoms.

Where affected trees have been removed replants can be successfully established.

In summary, the disease threatens avocado production in California, Mexico and beyond. Moving infected wood around as firewood is the most serious manner in which it is spread. Prompt removal of affected trees is critical (as it is for preventing the spread of *Phellinus noxius* in Australia).

White root rot (Rosellinia necatrix) - Clara Pliego Prieto

Clara Pliego Prieto (Andalucia, Spain) made a presentation about ***Rosellinia necatrix*** **(white root rot - WRR)**. Like Laurel wilt and Phellinus it induces water stress (moderate to severe), causes very rapid death of avocado trees and is transmitted by root to root contact. The Spanish researchers are tackling this disease through selection of more resistant rootstocks. It was found that resistant rootstocks use salicylic acid and jasmonic acid to fight the disease (like 'Dusa®' for Phytophthora root rot disease) but in the opposite order. They are trialling limited water stress treatments to induce resistance to Rosellinia, and have a breeding/selection program to test for resistant rootstocks.

Noelani van den Berg (University of Pretoria) spoke about the experience in South Africa with white root rot where it is an emerging issue. It has also been found in deciduous trees in the Cape Province of South Africa and in Mozambique. It has been confirmed to exist in avocado trees in the Limpopo, KwaZulu Natal and Mpumalanga provinces of South Africa. Noelani and her team is evaluating biological and chemical control options. She is testing rootstocks for tolerance and resistance and studying the genes involved in pathogenicity.

Liz Dann reports that WRR is found in Australia too.

Brown root rot (Phellinus noxius) and black root rot – Liz Dann

Liz Dann spoke about ***Phellinus noxius*** which she said is normally spread by root to root contact but could be spread by using chipped wood from infected trees as mulch around other trees. Liz also made a presentation about **black root rot**, the main pathogen being *Calonectria ilicola*.

Botryosphaeria diseases - Randy Ploetz

Randy Ploetz spoke about ***Botryosphaeria*** which causes branch dieback and graft failure. It can also cause fruit rot (eg. stem end rot). Management is difficult because the pathogens are endophytes already within the plant waiting for some stress in the plant to favour their development and adversely affect the plant. The advice is to use pathogen-free scion material. New pathogens are appearing: e.g. *Neofusicoccum nonquaesitum* which causes branch dieback and is thought to be triggered by climate change. Tatiana Cantuarias-Aviles (Brazil) believes in a holistic approach for managing Botryosphaeria which includes the use of gypsum and Trichoderma. Ben Faber mentioned that Botryosphaeria is a problem in California where irrigation is poorly managed.

Fruit rots – Kerry Everett

Kerry Everett from Mt Albert Research Station, Auckland (Plant & Food NZ) gave a presentation on the latest research on **avocado fruit rots** and ***Colletotrichum acutatum*** in particular. She pointed out that *Colletotrichum acutatum* prefers cooler temperatures than *Colletotrichum gloeosporioides. C. acutatum* causes body rots and stem end rots and increases as the season progresses (most infections take place in January) whereas *Phomopsis* (one of the main pathogens that causes stem end rot) decreases as the season progresses. It is thought that pathogens that cause stem end rot infect the tree at flowering. Kerry claims that NZ does not have *Lasiodiplodia* sp., one of the main stem end rot pathogens in Australia.

Stem end rot (SER) - Noam Alkan

Noam Alkan (Volcani Centre, Agricultural Research Organisation, Israel) spoke about **stem end rot**. In Israel, Botryosphaeria is a major issue and there are 193 species of *Botryosphaeria.* He also spoke about *Lasiodiplodia theobromae.* He said that he observes pycnidia (small hard structures containing spores) on branches and that these are the likely source of inoculum for flower infection. Inoculum on / from dead fruit stalks is thought to be a source of new infection on the next season's flowers. He found that spraying flowers with 'Switch' (cyprodinil + fludioxonil) and 'Cannonball' (fludioxonil) fungicides was very effective at reducing stem end rot. The onset of SER can be delayed when treated with 1-MCP. Leaving stem button in place reduces SER. So, management by fungicide at flowering, retaining the stem button, and, anti-ethylene treatment.

Summary of disease session

Note: Neither Avocado Sunblotch Viroid (ASBV) nor avocado scab were discussed.

Kerry Everett summarised the session.

Broad range of organisms involved in root, tree and fruit diseases. PRR is quite well managed. WRR is spreading. Botryospaeria is exacerbated by stress and is a 'universal' issue. Climate

variability / change may alter the disease 'spectra'; e.g. *C. acutatum*. Avocado scab and *Pseudocercospora purpurea* are not yet well studied.

MRLs for phosphonates

- 500 ppm in Australia
- 50 ppm in Europe, South Africa and Brazil
- 2 ppm in Germany

Achieving low MRLs are a big challenge in South Africa in order to meet the low levels demanded by their export markets and for this reason they are considering moving away from stem injection.

Lise Korsten's 'Big Five' in South African avocado diseases

1. Anthracnose
2. Phytophthora root rot
3. Stem End Rot & Botryosphaeria
4. Cercospora spot
5. Avocado Sunblotch Viroid (ASBV)

Important diseases in other parts of the world will include Laurel wilt and *Phellinus noxius*.

Final word: 'Don't forget soil health and a holistic approach'.

CHALLENGES TO PRODUCTIVITY: HOW THE TREE REGULATES RETURN BLOOM AND CROP LOAD

Co-chairs: Harley Smith, Rodrigo Iturrieta & Vered Irihimovitch

Fruit abscission – Harley Smith

Harley Smith (CSIRO Adelaide) led the discussion on fruitlet abscission.

Cessation of growth happens about 8 days prior to abscission, thus abscission is a secondary effect.

Likely process: Fruit abscission signals → Growth arrest → Seed abortion

There may be a threshold of growth necessary for proper seed development. Perhaps there are 'checkpoints' at certain points in the development process and if development hasn't reached a certain level then the fruit abscises.

Alternate bearing - Vered Irihimovitch

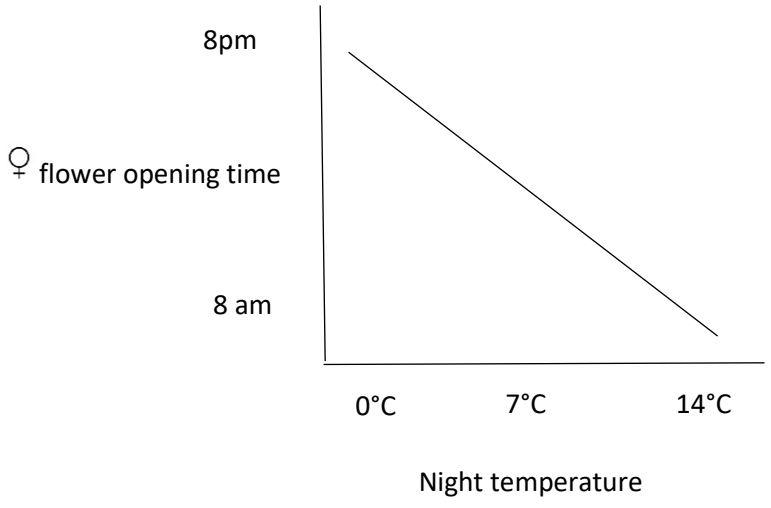
Vered Irihimovitch (Agricultural Research organisation, Israel) is exploring the **effects of fruit load on floral induction in alternate bearing 'Hass' trees**.

Vered has shown that floral induction is controlled by multiple factors, these include the current fruit load, phloem-mobile florigen which controls the expression of a gene called flowering locus T (PaFT), heavy fruit load represses the expression of PaFT in the leaves, high levels of sugar in the leaves allows expression of PaFT, i.e. 'a shoot full of sugar helps the flowering begin'. Hormones such as cytokinins also play a role. They are beginning to understand the relationship between sugar levels, floral genes expression and cytokinin levels.

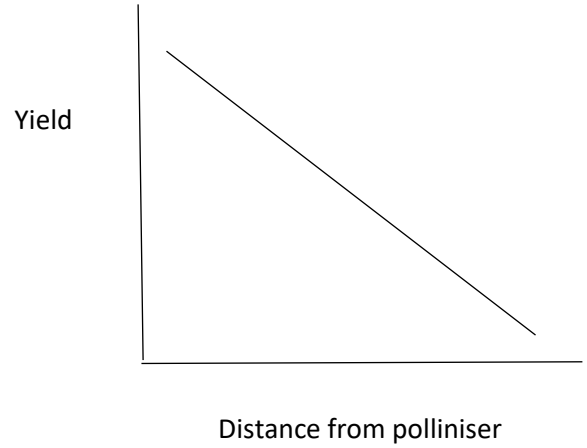
Pollination - David Pattemore

David Pattemore (New Zealand Plant and Food) discussed avocado **pollination and pollinators**.

- Pollination is an interaction between plant and pollinator.
- The variety of the pollen donor affects fruit weight and fruit quality
- Cross pollinated fruit is more persistent on the tree so can improve yield.
- Distance of hive from tree can affect fruit set, more than 60 m is problematic.
- Considerations - position of tree in orchard, distance to polliniser, and, identity of polliniser.
- Most bees have <10 pollen grains on them.
- The majority of stigmas had zero to one pollen grain. The number of avocado pollen grains being carried by bees was also low but in "on" years the bees carried more pollen.
- Pollinators include honey bees, bumble bees, flies, flesh flies, beetles etc.
- Having a diversity of pollinator species improves the chances of pollination.
- Considerations - how many insects, how far they travel, and, how quickly they visit flowers.
- Temperature affects time of flowering - there is a clear delay in opening after a cool night.
- Which insect visitors are the pollinators and what are the management practices to support them? Orchard design does effect pollinators.
- What are the impacts of land use changes, climate change and variability?
- What are consumers' preferences and concerns?



A NZ grower recorded fruit load on each individual tree for six successive years and compared this with the distance to the nearest polliniser variety and the variety of the polliniser.



Challenges:

- What are the effects of pollen parentage on yield and fruit quality?
- What insect species are providing the pollination service? Do management practices help or hinder the pollinators? What are the growers' back-up plans?
- How should orchards be managed to optimise pollination?

Flower quality and fruit set - Iñaki Hormaza

Iñaki Hormaza (Spain) has studied the **effect of flower quality on fruitset**. Considerations are: environmental variables, flower quality, pollinators, and pollinisers.

- Flower and fruit drop is problematic and even hand pollination does not significantly increase yields.
- The first fruit drop phase is the most significant.
- Environment - there are optimum temperature and relatively humidity ranges: 10^{o}C gives less pollen tube growth, 20^{o}C is about optimum, and, 30^{o}C is too high.
- Flower quality - starch content varies markedly per flower. (Use SI staining and OD to assess).
- Flowers with low boron produced less fruit, and flowers with lower levels of soluble carbohydrate also produced less fruit.
- Flowers need to contain sufficient levels of calcium, magnesium, boron and sucrose for fruitset.
- Pollinators – there were no honey bees where avocado evolved.
- Can use higher numbers of beehives per hectare e.g. 10 to 24.
- There are different groups of pollinator species, e.g. in Europe these include bumble bees. Some of these alternative pollinator species can be purchased. Iñaki, like David Pattemore, believes in using multiple pollinator species to improve the chances of pollination and cross pollination, bees, flies, butterflies, beetles etc are all important. Can build 'bee hotels' for solitary bees.
- A European honey bee hive should contain 40 – 50,000 bees with one queen. In almonds ½ hives are more efficient as pollinators but different crops need different types of hives.

- The greater the number of pollen grains on the stigma the better. Iñaki said that up to 40 pollen grains per stigma resulted in better fruit retention. Early drop flowers have no pollen grains. Very few flowers have more than 10 pollen grains and about 90% have none.
- Pollinisers – the pollen donor is very important; e.g. 'Fuerte' is poor, 'Bacon' is better.
- Proximity to polliniser trees is important. Graft some branches or co-plant pollinisers.
- There is quite a variation in starch content in avocado flowers and those with higher levels had a greater level of fruit retention. Iñaki is now measuring nectar levels in avocado flowers.
- Nitrogen application later can positively influence flower quality for next year.
- In the northern hemisphere, nitrogen applied in the October to December period (equivalent to April to June in the southern hemisphere) had a positive effect on fruit yield. Neil Delroy said that he has significantly reduced irregular bearing partly by feeding nitrogen through winter to maintain photosynthesis and build reserves of carbohydrate (starch) in storage organs to drive a strong spring flowering.

Impact of light exposure - Rodrigo Iturrieta

Rodrigo Iturrieta (University of California, Riverside) has been studying **avocado shoots** in relation to canopy management.

- Found that shoots are shorter when fruit is present and that non-fruiting shoots behave differently to fruiting shoots when exposed to full sunlight.
- At a depth into the canopy of only about 50 cm most of the sunlight has been lost.
- Characterising functionally determined shoots along their length requires a common language: viz., 1 flush, simple; 1 flush, branched; 2 flushes, simple; 2+ flushes, branched.
- Patterns may repeat along serial flushes, but dampen, from the shoot tip back.
- Look inside the buds for vegetative vs. reproductive primordia.
- Also important are determinate vs. indeterminate shoots.
- Sunlight gives more and longer flushes and shade prevents lateral branching.
- Branch growth can be modelled.
- Sugar, boron and magnesium interact with cytokinin synthesis that promotes return to flowering in conjunction with other hormone(s).
- 2,4-D sprays applied 3 to 4 months before harvest can reduce fruit drop because auxin plays a role in fruit growth and development and also inhibits the formation of abscission zones and is used in Israel.
- Rodrigo also pointed out that it is important to understand that there is a varietal difference in how shoots behave in response to sunlight, for example a 'Maluma®' branch behaves differently to 'Hass'.

CHALLENGES TO PRODUCTIVITY: WHERE THEORY MEETS PRACTICE

Co-chairs: Francisco Mena, GAMA, Chile & Ben Faber, University of California, Davis

Production considerations - Ben Faber

- Planting density: affects development costs, early returns, costs of maintenance and impacts all subsequent activities for the life of the orchard.
- In terms of tree size, consider economics including picking costs.
- Insect / disease pressures: pesticide application.
- Irrigation: timing, amounts, frequency, affected by rootstock / scion combination.
- Irrigation monitoring: soil based, plant based, evaporation pan based.
- Nutrition: application method, optimum amounts and rates, optimum sampling frequency and plant part sampled, rootstock / scion variability.
- Pollinators: honeybees, alternatives.
- Pollinisers: cultivar, % of tree sites planted.
- PGRs: management, fruit residues and export issues, use in canopy management.
- Phosphite: inject, soil, foliar.
- Fruit load / harvest date: maturity, ripening, shipping.
- Need to consider fruit size and pack out economics.
- Genetics: light interception, fruit productivity, density, natural architecture, ideal architecture.
- Growing conditions: temperature moderation, controlled environment (e.g. high tunnels).
- Plant and soil health.

Four questions:

1. What is the perfectly balanced tree?
2. How do environmental and food safety practices affect practices?
3. Are there any effects on fruit flavour and chemistry?
4. What research will give the best solutions?

High density orchards - Francisco Mena

Presented by Francisco Mena, GAMA, Chile. Francisco talked about his research work with **high density orchards**. High density plantings behave differently and they had to learn how to manage them. Aiming for 30t/ha, Francisco monitored the performance of 200 individual 'Hass' on 'Velvick' trees for 4 years. Pollinisers made up 11% of tree spaces.

- The best 20 trees produced fruit each year whereas the worst 20 worst did not.
- The characteristics of the 20 most productive trees were more consistent.
- 35% of trees produced the equivalent of over 20 t/ha.
- 5% of trees produced the equivalent of over 30 t/ha.
- Did not find a spatial (across the orchard) reason for yield variation from yield maps. Are the results due to the scion, the rootstock or the soil?
- Each year you can mark the trunk of each tree with a colour code to represent its productivity, using say three different levels. If you start with a high density orchard then after a few years you can identify the poor performers and weed out them out so that the more productive neighbours can fill the space.

- You need trees to fill a good degree of the available orchard space but if close spacing doesn't work you can remove every second tree and the trees will still fill the space.
- Trees with the most flowers don't necessarily have the highest yield.
- Flower quality is at least as important as flower number, perhaps more.
- Delayed fruit removal gave reduced flowering.
- Trees that were consistently harvested early had consistently the best yields. Trees that were consistently harvested late resulted in 10 t/ha less yield over a period of 4 years.
- Not sure of the best timing for irrigation and will look at effects on fruit drop.
- The 3x3m planting on the DASA orchard averaged 28 t/ha each year from 2009 to 2014.
- A 6 x 6m planting averaged 19 t/ha compared to a 3 x 3m spacing of the same age which yielded 23 t/ha.
- Tried 1.25 x 1.25 m and got 25% yield increase.
- Pruning with respect to tree age and shading levels and timing during the year, light intensity and long term light penetration.
- They were over-concerned about tree shape and found themselves pruning too much in order to reach a particular canopy shape but timing of pruning is very important.
- Manage each tree branch as an individual 'tree' and maintain <80 cm canopy thickness.
- GAMA typically applies three doses per year of paclobutrazol to the soil in the high density through the drip irrigation.
- Use PGRs to increase yield via more balanced trees. Applied via drippers or via sprinklers with and without a deflector for better distribution across the root zone.

Paclobutrazol rate	**Yield**
0	9.5 t/ha
2 L/ha	14 t/ha
4 L/ha	22 t/ha

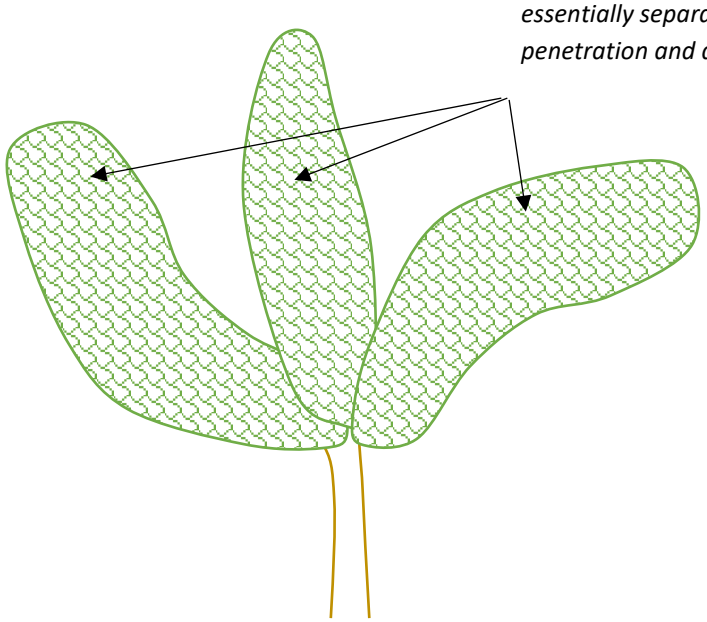
Uniconazole rate	**Yield in 1st year used**	**Yield in 2nd year used**	**Yield in 3rd year used**
0	20 t/ha	15	12.5
2 L/ha	21	11	26
4 L/ha	29	19	30

- Uniconazole results in more complexity in the branches and shorter internodes resulting in a different tree shape.
- GAMA has experimented with 2 L/ha of Sumagic (active ingredient uniconazole) at different times of the year, namely Oct, Nov, Dec, Jan & Feb.
- They have found that if PGRs are applied when the trees are too young they won't grow enough and fill out the space properly.
- They haven't been able to detect residues of PGRs in fruit as a result of soil applications.

- PGRs are sprayed by helicopter in spring but applied at other times of the year through the irrigation.
- The smaller the trees the longer the hours of photosynthesis.
- For picking safety they like to keep the trees at 2 to 2.5m maximum height.
- Francisco's current recommendation in the Chilean environment that he works is for a tree spacing of 2.5 x 2.5m (1,600 trees / ha).

In WA Neil Delroy pointed out that one of his pruning strategies is to prune the tree in such a way that each individual branch is treated as an individual tree with its individual 'canopy' no wider than 80 cm. This is based on the fact that light intensity is 40% of full sunlight at 0.5m inside the canopy and is only 20% at 1m inside the canopy.

The tree is pruned to create branches that are essentially separate trees with respect to light penetration and distribution.



There was general consensus that PGRs are required to manage 'Hass' but 'Maluma®' may be able to be grown without.

Sustainable production in Brazil - Tatiana Cantuarias-Aviles

Tatiana Cantuarias-Aviles (Brazil) explained her work creating better **soil health** with **more sustainable farming practices**.

- Tatiana has found that as growers become more dependent on pesticides and chemical fertilisers avocado trees become more susceptible to pests and diseases.
- By using green manure crops before planting and mineral amendments such as rock dust, lime and gypsum and organic amendments they are seeing lower levels of pests.
- Using this more sustainable approach they are noticing more diversity in weeds and soil microbiology and there is more release and availability of minerals for plant uptake.
- Systemic herbicides such as glyphosate are being replaced by contact herbicides.
- Weed species can reflect soil conditions, including nutrient ratios.
- Use biological pesticides / biocontrol for disease and insect management.
- *Trichogramma* spp egg parasites are being distributed over the orchard using drones.

- Use supernatant of aerobic fermentations.
- For Phytophthora root rot they use biological control with *Trichoderma* spp etc along with sustainable plant and soil health practices - verging on 'biodynamic' practices.
- They have been able to reduce the number of pesticide sprays from 8 to 10 down to 3 to 5.

ZZ2 is paying a lot of attention now to soil health.

CHALLENGES TO PRODUCTIVITY: GENETICS, GENOMICS AND BIOTECHNOLOGY

Co-chairs: Aureliano Bombareley & Iñaki Hormaza

Community genomic resources - Aureliano Bombareley

Aureliano Bombareley (Virginia Tech, USA) floated the idea of developing a **community driven avocado genomic resource** to bring together a network of multiple and diverse experts to work together. He likened it to how Google works where everyone contributes. He suggested it be referred to as the 'Avocado Genomic Consortium'. However he thought that 'Hass' is too heterozygous to use and 'VG75' is now sequenced, it is less heterozygous and would be a better variety to conduct the work on. 'Tripal' was recommended as a suitable community database for working on the genome. The strength of community driven genomic resources are a network of experts, efficient use of resources, resolution for the big picture, long term strategy optimisation, high impact publications, and, data mining training network.

Aureliano Bombarely, Iñaki Hormoza, Sarah Mwanga (University of Pretoria, South Africa), Fernando Pliego-Alfaro and Elena Palomo (the latter two from University of Malaga, Spain) discussed technical details of avocado genomics including the concept of genetic research to develop a molecular toolbox resource containing information about each gene that could dipped into when required. An avocado genome consortium has been formed. Their areas of specialisation are as follows.

- Characterisation of cultivars by morphometric and genomic tools - Inaki Hormaza
- Genomics and transcriptomics of avocado - Sarah Mwangi
- Avocado genetic transformation and micropropagation - Elena Palmo Rios

Preserving avocado germplasm - Jose Chaparro, Neena Mitter and Mary Lu Arpaia

Jose Chaparro (University of Florida), Neena Mitter (UQ) and Mary Lu Arpaia (University of California, Riverside) discussed the need to collect and preserve wild avocado germplasm before it was too late since loss of habitat all over the world is a major issue. Cryo-preservation of shoot tips is an option although somatic embryos are not true types. Mary Lu pointed out that Alejandro Barrientos-Pliego (Mexico) manages an avocado genetic collection at Centro de Investigaciones Cientificas y Tecnológicas del Aguacate en el Estado de Mexico (CICTAMEX) in Mexico.

MEETING THE CHALLENGES OF THE FUTURE

Co-chairs: Mary Lu Arpaia, Zelda Van Rooyen & Tim Spann

A session was held to identify and then discuss what delegates felt were important topics for avocado research going into the future.

The top three issues

1. **Plant improvement and genomics**
    - Variety diversification
    - Rootstocks
    - Breeding tools
    - Genomics
    - Climate adaptation
2. **Productivity and crop management**
    - Water availability, quality and cost
    - Alternate / irregular bearing to achieving more stable production
    - Canopy management
    - Precision agriculture/harnessing new digital and remote technology
    - Sustainability
3. **Quality and post-harvest**
    - Food safety (without hysteria) – human pathogens, post-harvest pathogens, food contamination, chemicals and chemical residues
    - Quality in the supermarket and in the consumers' homes – there is currently little feedback about this to growers

Other important areas include propagation, genetic resources, profitability, economic analysis, communication and funding.

DISCUSSION

Variety diversification

A better 'Hass'; different avocados (viz. need to change); disease; education; genetic resources; sharing databases; markers.

Rootstocks

Characteristics sought – stress resistance e.g. for salinity; Phytophthora root rot resistance; water use efficiency (WUE), dwarfing; fruit quality; canopy architecture; biochemical characterisation; priming for defence.

Breeding and selection process - standardised and faster selection process informed by genomics; manufacture a dwarfing gene via gene editing; markers for disease tolerance; foci of Phytophthora root rot tolerance; marker assisted selection, including metabolomics and biochemical characterisation; priming rootstocks for epigenetic characteristics; introducing RNAi in clay nanoparticles; community sharing of information on rootstocks.

Commercialisation - graft compatibility; faster propagation rates for desired selections; inoculation with beneficials (e.g. mycorrhizae); micro-grafting; rootstock availability; longer protection, cf. patent (~20-25 years) and Plant Breeders Rights (~30 years).

Breeding tools

Global community based approach base; genetic resource response team; ID of markers; mutagenics; RNAi; GMO; gene editing (e.g. CRSPR).

Genomics

For breeding programs (cv. identification and relationships); performance in different environments; resources for growers and researchers to understand; how to contribute / assist; and, communication, such as via Blockchain.

Climate adaptation

Varieties with a shorter development period to avoid early and late frosts; flower initiation.

Water availability, quality and cost

Water use efficiency (WUE); sufficient, clean, safe, low salt, etc.; monitoring / testing; runoff; management; precision irrigation on a per tree basis; scion-rootstock tolerance to stress (e.g. drought, heat, salinity); plus sunblocks, biofilms, netting etc. to reduce stress and enhance WUE.

Alternate / irregular bearing to achieving more stable production

Applying heavy nitrogen early to induce more fruit drop at the 1st drop rather than 2nd; the need for a light management model; the high variability between trees highlights the need for yield mapping to identify rootstocks that yield more consistently; the use of fertiliser through winter; rootstock and scion characteristics; flower thinning; canopy management; treating each branch as a tree; girdling and removed over 3 years; spiral girdling; timing of pruning relative to irrevocable commitment; PGRs and their application timing; mitigation of on/off years; removing water shoots; shading; flower quality; pollination; carbohydrate levels.

Canopy management

Canopy management research based on modelling light penetration and utilisation with respect to production is needed for varying environments; the practice of maintaining four main branches on a tree and girdling one of these each year before cutting it off after harvest

Precision agriculture/harnessing new digital and remote technology

Drones, satellites, etc.; advisory centres that are accessible; soil and soil health maps; robotics; apps on tablets and phones for growers; fruit tracking; decision aid tools based on data management considering data mining, data mass and scale, data timing, data precision and data accuracy; responses to incoming information; yield mapping, including with respect to tree health, irrigation, nutrition etc. offers opportunity.

Quality and post-harvest

Quality to consumer:

Operator error factors = feedback to grower from consumers; consistent postharvest safe operating procedures (SOPs); testing of fruit through the supply chain (e.g. NIR, destructive sampling, etc.); confirmation of product origin (e.g. chemical, gene profile); endogenous factors = gene expression changes in fruit, epigenetic changes in harvested fruit; greater focus on taste and consistency through postharvest in variety development.

Food safety:

PGRs, standardisation of MRLs for chemicals such as phosphonates - understanding and regulation around phosphonate is confusing and confounded; standardisation of tests; traceability systems (e.g. using Blockchain); communication (e.g. be prepared to address concerns; communicate in a consumer-orientated manner and have consistent messages ready to go).

TYING THE LOOSE PIECES TOGETHER – PLANNING FOR THE FUTURE

Co-chairs: Nigel Wolstenholme & Jose Chaparro

Avocado growing: Planning for the future - keeping the big picture in mind – Prof Nigel Wolstenholme

Nigel Wolstenholme (Professor of Horticulture Emeritus who had spent 40 years at the University of Kwa-Zulu Natal, Pietermaritzburg, South Africa) had prepared an eight page paper entitled ***"Avocado growing: Planning for the future – keeping the big picture in mind"*** which he presented to the delegates. In this paper he looked at the development of the avocado as a commercial crop and attempted to look into the future to try and predict what changes there would be and how to position avocado to take advantage of new technology and changing consumer preferences.

Nigel attempted to look at the world in 2030 and listed the following:

- Major scientific advances particularly in the fields of genomics, robotics, artificial intelligence
- Climate change – higher temperatures and more extreme weather events
- Poverty, over-population, inequality and unemployment across the world
- The rise of China

Trends in agriculture and horticulture

- Changes in land ownership and operation
- Commodities vs. products
- Globalisation, free trade and fickle consumers
- Sustainable farming, safer food trends and traceability

The evolution/development ('evo-devo') of the avocado – a unique tree crop

What is unique about avocado?

- The mature flesh is high in oil (8 to 30%)
- It is 'expensive' for a plant to make oil
- The fruit will not soften on the tree

- The harvested fruit has a very high respiration rate (especially 'Maluma®' variety) requiring prompt cold storage to slow down fruit softening
- The main translocation sugar are 7 carbon sugars (perseitol and mannoheptulose)
- In evolutionary terms avocado is a primitive plant of the Magnoliid clade near the origin of flowering plants and is an unusual fruit tree (e.g. high flower number and low fruit set, energy-expensive, low carbohydrate but high oil fruit, non-ripening on tree fruit; 7-carbon transport sugar), primitive plant,

Vegetative adaptive strategies

- Tree architecture facilitates competition with montane climax forest trees. Growth is very responsive to pruning.
- Leaf flushes are episodic, typically there are two per year in the humid subtropics, three in semi-arid winter rainfall climates and up to four in tropical Mexican highlands and several more in tropical lowland bearing trees.
- High net photosynthesis rates are possible resulting in vigorous peripheral growth, in native forests growth is vertical until an emergent canopy is formed.
- Leaves are short-lived (typically 10 – 12 months) and fairly shade tolerant (at the expense of flowering and fruiting).
- Feeder root growth is shallow and proliferates in well-aerated topsoil (roots have a high oxygen requirement).
- Tree growth does not make heavy demands on the soil and so fruiting is relatively 'mineral cheap'.

Reproductive strategies

- Flowering has a high light requirement and occurs on well-lit peripheral shoots of sufficient age.
- Flowering is intense and can be prolonged thus making heavy demands on water, nutrients and carbohydrate resources at a critical time.
- Honeybees are not present in native forests, pollination was carried out by a range of small insects.
- The flowering behaviour (male/female stages) known as synchronous alternating dichogamy favour outcrossing but self-pollination is common.
- Massive abscission of flowers and fruitlets occurs and results in only highly selected fruitlets remaining.
- A second fruit shedding occurs to prevent over-bearing.
- Crop size is correlated with flowering intensity on healthy trees.
- The avocado fruit is strongly dependent on its large seed and seed coat until maturity.
- Fruit softening only occurs in 'subtropical' varieties after separating from the tree.
- Avocado is not good at regulating its crop – it has irregular and alternate bearing which is thought to have evolved to give the species greater chances of survival in stressful environments.

Past, present and future avocado orchards:

Past

- Large trees
- Long juvenile period
- Profuse flowering
- Irregular bearing
- Low yield
- Large seed
- Susceptible to Phytophthora root rot

Present

- Medium sized trees
- Precocious
- Annual bearing
- Average yield (10 – 15 t/ha)
- Moderate seed size
- Phytophthora root rot tolerant rootstocks

Future

- Semi-dwarf trees
- Precocious
- Annual bearing
- High yield (30 t/ha)
- Small seed
- Phytophthora root rot resistant root stocks

Current technical problems

- Low yield
- Alternate and irregular bearing
- Susceptible to Phytophthora root rot
- Scion monoculture ('Hass')
- Rootstock monoculture
- Uncertainty about best practice orchard management

Future avocado breeding - Jose Chaparro

Jose Chaparro (University of Florida) gave an address focussed mainly on **future avocado breeding**.

To put things in context he compared how many generations different horticultural tree crops have been the subject of domestication:

- Avocados – 2 generations
- Macadamia – 2 to 3 generations

- Citrus - 5 to 7 generations
- Stone fruit - more than 20 generations

What domestication traits exist in current avocado cultivars? Apart from historic selection of types with more flesh around the seed by Central American civilisations (e.g. Aztecs, Incans) the avocado has hardly changed from its wild state.

A plant breeder needs to be thinking about the likely needs of the consumer and supply chain including the grower 20 to 30 years ahead. What is the ideal type ('ideotype') of avocado?

Yield enhancements may come from changing plant architecture; e.g. dwarfing, determinant growth, leaf arrangements, flower structure.

Vegetatively:

- Reduced branching
- Reduced extension growth
- Reduced tree height

Reproductively:

- Short juvenile period
- Less flowers
- Reduced dependency on flower dichogamy for fruitset
- Shorter bloom period, less out-of-season flowering

Possible fruit traits to pursue:

- Different flesh types, e.g. hard?
- Different flesh colours?
- Edible peel?
- Seedless fruit?
- Non-climacteric fruit

POSTERS

About 26 posters were prepared and displayed at the conference by delegates.

Topics covered included:

- Diseases including Phytophthora root rot, soilborne nectriaceous fungi, Laurel wilt, branch canker, dieback and stem end rot associated with Botryosphaeria, Verticillium (Australia, Chile, Florida, Israel, South Africa, USA)
- Effect of crop load on return bloom (New Zealand)
- Salinity (USA)
- Water use by avocado (New Zealand, South Africa)
- Use of plastic mulch for more efficient water use (Israel, Chile)
- Use of plastic greenhouses for more efficient water use (Chile)
- Frost damage and tolerance (Israel)
- Flesh bruising (Australia)
- High density plantings (New Zealand, USA)
- A new type of avocado discovered in Mexico
- Cryopreservation of avocado germplasm (Australia)
- Avocado propagation (Australia)
- MicroRNA control of vegetative phase transition in avocado (Australia)
- Effects of temperature on fruitset (New Zealand)

SUMMARY

The South African avocado industry is predominantly aimed at export and continues to expand through good leadership, innovation and research. The excellent tree health at all the orchards we visited was noticeable, attributable at least in part to strict adherence to phosphorous acid application protocols, well drained soils, universal use of planting mounds and the widespread use of proven Phytophthora resistant/tolerant clonal rootstocks such as 'Dusa®' and 'Bounty®'.

The small 'Avocado Brainstorming 2018' conference was an ideal opportunity to network, catch up on innovative research and find out about the latest nursery and orchard management practices.

ACKNOWLEDGMENTS

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