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Reducing flesh bruising and skin spotting in Hass avocado

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The Department of Agriculture and Fisheries (DAF)

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Reducing Flesh bruising and Skin Spotting in ‘Hass’ Avocado

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Research Provider: Department of Agriculture and Fisheries

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Summary

Flesh bruising is a major postharvest concern of the avocado industry. As much as ~ 80% of fruit on retail display can have some degree of internal quality issues, mainly flesh bruising. HIA Limited Project AV10019 was commissioned with the objective of identifying critical points in the supply chain where events that lead to flesh bruising happen. Also, the incidence of skin spotting at different stages of the supply chain was evaluated with a view to scope the need for future research on this defect. The target audience of this project is commercial producers, traders and research organisations.

The project was comprised of four parts:

- Through a series of laboratory experiments, relationships between applied mechanical forces to elicit bruise expression in 'Hass' avocado flesh and impact energy absorbed by individual fruit and fruit in trays, fruit dry matter at harvest, fruit holding duration pre-ripening, fruit firmness at bruising, time period after impact, and pre and post-impact fruit holding temperature were investigated. Also, proton magnetic resonance imaging (H^1-MRI) was evaluated as a non-destructive tool for assessment and monitoring of bruise development and severity over time in 'Hass' avocado fruit. The research determined that bruise severity was increased with: greater impact energies, tray dropping on an angle as compared to dropping from the horizontal, softer (i.e. less firm) fruit, fruit harvested earlier in the season, and ambient temperature handling versus lowered pre and post-impact temperatures. As was confirmed by destructive sampling in parallel, MRI proved to be a useful tool for non-destructively visualizing expansion in bruise volume over time after initial impact events.

- Relatively extensive fruit sampling was undertaken at six serial supply chain points: ripener arrival, ripener dispatch, distribution center arrival, distribution center dispatch, retail store arrival, and retail store display. Attendant bruise assessment through the supply chain showed that bruising trended to increase as the fruit passed through the supply chain. However, bruise severity was especially problematic at the retail store display point, being significantly higher than at all preceding sampling points.

- Three commercially available means of determining impacts were tested in supply chain experiments as potential decision aid tools: tri-axial ShockWatch® ShockLog, Impact Recording Device®, and ShockWatch® impact indicator clips. The two electronic devices placed into trays of avocado fruit reliably discerned impact events. However, relatively low cost 5, 10, 25, 35, and 50 G ShockWatch® impact indicator clips attached to trays were insensitive.

- Surveys of wholesalers, retailers, and shoppers suggested that skin spotting particularly concerns wholesalers and retailers as compared with shoppers. The former considered that sales price and volumes are negatively affected by increased skin spotting. Skin spotting data acquired monthly by Avocados Australia Limited (AAL) from independent and supermarket retail stores in Western Australia, Victoria, New South Wales, and Queensland was interrogated. Assessment of the data determined that skin spotting does not follow any particular pattern for either incidence or severity.

The learnings from this project were extended to industry through articles in Talking Avocados, other print and also electronic and social media, talks at conferences and industry meetings (including Qualicado workshops), and one-on-one discussions with stakeholders including AAL, ripeners, and retailers. Key strategies to lessen bruising and bruise expression in avocado cv. 'Hass' fruit are: harvest fruit at and above the minimum recommended dry matter content, maintain stringent low temperature management including at retail, and rapid fruit handling through the supply chain, so as to minimize 'time in the chain'. Complimentary HIA Ltd project AV12009 focused on the potential contributions of shoppers and consumers in causing unsightly bruising of 'Hass' avocado fruit. That report should be read in conjunction with the present report. With a view to addressing an evident issue, further research is recommended into quantifying relationships between skin spotting and fruit physicochemical condition (e.g. turgor pressure) and transport conditions and associated handling operations in avocado supply chains.

Keywords

Bruise intensity, bruise severity, dry matter, firmness, flesh bruising, holding duration, magnetic resonance imaging, *Persea americana* M., supply chain, temperature.

1. Introduction

Avocado (*Persea americana* M.) is a subtropical fruit of high nutritional and economic value. Queensland produces ~ 80% of the total avocado production in Australia. 'Hass' is the predominant commercial cultivar comprising ~ 81% of the total production.

1.1 Flesh bruising

Consumers like to buy ripe avocado fruit for fresh consumption (Gamble et al., 2008). However, retail surveys (Embry, 2009; Gamble et al., 2008; Hofman et al., 2001) have established that up to 80% of fruit displayed on retail shelves can have some degree of internal fruit quality defects, often flesh bruising (Fig. 1.1) (Hofman, 2011). These retail surveys have also confirmed that a consumers' intent to repeat purchase is negatively affected if > 10% of the fruit flesh and > 10% of the total number of fruit are adversely affected by flesh damage (Gamble et al., 2010).

Fig. 1.1 Flesh bruising in a 'Hass' avocado fruit sampled from a retail store display.

Avocado fruit do not express visible bruising until they start softening in the ripening process (Mazhar et al., 2015). Hofman (2003) reported that 55% of 185 consignments from different sources representing average industry practices did not yield any fruit with bruising when sampled from the end of the packing line at hard green mature stage. Only 7.4% of the total fruit number had minor damage to < 5% of the fruit flesh volume when assessed at fruit ripening. Moreover, only 0.6% of the 3700 avocado cv. 'Hass' fruits examined had >15% of their total volume affected by flesh bruising when assessed at ripe stage. These results affirmed earlier findings of Arpaia et al. (1987), Katz (1988), and Milne (1998) as to the close association of flesh bruising with fruit ripening.

The fruit ripening process continues to progress as fruit travel along the supply chain from orchard to retail store. In this context, fruit firmness continues to decrease and fruit susceptibility to flesh bruising increases, even in response to relatively small impact and compression events (Baryeh, 2000). However, detailed relationships between bruising and specific fruit condition and handling variables, such as impact energy absorbed by individual fruit and by those in fruit trays, dry matter at harvest, pre-ripening fruit holding duration, fruit firmness at injury, time elapsed period after impact, and pre and post-impact fruit holding temperature, were little understood.

In general, fresh produce quality deteriorates markedly as it travels through the supply chain (Batt and Cadilhon, 2007). With regard to flesh bruising, it is often reported as an issue with avocado fruit dispatched from the ripener and from the DC and, even more so, subsequently with fruit on the retail shelf (Hofman and Sandoval (2002). Improper handling practices at all stages through the supply chain and merchandising contribute to the incidence and severity of bruising in 'Hass' avocado fruit (Bennett, 1994). Hofman and Ledger (2001) indicated that avocado fruit bruising events can occur anywhere in the supply chain and so recommended careful fruit handling from harvesting onwards. These researchers suggested a need for the development and application of methodologies to identify where and how bruising occurs in the supply chain with a view to improve postharvest practices. They further suggested that the research and development into bruising might focus on from ripening onwards in avocado fruit supply chains. In general however, incidence and severity levels and the points of initiation of flesh bruising in avocado fruit supply chains were and are poorly understood.

In the retail sector, supermarket supply chains are growing worldwide, including in Australia (HAL, 2011). Aside from convenience and other factors (e.g. prices), their growth is also attributed to compliance with quality, health, safety, and hygiene expectations of consumers. In Australia, supermarkets account for ~ 65% of total retail sales of fresh avocados. Accordingly, most previous research has focused on avocado fruit quality on display in supermarket retail stores (Embry, 2009; Gamble et al., 2010). Independent fruit retailers capture the second largest share at ~ 35% of avocado fruit supply to consumers (McGrath, 2008). It appears that no prior study has reported comparative assessment of incidence and severity of flesh bruising in avocado cv. ‘Hass’ fruit on display in independent and supermarket retail stores.

In this general context, an understanding of avocado fruit physiology is potentially useful for stakeholders’ businesses in regard to managing fruit handling practices. Avocado fruit are exceptional in that they do not ripen on the tree. Once harvested, the natural fruit ripening processes commence. The biosynthesis of ethylene by avocado fruit is high (~ 80 - 100 μ.L.L^{-1}) as compared, for example, with that by banana (~ 40 μ.L.L^{-1}) and mango (~ 3 μ.L.L^{-1}) fruit (Seymour and Tucker, 1993). Binding to receptors of the ethylene produced initiates an increased rate of respiration. In concert with the respiratory climacteric, cell wall degrading enzymes soften the ripening fruit. For ‘ready to eat’ fruit, exogenous application of ethylene by ripeners is carried out to initiate and co-ordinate uniform and timely fruit ripening. Changes in avocado fruit cell wall structure are attributed to the activity of cell wall degrading enzymes. In the course of the ripening process that leads into senescence with ultimate cell disassembly, decreased tissue cohesiveness is largely attributable to pectin degradation between adjacent flesh cells by polygalacturonase (Brummell, 2006).

In the current study, bruise severity in avocado cv. ‘Hass’ fruit as affected by impact energy absorbed by the fruit, dry matter content at harvest, firmness, holding duration, and holding temperature was assessed. Actual incidence and severity of bruising in avocado fruit passing through the supply chain from the ripener to the retailer was characterised. Also, an impact recording device (IRD), a ShockLog, and simple impact indicator clips were evaluated in a supply chain context. As indicated, fruit quality in terms of flesh bruising was also compared for avocado fruit on retail display in independent and supermarket retail stores.

1.2 Skin Spotting

Skin spotting (SS) on avocado fruit is typically associated with mechanical injury during harvest and packing (Fig. 1.2) (Everett et al., 2008). The symptom typically manifests 1 - 4 days after damage in the form of small dark spots of < 1 mm diameter (White et al., 2009). SS on ‘Hass’ can be all but invisible on fully coloured ripe fruit. However, it is easily discerned on partly ripened and poorly coloured fruit (Hamacek et al., 2005).

Typical levels of SS severity on partly or poorly coloured fruit can reduce the consumers’ intent to purchase (Harker and White, 2010). Excessive SS may result in loss of value from either rejection of consignments and / or price reductions at wholesale and retail levels. However, limited appraisal of SS in the supply chain has been conducted in the Australian situation.

Fig. 1.2 Skin spotting on avocado cv. ‘Hass’ fruit.

Towards better understanding the incidence, severity and perception of SS for fruit in retail outlets across Australia, this study explored retail store survey data sets collected in monthly avocado fruit quality surveys coordinated by AAL.

2. Methodology

The project research agenda was divided into four distinct but complimentary areas.

2.1 Bruise expression in avocado fruit

A series of experiments was conducted to discern relationships between flesh bruising levels in avocado cv. 'Hass' fruit and: impact energy absorbed by individual fruit and fruit in trays; fruit dry matter content at harvest; pre-ripening fruit holding duration; fruit firmness at bruising; time period after impact; and, pre and post-impact fruit holding temperatures. Experiments described in Sections 2.1.1 and 2.1.2 also are included in the final report of HIA Project AV12009. The fundamentals underpinning the incidence of flesh bruising in avocado fruit as covered in these experiments are general and, as such, facilitate understanding flesh bruising as fruit travel through the supply chain.

2.1.1 Effect of impact energy absorbed by individual fruit

This experiment was conducted to confirm the proposition that bruise severity in avocado cv. 'Hass' fruit increases with high impact force applied (Arpaia et al., 1987).

2.1.1.1 Fruit samples: Hard green mature avocado cv. 'Hass' fruit were collected from a ripener in the Brisbane Produce Market, Rocklea. These fruit were transported in ~ 1.5 h to a postharvest laboratory at the Gatton campus of The University of Queensland (UQG). The fruit were dipped for 10 min in a solution of 1000 $\mu L.L^{-1}$ ethephon (ethylene releasing agent) as Ethrel® (480 $g.L^{-1}$ 2-chloroethylphosphonic acid; May & Baker Rural Pty Ltd., Homebush Bay, NSW, Australia) plus 0.01% Tween® 40 (polyoxyethylenesorbitan monopalmitate, Sigma-Aldrich Inc., St. Louis, MO, USA) wetting agent for initiating the fruit ripening process. These fruit were then air dried and kept in a darkened shelf life room at 20 °C and 85% RH until they reached the firm ripe stage of hand firmness (Table 2.1) (White et al., 2009). Fruit weight was recorded to one decimal point in grams (g) with a Sartorius GMBH B100S digital balance (Sartorius®, Dandenong South, Victoria, Australia) to select uniform fruit for each treatment. Each fruit was labelled with Pental™ white 100 WM marker.

2.1.1.2 Firmness: Fruit were initially assessed for hand firmness after (White et al., 2009). Subsequent quantitative firmness values were measured with a non-destructive analogue firmness meter (AFM) (Fig. 2.1) (Macnish et al., 1997). The AFM was used to quantitatively measure fruit firmness without causing bruising in the actual process of firmness measurement.

Table 2.1 Avocado hand firmness guide (White et al., 2009).

0	Hard, no ‘give’ in the fruit.
1	Rubbery, slight ‘give’ in the fruit.
2	Sprung, can feel the flesh deform by 2-3 mm. under extreme thumb force.
3	Softening, can feel the flesh deform by 2-3 mm. with moderate thumb pressure.
4	Firm ripe, 2-3 mm deformation achieved with slight thumb pressure. Whole fruit deforms with extreme hand pressure.
5	Soft ripe, whole fruit deforms with moderate hand pressure.
6	Over ripe, whole fruit deforms with slight hand pressure.
7	Very over ripe, flesh feels almost liquid.

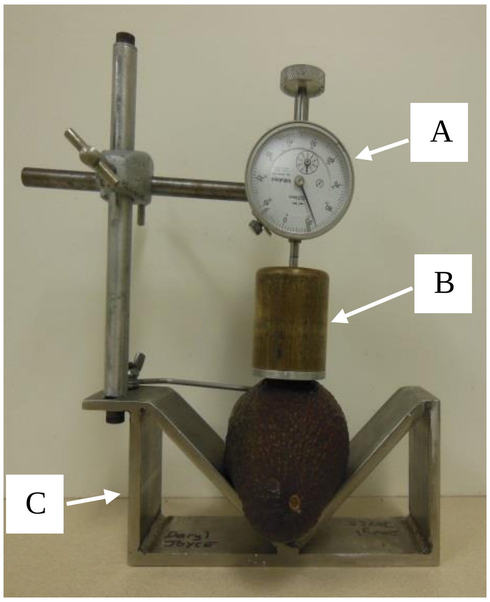

Fig. 2.1 Analogue firmness meter used for firmness (mm) assessment of avocado cv. ‘Hass’ fruit. The round dial gauge (A) is manually to zero and then fruit is placed under a 0.5 kg load (B) for 30 sec in a fruit holder (C). Fruit deformation in mm is recorded.

2.1.1.3 Experimental design and treatments: This experiment was conducted as a completely randomised design. Fruit were sorted into matched samples and assigned to treatments (n = 10) T1 = dropped from 25 cm (energy absorbed ~ 0.38 J), 50 cm (~ 0.81 J), and 100 cm (~ 1.67 J).

2.1.1.4 Impact force application: Each fruit was impacted against a solid metal surface with a swing arm avocado fruit impact device (Fig. 2.2), after Opara et al. (2007), from treatment specific heights. The energy absorbed by each fruit was calculated after Schoorl and Holt (1980). Briefly, $E = m \cdot g \cdot (h_d - h_r)$; where , E = energy absorbed (J), m = fruit mass (kg), g = acceleration due to gravity (the constant, 9.8 $m.sec^{-2}$), h_d = drop height, and h_r = rebound height.

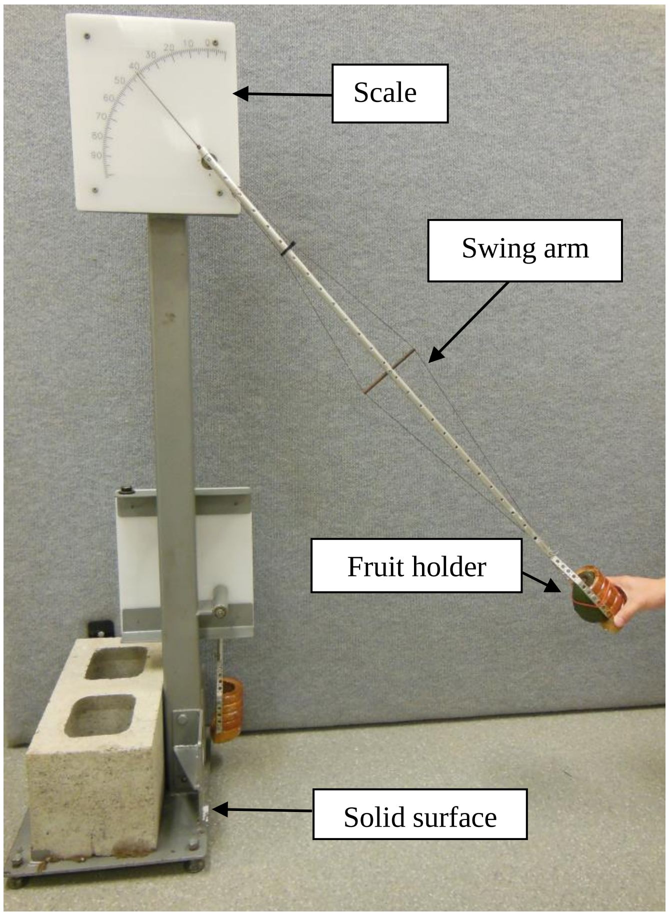

Fig. 2.2 Individual avocado fruit drop equipment. A single fruit was placed in the holder attached at the distal end of the swinging arm. The fruit was raised to the desired drop height for release and free fall onto the solid metal plate surface. The rebound height of fruit was observed against the measuring scale and recorded.

White paint was labeled on the solid metal surface of impact device, so that upon impact the impact site of the fruit surface could be distinguished. The impact surface area on each fruit was traced with a white marker. The treated fruit were then held at 20 °C for subsequent destructive bruise volume assessment at 48 h.

2.1.1.5 Bruise severity: Bruise severity was measured after Rashidi et al. (2007). The bruise-affected flesh of the fruit was excised and submerged into tap water in calibrated measuring cylinders of different volumes. The displacement volume of water was recorded. The volume of any cracks resulting from impact was also taken into account by filling them from a calibrated syringe. When appropriate, the crack volume was added to that of bruised tissue to estimate the total bruise volume. An indicative relationship of bruise severity in terms of the volume and the percentage of bruised flesh was established. In an average fruit (~ 250 g), ~ 2 mL of bruise volume equates ~ 1% of bruised flesh. In individual instances, the relationship between bruise volume and proportion of bruised flesh depends on fruit size and on the size of the seed in that fruit.

This experiment was arranged, conducted, and analysed as a completely randomised design. Data were collated in Microsoft Office 2003 Excel (Microsoft®, North Ryde, NSW, Australia). The experiment data were subjected to ANOVA using Minitab® 16. LSD tests at $P = 0.05$ were applied to determine significantly different treatments.

2.1.2 Effect of impact force applied to fruit in trays

Twelve trays of firm ripe (White et al., 2009) avocado cv. 'Hass' fruit were prepared as described in section 2.1.1.1. Fruit were match sampled on the basis of visual size and hand firmness, and were assigned into trays ($n = 3$) for each treatment. Each tray contained 24 fruit. An Impact Recording Device® (IRD) (SN 634 Techmark®, Inc., Lansing, MI, USA) was placed in each tray in turn for treatment specific drops. Tray drops were affected with a purpose built avocado tray drop device. Tray drop height was measured from the centre of the tray. Individual fruit were labeled with a white marker. The firmness of each fruit was objectively measured with the AFM. The weight of individual fruit as well as the weight of the tray full of avocado fruit were was recorded using a digital mass balance. Treatments based on tray drop height and drop angle were: T1 = 25 cm, 0 degrees angle from horizontal; T2 = 25 cm, 30 degrees from horizontal; T3 = 50 cm, 0 degrees; and T4 = 50 cm, 30 degrees.

The avocado tray drop device was designed and manufactured at the School of Agriculture and Food Sciences of UQG (Fig. 2.3 A). The equipment has a central avocado fruit tray holder which is adjustable to hold fruit trays at different angles from 0 degrees to 90 degrees from horizontal. The fruit tray holder is connected to a stand through a rod adjustable at different heights by 5 cm increments to 150 cm maximum. In operation, the fruit holder height is adjusted according to the relevant treatment. An avocado fruit tray is then locked with a springs aided clip into the holder adjusted to the required angle. The lever to unlock the springs is lastly released allowing the avocado fruit tray to free fall to the ground.

The IRD was used after Tennes et al. (1990). Briefly, it was calibrated with its batteries fully charged. It was connected to a laptop computer (Latitude E6440, Dell® Australia Pty Limited, Frenchs Forest, NSW, Australia) (Fig. 2.3 B) running PCIRD software (Techmark®, Inc., Lansing, MI, United States) installed. The PCIRD interface software was used to acquire and analyse the data stored on the IRD and to enable its graphing. The IRD was programmed to record impacts in G force units, where G is the acceleration due to gravity (9.8 $m.s^{-2}$). It was consistently placed in the middle of each fruit tray. After impact, the IRD was removed from the fruit tray and the data uploaded into the computer. Impact data sets were acquired for each replication of each treatment.

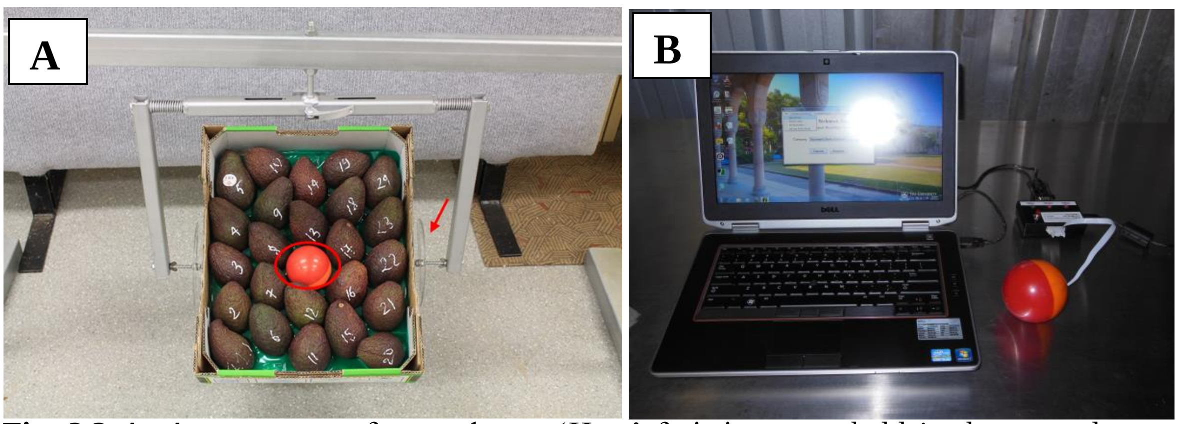

Fig. 2.3 A: Arrangement of avocado cv. 'Hass' fruit in a tray held in the avocado tray drop equipment for drop from treatment specific height and drop angle. The red circle highlights the impact recording device placed in the center of the fruit tray. The red arrow points to a protector fitted to help adjust drop angles. B: The IRD connected with the laptop for set up for data acquisition or for data downloading.

Post-impact, the fruit trays were held in a darkened shelf life room at 20 °C for 48 h. Thereafter, destructive bruising assessment was conducted as per section 2.1.1.5. The distribution of fruit bruising in individual fruit in each tray was mapped.

This experiment was conducted as a completely randomised block design. Statistical analyses by ANOVA of bruise severity due to tray drop height and angle and of impacts recorded with the

IRD were conducted with Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

Another experiment was conducted following the same operating procedure. The treatments were: T1 = control; T2 = 15 cm, 0 degrees; T3 = 15 cm, 15 degrees; T4 = 15 cm, 30 degrees; T5 = 25 cm, 0 degrees; T6 = 25 cm, 15 degrees; and T7 = 25 cm, 30 degrees. Data were acquired and analysed as above.

2.1.3 Effect of fruit dry matter at harvest

This experiment was conducted to investigate whether the increasing fruit maturity in terms of dry matter content (%) at harvest decreases bruise severity in avocado cv. 'Hass' fruit (Arpaia et al., 1987). Two ~ 18 year old healthy avocado trees were tagged early in the season at a commercial orchard in Toowoomba. Fruit (n = 25) were harvested fortnightly thereafter from each tree over 1 May 2013 to 4 September 2013 and transported to the laboratory at UQG.

Fruit dry matter content (n = 5) for each tree was determined as described by Wedding et al. (2011). Briefly, 15 mm wide pieces of avocado flesh were taken longitudinally from opposite sides of the fruit at its maximum radius. The skin and seed coat were excised. The sampled flesh slices were cut into quarters. Fresh weight was measured and the samples then placed in a fan forced oven (TD-500F-AS1681, Thermoline, Wetherill Park, NSW, Australia) pre-heated to 65 °C. Constant dry weight was achieved in ~ 48 h and dry matter content was calculated as the proportion (%) of fresh weight (Lee et al., 1983).

Fruit (n = 20) for each tree were subjected to the ripening treatment as described in Section 2.1.1.1 until they reached the firm ripe stage (White et al., 2009). Fruit weight was recorded with digital balance and objective firmness of each fruit was measured with the AFM.

The firm ripe fruit were individually subjected to a controlled impact from 50 cm drop height with the swing arm impact device. These fruit were held at 20 °C for 48 h to give sufficient time for bruise expression. Bruise intensity was determined as changes in hue angle and chroma with a chroma meter (CR 400, Minolta Ltd. Osaka, Japan) after Darrigues et al. (2008) and Lim et al. (2011). Both hue angle and chroma values of bruised flesh decrease with increasing intensity of bruising in terms of flesh browning: viz., hue angle and chroma values were relatively high for green and bright colours and were comparatively low for brown and dark colours, respectively (McGuire, 1992). Bruise severity were measured as described in Section 2.1.1.5.

This experiment was conducted in a randomised complete block design. The orchard (*n* = 1) was a typical commercial avocado orchard. Healthy trees (*n* = 2) were tagged for random sampling of individual replicate fruit for determination of their dry matter contents (*n* = 5) and for assessment of fruit maturity effects on bruise severity and intensity (*n* = 20) over 10 fortnightly harvest treatments. Data were statistically analysed by ANOVA with Minitab® 16. LSD tests at $P = 0.05$ were applied to determine significantly different treatments.

2.1.4 Effect of fruit firmness

The effect of fruit firmness on bruise severity was determined in two separate experiments. One experiment was conducted to evaluate the proposition that green mature 'Hass' avocado fruit either do not exhibit or show very little visible flesh bruising symptoms in response to impact (Hofman, 2003). Avocado cv. 'Hass' fruit were harvested at an orchard in Toowoomba and, using the swing arm impact device, subjected to the following impact treatments: T1 = control (no impact), T2 = impact from 50 cm drop height (energy absorbed ~ 1.27 J), and T3 = impact from 100 cm (~ 2.1.36 J). Each treatment involved *n* = 75 fruit. They were transported to UQG and given the ripening treatment described in section 2.1.1.1. They were then held at 20 °C for daily destructive bruise assessment of fruit (*n* = 5) over 15 days as per section 2.1.1.5. This experiment was a completely randomised design with three impact level treatments assessed over 15 times of assessment on individual fruit (*n* = 5) replicates. Data were subjected to Pearson Chi-Square analysis to compare the incidence of bruising in different treatments. Bruise incidence was assessed in terms of proportion (%) of fruit affected with a specific level of bruise severity (White et al., 2009).

The other experiment was to determine if the decreasing fruit firmness increases bruise expression in ripening avocado cv. 'Hass' fruit. Fruit were acquired at the hard green mature stage of hand firmness (White et al., 2009) from Brisbane Produce Market and ripened as per section 2.1.1.1. They were sorted for size, shape and hand firmness, and were assigned to treatments (*n* = 10): T1 = softening, T2 = firm ripe, and T3 = soft ripe. Quantitative firmness was measured with the AFM. Each fruit was impacted from 50 cm drop height (energy absorbed ~ 0.8 J) with the swing arm impact device and was held in the shelf life room (20 °C) for bruise assessments at 48 h after impact. Bruise colour measurements were recorded as per Section 2.1.3 and the bruise volume was measured as per Section 2.1.1.5. This experiment was a completely randomised design with three fruit firmness treatments and individual fruit (n = 10) replicates. Data of bruise severity and intensity were subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

2.1.5 Effect of pre-ripening fruit holding duration

An experiment was conducted to determine if longer pre-ripening fruit holding durations increases bruise severity in impacted ripening avocado cv. 'Hass' fruit. The fruit (n = 120) were harvested in the cool of the morning from a commercial orchard in Toowoomba and transported to UQG within ~ 1.5 h from harvest. These fruit were held at 5 °C and a sub-sample (n = 20) was withdrawn weekly over 5 weeks, with the week 0 sample being the day of harvest.

Fruit (n = 20) for each week were ripened as described in Section 2.1.1.1. They were held until they reached the firm ripe stage (White et al., 2009). Quantitative firmness of each fruit was measured with the Sinclair Internal Quality Firmness Tester (SIQFT) (Fig. 2.4) (Howarth and Ioannides, 2002). The SIQFT is a non-destructive firmness assessment device. It measures fruit firmness at four points around its circumference and displays the averaged value for fruit firmness.

Fig. 2.4 The Sinclair Internal Quality Firmness Tester. A piezoelectric sensor at the tip of the air-blow bellows taps at four points around the horizontal axis of the fruit and the liquid crystal

display indicates the average value of firmness.

The firm ripe fruit were then impacted from 50 cm drop height (energy absorbed ~ 1.0 J) with the swing arm device and held at 20 °C for 48 h for full bruise expression. Bruise intensity and bruise severity were measured as per Sections 2.1.3 and 2.1.1.5 respectively.

This experiment was a completely randomised design. Individual fruit (n = 20) replicates were maintained for assessment of pre-ripening fruit holding duration effects on bruise severity over treatment periods of 6 weeks. Data were statistically analysed by ANOVA with Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

2.1.6 Effect of post-impact fruit holding duration

Two experiments were conducted to investigate the effect of post-impact holding durations on bruise severity in firm ripe avocado cv. 'Hass' fruit. In the first experiment, hard green mature fruit were collected from a ripener's facility at Brisbane Produce Market and transported to UQG in ~ 2 h. They were given the ripening treatment in Section 2.1.1.1 and held until they reached the firm ripe hand firmness stage (White et al., 2009). Fruit were initially sorted on size, shape, and hand firmness, and were assigned to treatments of different post-impact destructive bruise assessment times. The treatments were: T1 = control (no impact, assessment at 96 h), T2 = 0 h, T3 = 2 h, T4 = 4 h, T5 = 8 h, T6 = 12 h, T7 = 24 h, T8 = 48 h, T9 = 72 h, and T10 = 96 h. Quantitative firmness of each fruit was measured with Anderson® Electronic Firmometer (EF) (Fig. 2.5) (White et al., 1997).

The EF is a reportedly efficient device for measurement of objective firmness. Nonetheless, it can cause bruising in fruit flesh at the site of firmness assessment.

Given that three different devices have been used in this Project (sections 2.1.1, 2.1.5, and 2.1.6), a correlation of firmness measurements study with the AFM, SIQFT and EF was conducted (Appendix G & I).

Fruit in T2 to T10 were impacted from 50 cm drop height (energy absorbed ~ 0.8 J) with the swing arm impact device. All the fruit were held in a darkened shelf life room at 20 °C for treatment specific bruise assessment. Bruise colour parameters were measured as described in

Section 2.1.3 and bruise volumes were measured as per Section 2.1.1.5. Data were subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

Fig. 2.5 Anderson® Electronic Firmometer. A 9 mm diameter probe contacts the fruit under a load of 200g applied on a lever arm for 10 sec. The objective value of firmness is displayed (mm).

A second experiment was conducted to confirm the findings of the first experiment and to assess the bruise expression in firm ripe avocado fruit in response of an impact for extended duration of up to 7 days. Treatment in this confirmatory experiment were: T1 = control (no impact, assessment at day 7), T2 = 0 d, T3 = 1 d, T4 = 2 d, T5 = 3 d, T6 = 4 d, T7 = 5 d, T8 = 6 d, and T9 = 7 d. All the other parameters and procedures were as described in the first experiment.

These two experiments were completely randomised designs with bruise assessment times plus control treatments for individual fruit (n = 10) replicates. Data were subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

2.1.7 Effect of pre- and post-impact fruit holding temperature

Six experiments were conducted to determine the effect of fruit holding temperatures on bruise severity. The first experiment was to determine if the higher post-impact fruit holding temperature increases bruise severity. Hard green mature 'Hass' avocado fruit were collected from the ripener's facility at Brisbane Produce Market and transported to UQG for ripening to the firm ripe stage as described in section 2.1.1.1. Quantitative firmness was measured with the AFM. Fruit (n = 20) were assigned to the following post-impact fruit holding temperature treatments: T1 = impacted and held at 5 °C, T2 = impacted and held at 15 °C, T3 = impacted and held at 25 °C, T4 = control held at 5 °C, T5 = control held at 15 °C, and T6 = control held at 25 °C. Fruit in T1, T2 and T3 were impacted from 25 cm drop height (energy absorbed ~ 0.35 J) at a flesh temperature of 20 °C. They were held at their treatment specific post-impact holding temperature along with their respective control for 48 h. Colour parameters of bruised flesh were measured as explained in section 2.1.3 and bruise volume was measured as per section 2.1.1.5. This experiment of six post-impact fruit holding temperatures and their corresponding control treatments involved individual fruit (n = 20) replicates. Data of both experiments was subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

The second experiment evaluated the effect of a range of post-impact fruit holding temperatures on bruise severity in firm ripe avocado cv. 'Hass' fruit using a temperature gradient block (Fig. 2.6) giving serial temperatures ranging from 1.2 °C to 29 °C.

The temperature gradient block after Battley (1964) was made by CSIRO (R.M. Smillie, pers. comm.). 'Hass' fruit (n = 25) were collected from the ripener's premises at firm ripe stage of firmness. These fruit had been harvested in a commercial orchard in Cairns and transported to Brisbane Produce Market in 2 days from harvest. They were ripened to a firm ripe stage by 48 h treatment with ethylene gas after Bill et al. (2014). The firm ripe fruit were then transported to DAF laboratories at Dutton Park, Brisbane, where they were impacted from a drop height of 50 cm (energy absorbed ~0.8 J). The colour parameters of hue angle and chroma for the impacted mesocarp of individual fruit were recorded as per section 2.1.3.

All of the impacted flesh of each fruit was transferred into each of two duplicate test tubes for each of 25 serial temperature points in the temperature gradient block. After 48 h to allow bruising symptoms to fully express, second measurements of hue angle and chroma were made. This experiment was a completely randomized split block design. It involved 25 treatments of different temperatures assessed for bruise intensity at two times. Each treatment comprised of n = 2 duplicate measurements. The average of the two values measured for each duplicate was used for statistical analysis. The experiment was repeated with the same procedures. Data from the two repeat runs were subjected to ANOVA using Minitab® 16. LSD tests at $P = 0.05$ were applied to determine significantly different treatments.

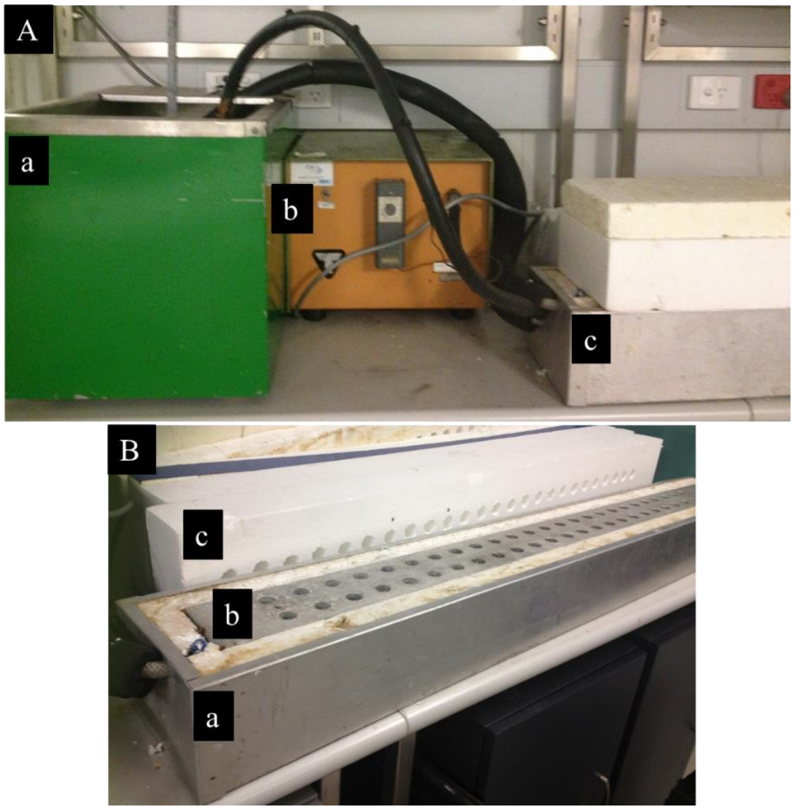

Fig. 2.6 A: Temperature gradient block set up with associated apparatus; a) chilled water bath unit, b) refrigeration unit, and c) the temperature gradient block. B: a) Temperature gradient block with; b) drilled holes in positions ranging from low temperature (left) to higher temperature (right), and c) insulation. The far end is connected to a heating unit to maintain the higher temperature at desired level.

The third experiment was conducted to determine if higher post-impact fruit holding temperature increases bruise severity in softening and firm ripe avocado cv. 'Hass' fruit. Fruit at softening and firm ripe firmness stages were prepared as described in Section 2.1.1.1. They were sorted on the basis of size, shape, and hand firmness, and were assigned to treatments (n = 20): T1 = softening, impacted, held at 5 °C; T2 = softening, impacted, held at 25 °C; T3 = firm ripe, impacted, held at 5 °C ; T4 = firm ripe, impacted, held at 25 °C; T5 = softening, control, held at 5 °C; T6 = softening, control, held at 25 °C; T7 = firm ripe, control, held at 5 °C ; and T8 = firm ripe, control, held at 25 °C. Fruit firmness was measured with the AFM. In T1 to T4, fruit were impacted from 25 cm drop height (energy absorbed ~ 0.35 J) at a flesh temperature of 20 °C. All fruit were then held at the various different temperature treatments for bruise assessment after 48 h as per sections 2.1.3 and 2.1.1.5. This experiment involved 8 treatments comprised of 2 firmness stages x 2 holding temperatures and their respective controls, with each treatment comprised of n = 20 individual replicate fruit. Data were subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

The fourth experiment examined if the bruise severity in firm ripe avocado cv. 'Hass' fruit is affected by holding the fruit post-impact at different temperature regimes for different durations. Firm ripe fruit (n = 20) were prepared (Section 2.1.1.1) and assigned to treatments of: T1 = impacted, held at 5 °C for 8 h then at 25 °C for 40 h; T2 = impacted, held at 25 °C for 8 h then at 5 °C for 40 h; T3 = control, held at 5 °C for 8 h then at 25 °C for 40 h; and T4 = control, held at 25 °C for 8 h then at 5 °C for 40 h. Fruit firmness was measured with the AFM. Fruit in T1 and T2 were impacted from 25 cm drop height (energy absorbed 0.35 J). All the fruit were held at their specific temperature treatment regime for bruise assessment after a holding duration of 48 h. Bruise colour and severity were recorded as described in sections 2.1.3 and 2.1.1.5. This experiment included four treatments of two temperature regimes and their respective controls. Data were collected for n = 20 individual fruit replicates and subjected to ANOVA using Minitab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

The fifth experiment evaluated if the interaction of higher pre-impact flesh temperature and higher post-impact fruit holding temperature regimes increase bruise severity in firm ripe avocado cv. 'Hass' fruit. Firm ripe fruit for each treatment were prepared following the procedure explained in 2.1.1.1 and were sorted and assigned to the treatment regimes (n = 10): T1 = impacted at 2.5 °C and held at 2.5 °C; T2 = impacted at 2.5 °C and held at 5 °C; T3 = impacted at 2.5 °C and held at 7.5 °C; T4 = impacted at 2.5 °C and held at 10 °C; T5 = impacted at 2.5 °C and held at 20 °C; T6 = impacted at 20 °C and held at 2.5 °C; T7 = impacted at 20 °C and held at 5 °C; T8 = impacted at 20 °C and held at 7.5 °C; T9 = impacted at 20 °C and held at 10 °C; and T10 = impacted at 20 °C and held at 20 °C in fifth experiment. Firmness was measured with the AFM. All fruit were impacted from 50 cm drop height (energy absorbed ~ 0.8 J) followed by their holding in the shelf life room for bruise assessment after 48 h. Hue angle and chroma value were measured as described in section 2.1.3, and bruise volume was measured as per section 2.1.1.5. This experiment involved 10 treatments and each treatment was comprised of *n* = 10 individual fruit replicates.

The sixth experiment was conducted following the same procedure as described for the fifth experiment (immediately above) with a view to confirming the findings of the fifth experiment for different treatments of: T1 = impacted at 5 °C and held at 5 °C, T2 = impacted at 5 °C and held at 10 °C, T3 = impacted at 5 °C and held at 20 °C, T4 = impacted at 20 °C and held at 5 °C, T5 = impacted at 20 °C and held at 10 °C, and T6 = impacted at 20 °C and held at 20 °C. The quantitative firmness of individual fruit replicates (*n* = 20) in this experiment was measured with the SIQFT. Data on bruise intensity and bruise severity were collected as per sections 2.1.3 and 2.1.1.5, respectively.

The fifth and sixth experiments were conducted as completely randomized designs. Their data were analysed with Minitab® 16. LSDs ($P = 0.05$) were calculated to determine differences between treatments. Pearson Chi-Square analysis was used to compare the bruise incidence in different treatments.

2.1.8 Application of magnetic resonance imaging for bruising assessment in avocado fruit

This experiment was comprised of two components. Proton magnetic resonance images (^{1}H MRI) were acquired and, in concert, destructive bruise severity assessments were conducted.

The ^{1}H-MRI experiment was comprised of the following treatments: (i) firm ripe fruit dropped from 25 cm height (energy absorbed = 0.38 J ± 0.004; *n* = 2), (ii) firm ripe fruit dropped from 50 cm height (energy absorbed = 0.81 J ± 0.011; *n* = 2), and (iii) hard fruit dropped from 100 cm height (energy absorbed 1.68 J ± 0.020; *n* = 1). Firm ripe fruit (White et al., 2009) ripened as described in Section 2.1.1.1 were used as a typical degree of ripeness (softening) such as is presented to store staff and shoppers in the retail store and as is taken by customers into their homes. Relative to the lower drop heights for firm ripe fruit, the greater drop height for hard green mature fruit was to represent potentially rougher handling during harvest and packing operations. Uniformly ripe, damage free fruit were selected for the first and second treatments. A fresh fruit at the hard green mature stage of firmness that was from the same farm and that had been handled as described above was collected from the ripener on the day of the experiment for the third treatment. The five sample fruit were individually impacted by dropping in a pendulum swing arm device against a rigid metal surface (Fig. 2.2). The impact energies (J) absorbed by the fruit in each treatment were calculated (Section 2.1.1.4).

For MR imaging, the avocado fruit were secured into a foam-lined purpose built circular wooden clamp (Fig. 2.7A). The clamp held firm ripe fruit dropped from 25 cm in positions 1 and 5, firm ripe fruit dropped from 50 cm in positions 2 and 3, and hard fruit dropped from 100 cm in position 4. The clamp was placed into a standard 12-channel head coil (Fig. 2.7B, as represented from a different experiment) of a Siemens (Erlangen, Germany) TRIO 3T clinical ^{1}H-MRI scanner. T_2 weighted turbo-spin echo (TSE) images were acquired with the following parameters: TR = 6450 ms, effective TE = 75 ms, turbo factor = 7, slice thickness = 2 mm, number of contiguous slices = 65, field of view = 240 x 240 mm, matrix 320 x 320, in plane resolution = 0.8 x 0.8 mm, number of averages = 2, and acquisition time = 10 min. These optimised parameters were selected following preliminary TSE experiments on cv. 'Hass' avocado fruit (data not shown). The first ^{1}H-MRI scan was acquired within 20 min of impact on d 0. Twenty (20) min delays between the end of one scan and the start of the next scan were adopted and one serial image was acquired every 30 min for 3 days following impacts on d 0. The fruit were not removed from the wooden clamp and were held at a controlled temperature of 20°C for the duration of the experiment.

Acquired ^{1}H-MRI images were analysed with OsiriX (Pixmeo SARL, Bernex, Switzerland) DICOM viewer software on an Apple Macintosh (Cupertino, US) system to quantify the pixel intensities (n = 5) of randomly selected regions of interest (ROI). ROI were the different parts of the fruit tissue, bruised flesh, and also flesh areas affected by pathogens. ROI pixel intensity values were compared with a standard reference point (n = 5) in air space around the fruit.

In parallel with ^{1}H-MRI, a destructive assessment experiment using fruit from the same consignment batch was conducted. Using the same procedures as described above, fruit at firm ripe were dropped from either 25 cm or from 50 cm and at hard were dropped from 100 cm. Individual fruit were labelled using a white marker pen and were held in a darkened shelf life evaluation room at 20 ºC and 85% RH for serial destructive evaluations (n = 5) at d 1, 2, and 3 after impact on d 0. The first destructive evaluation was conducted within 20 min of impact on d 0 and then destructive evaluations were made every day until d 3 after impact as per Section 2.1.1.5.

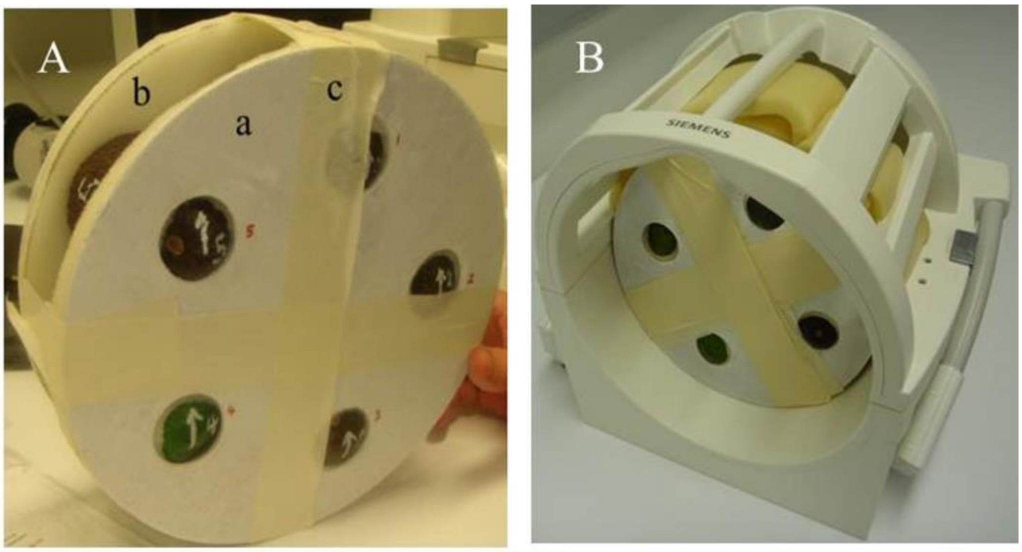

Fig. 2.7 A: The arrangement in a foam-lined wooden clamp of avocado cv. ‘Hass’ fruits for ^{1}H-MRI scans. Avocado fruit orientated with painted arrows were clamped between two wooden plates: (a) Paint coated laminated foam lined wooden plates with holes to hold the avocado fruit; (b) Foam liner for cushioning; and, (c) Paper sticky tape around the wooden plates to secure the avocado fruit in between. B: The fruit clamped in wooden structure as placed in a human head coil for ^{1}H-MRI.

The experiment was conducted as a randomised complete block (RCB) design. All data were statistically analysed with Minitab® 16. LSD tests at P = 0.05 were applied to determine the level of significantly different treatments. In addition to ^{1}H-MRI images for non-destructive assessments, destructive assessments were photographed using a Nikon Coolpix S9300 digital camera.

2.2 Sampling through the supply chain

2.2.1 Sampling from the ripener to the retail display

Two experiments were conducted to evaluate the hypothesis that bruise severity in avocado cv. ‘Hass’ fruit increases as the fruit passes through the supply chain from the ripener to the retail store display.

Experiments were designed and implemented in collaboration with the two major supermarket supply chains (i.e. Coles, Woolworths) of fresh avocado cv. ‘Hass’ fruit in Australia. Avocado fruit from a major grower in Queensland were collected on arrival and at dispatch (sampling points 1 & 2) from a ripener in Brisbane, then at arrival and at dispatch (sampling points 3 & 4) from each supermarket chain DC, then again on arrival (sampling point 5) at the storage area at the back of each supermarket store involved, and finally from the retail shelf (sampling point 6) in each store.

Four retail stores for each supermarket supply chain participated in the first experiment. Participating retail stores of each supermarket supply chain were located at increasing distance from the respective DC. Participating retail stores of one supply chain (chain 1) were Mount Ommaney, Ipswich, Gatton and Toowoomba. Stores representing supply chain 2 were Acacia Ridge, Booval, Plainland and Toowoomba. One tray of fruit was randomly collected at each of the six aforementioned sampling points on a weekly basis for 5 weeks in July 2011.

In the second experiment, one lot of avocado cv. 'Hass' fruit harvested in Childers (~ 320 km from Rocklea) and transported to the ripener's facility in Brisbane Produce Market, Rocklea, was randomly selected and tagged for monitoring by labeling stickers on fruit trays upon arrival at the ripener's facility. One tray of fruit was collected from the tagged consignment at the above mentioned six sampling points on a weekly basis for 4 weeks in July 2012. Two retail stores for each of the two supply chains participated. Retail stores of supply chain 1 were Mount Ommaney and Gatton, and those of supply chain 2 were Plainland and Toowoomba.

The sampled trays of fruit were carefully transported to the laboratory at UQG. The ripener's arrival samples were ripened (Section 2.1.1.1). This fruit and the fruit collected from all subsequent sampling points were held in a shelf life room at 20 °C and 85% RH for ~ 48 h after collection. Individual fruit were weighed with a digital mass balance and fruit firmness recorded using the AFM. Bruising assessment was conducted for fruit (n = 10) at the firm ripe and soft ripe stages of hand firmness (White et al., 2009) in the first experiment and for fruit (n = 20) at the firm ripe stage in the second experiment.

Fruit were destructively assessed for bruise incidence and severity. Each fruit was peeled and cut into four longitudinal sections. Each section was further cut into small pieces to make sure that all bruised flesh could be separated from unbruised flesh. Bruise severity was measured as per Section 2.1.1.5. Typical, minimal, maximal, and unusual flesh bruising in sampled avocado fruit were photographed with a Nikon Coolpix S9300 digital camera (Nikon®, Lidcombe, NSW, Australia) against a white background under ambient light conditions. Data relating to bruise severity were subjected to ANOVA using MiniTab® 16. LSD tests at $P = 0.05$ were applied to determine significantly different treatments.

2.2.2 Retail store staff contribution to flesh bruising

This experiment was conducted to discern if the bruise severity in avocado cv. 'Hass' fruit increases due to the fruit handling practices of supermarket retail store staff.

Avocado fruit trays ($n = 2$) at the firm ripe stage were randomly collected from a ripener's facility at the Brisbane Produce Market, Rocklea and transported to two stores for each of the two supermarket supply chains participating in experiment described in Section 2.2.1. Specifically, in Mount Ommaney and Gatton for supply chain 1 and in Toowong and Plainland for supply chain 2. Fruit were held at the back of the retail store for 24 h to pass through any staff handling practices during this time. They were then placed on retail display by store staff as per normal practice. Next, they were passed through check out points by research team members to cover off on check out staff handling practices. These fruit were then transported to the laboratory at UQG and held for 48 h before bruise assessment. Fruit firmness was measured with the SIQFT. Fruit weight was measured to one decimal point with a digital mass scale. Destructive bruising assessment was conducted as described in Section 2.2.1 and compared with an un-handled control to assess the discrete contribution of store staff handling practices. Data relating to the severity of flesh bruising were analysed by ANOVA with MiniTab® 16. LSD tests at $P = 0.05$ were applied to determine significantly different treatments. Bruise incidence was assessed in terms of proportion (%) of fruit affected with a specific level of bruise severity.

2.2.3 Flesh bruising in avocado fruit displayed in independent and supermarket retail stores

This experiment was conducted to determine if the bruise severity in avocado cv. 'Hass' fruit displayed in independent retail stores is different to that in the fruit at the supermarket retail stores.

In addition to the supermarket chains participating in experiments described in Section 2.2.1 and 2.2.2, independent retail stores in the greater Brisbane area (Fig. 2.8) were identified through consultation with the avocado industry stakeholders including the peak industry body, wholesalers, ripeners, and retailers. Two retail stores of each of the two major supermarket supply chains (Sections 2.2.1 and 2.2.2) were selected. The stores were located in Fairfield, Mount Ommaney, Annerley and Toowong. Four independent retail stores were selected, located in Toowong, Indooroopilly, Wilston and Fortitude Valley. All of these retail stores sell fruit initially ripened by the same ripener at Brisbane Produce Market in Rocklea.

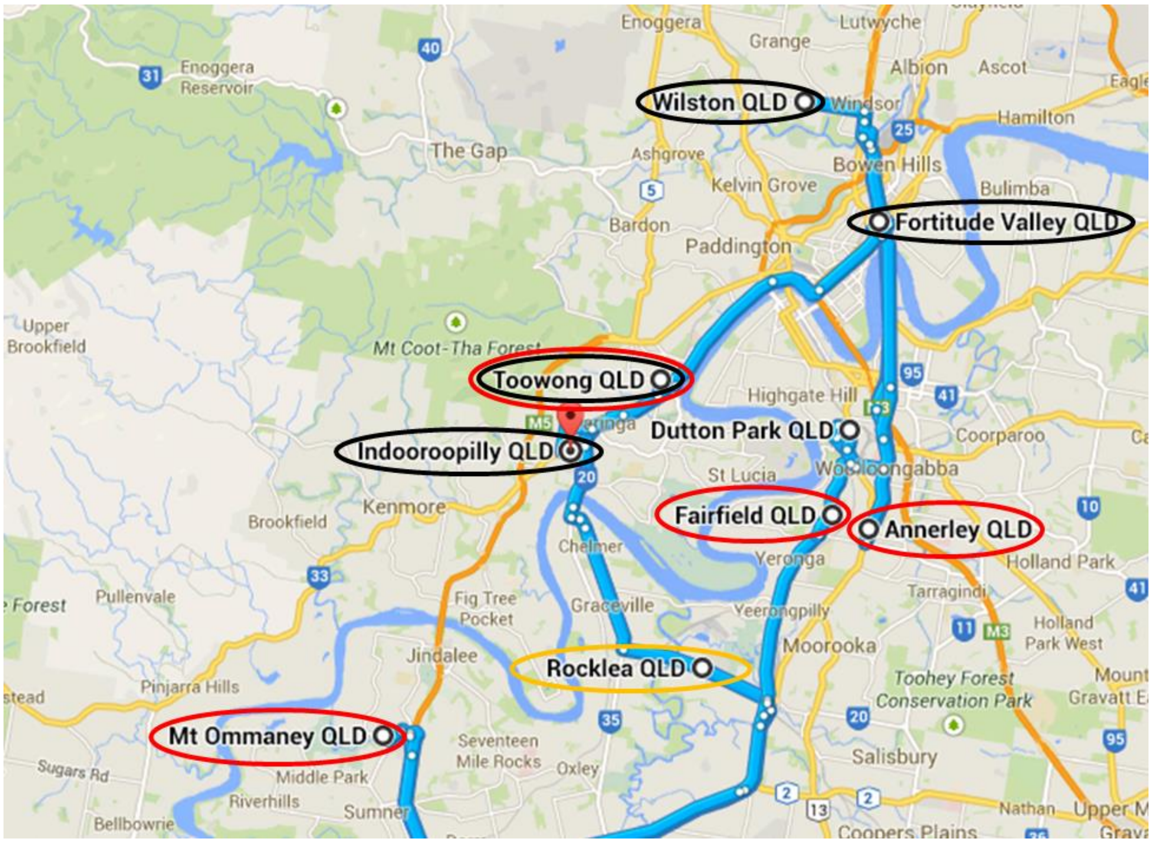

Fig. 2.8 Map of Brisbane and suburbs indicating the location of supermarket retail stores (red circles), independent retail stores (black circles), and Brisbane Produce Market in Rocklea (yellow circle). https://www.google.com.au/maps/place/

Participating retail stores consented to the replacing of avocado fruit on display with undamaged fruit from the ripener of the same size by a research team. The research team contacted each participating store before each sampling to confirm the size specification for collection from the ripener. This requirement was communicated to the ripener. Avocado cv. ‘Hass’ fruit matching the size requirements of the participating stores were collected from the ripener’s facility on the morning on each day of sampling. Repeat runs of fruit sampling from the retail stores were conducted on Monday 14 July, Friday 18 July, Monday 21 July and Tuesday 22 July in 2014 at different random times of the day. Based on the experience of the research team, fruit (n = 25) that was suitable for consumption within 2 days of purchase were randomly sampled from the retail store display. Store managers were requested to advise the duration that the fruit had spent on the display. For the first two sampling days, fruit collection from the retail stores was in the order of Mount Ommaney, Indooroopilly, Toowong, Wilston, Fortitude Valley, Fairfield and Annerley. Fruit collection was conducted in the reverse order for the last two samplings.

Fruit (n = 25) from each of the participating retail stores were taken to the laboratory at UQG and held in a shelf life room at 20 °C for ~ 48 h. The 48 h period was allowed to provide opportunity for bruise symptoms to fully express (Mazhar et al., 2012) before fruit assessments for firmness, weight, and bruise incidence and severity were conducted. Fruit firmness measured with the SIQFT, and weight measured using a digital mass scale, were recorded. Bruise severity was measured as explained in Section 2.2.1. Bruise incidence was assessed and photographs of typical, minimal, maximal, and unusual flesh bruising in the sampled fruit were acquired.

The experiment was a randomised complete block design. Bruise severity data were subjected to ANOVA using MiniTab® 16. LSD tests at P = 0.05 were applied to determine significantly different treatments.

2.3 Evaluation of Impact Recording Device, ShockLog and impact indicator clips

This experiment was conducted to evaluate if IRD, ShockLog (Fig. 2.9A), and / or low cost impact indicator clips (Fig. 2.9B-C) might be effectively used as decision aid tools to inform on critical points in the supply chain through recording of impact events in terms of magnitude and number, as appropriate. An IRD after Yu et al. (2011) and a tri-axial ShockLog (SL298 Shockwatch®, Sydney, NSW, Australia) after Bollen (2006) were included in four tagged consignments along with the low-cost poly-axial ShockWatch impact indicator clips (5G, 10G, 25G, 35G, and 50G MC CX Shockwatch®, Sydney, NSW, Australia) at ripener arrival (Fig. 2.10A-B).

The IRD and ShockLog were activated at the beginning of each trip and placed in the center of the tray by replacing an avocado fruit. The impact indicator clips were either attached on the outer face of a short side of the fruit tray or inside the short side of the fruit tray, and the colour of the clips was recorded. The clips change colour from transparent to bright red in the event of an impact greater than the value indicated on the clip (Anonymous, 2014).

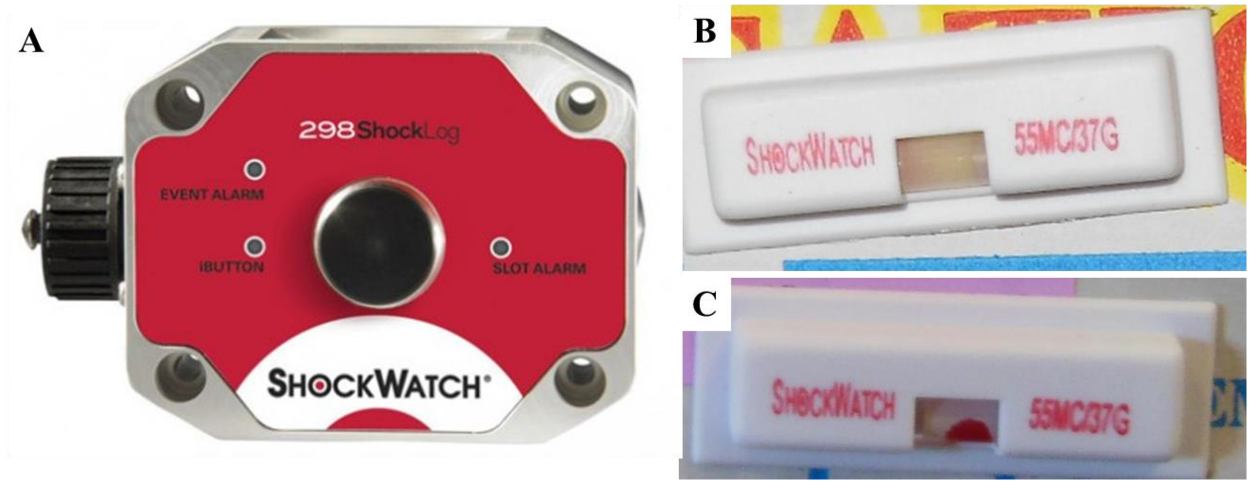

Fig. 2.9 A: A ShockLog device used to record impact magnitudes and events (http://www.shockwatch.com/products/impact-recorders/shocklog-298/). B: An un-triggered impact indicator clip of 37G attached to an avocado fruit tray. C: An impact indicator clip that has changed colour to red due to an imposed impact event above the threshold limit.

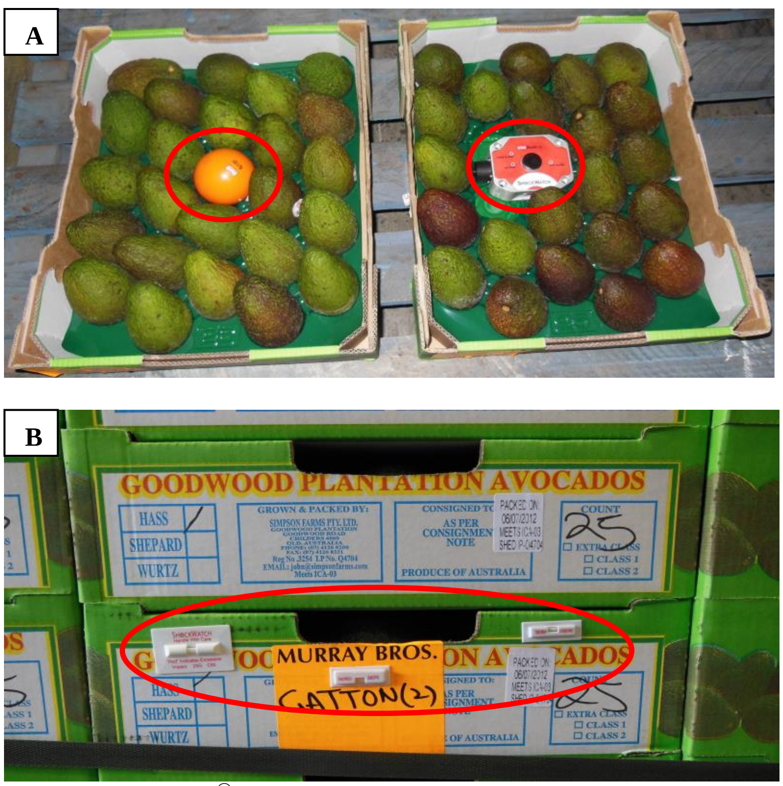

Fig. 2.10 A: Impact Recording Device® (L) and ShockLog (R) placed in avocado fruit trays in a

tagged consignment at ripener's arrival stage of the supply chain. B: ShockWatch impact indicator clips (25G, 35G, and 50G) placed on the short face of an avocado fruit tray in a monitored consignment at the ripener arrival point of the supply chain.

The IRD, ShockLog and impact indicator clips travelled along with the avocado fruit through the supply chain. The IRD and ShockLog were recovered at retail store display and their data retrieved. The colour of the impact indicator clips was recorded at each sampling point to determine if any impact greater than the threshold of the clip had occurred during the fruit tray's handling through the supply chain. The impact events data were combined with data on the incidence and severity of flesh bruising determined in experiment described in Section 2.2.1.

2.4 Skin spotting

Small surveys were conducted by AAL and DAF staff to gather perspectives from wholesalers, retailers, and shoppers on skin spotting (Appendix M).

Also, marketplace avocado retail quality surveys were conducted monthly by trained contractors engaged by AAL (Embry, 2009). Data from September 2011 to May 2014 at 16 independent and supermarket retail stores covering Sydney, Brisbane, Melbourne and Perth are considered in this report. The prior training of assessors was towards consistent identification and rating practices across the State based assessors. Random samples of 'Hass' avocado fruit (n = 15) on display in each participating retail store were purchased. These fruit were rated for SS based on a 0 - 4 rating scale: 0 = no SS, 1 = 0 - 10 % SS, 2 = 11 - 25 % SS, 3 = 26 - 50 % SS and 4 = > 50 % SS (Fig. 2.11). This scale was based on White et al. (2009).

Based on perspectives of wholesalers (n = 3) and retailers (n = 69) that fruit with SS ratings of 3 (26 - 50 %) and 4 (> 50 %) are unacceptable (Fig. 2.11), the data for these two categories in the surveys conducted by the AAL contractors were collated and statistically analysed for variance between survey variables with Minitab® 16.

Skin spotting

This may be called 'lenticel spotting', nodule damage or 'peel spotting'/damage'.

Rating Scale for skin surface area	Rating	Description
0	0%	Nil
1	1-10%	Slight
2	11-25%	Moderate
3	24-50%	Severe
4	>50%	Extreme

Description

- Brown or black areas on the skin, less than 3mm diameter
- In 'Hass' it is often on top of the nodules (bumps) on the skin surface
- This damage excludes damage due to insect feeding or tree rub
- These symptoms are confined to the skin and do not penetrate into the flesh, which distinguishes the injury from damage due to rots
- Becomes less obvious in 'Hass' as fruit ripens and the skin darkens

Causes

Physical damage from abrasion, impact or compression during harvesting, grading, packing and transport

Rating **0 (Nil)** **1 (1-10% slight)** **2 (11-25% moderate)** **3 (26-50% severe)**

Fig. 2.11 Skin spotting assessment guide. Four distinct levels of skin spotting are illustrated. The rating scale shows the rating score for percentage of skin surface affected by skin spotting.

3. Outputs

Confidential reports to project participants on project findings and recommendations for improvement

At the end of each avocado season from 2011 to 2014, written and oral reports were shared with all project participants, including AAL, growers, ripeners, wholesalers, and supermarket and independent retailers.

- Project planning and feedback meetings with the stakeholders included:
- Pre-season industry (ripener, retailers, AAL) meetings; 15th July 2011; Rocklea.
- Post-season meeting with AAL; 20th December 2011; AAL, Woolloongabba.
- Pre-season planning meeting of project scientists, HIA and AAL; 14th May 2012; Woolloongabba.
- Pre-season industry (ripener, retailers, AAL) meetings; 19th May 2012; Rocklea.
- Post-season industry (ripener, retailers, AAL) meetings; 24th September 2012; Rocklea.
- Post-season industry (growers, ripener, AAL) meeting; 17th December 2012; Woolloongabba.
- Pre-season meeting (project scientists, AAL and HIA); 14th January 2013; Woolloongabba.
- PhD advisory team meeting; 16 January 2013; University of Queensland, Gatton.
- Project planning meeting (project team, AAL); 4th April 2013; Dutton Park.
- Pre-season industry (growers, ripener, AAL) meeting; 8th April 2013; Dutton Park.
- Pre-season industry (ripener, retailers, AAL) meeting; 7th May 2013; Toowong.
- Pre-season industry (ripener, retailers, AAL) meeting; 5th June 2013; Larapinta.
- Mid-season debrief industry (ripener, retailers, AAL) meeting; 23rd July 2013; Rocklea.
- Post-season industry (ripener, retailers, AAL) meeting; 10th December 2013; Larapinta.
- Post-season industry (growers, ripener, AAL) meeting; 20th January 2014; Dutton Park.
- Post-season industry (ripener, retailers, AAL) meeting; 23rd January 2014; Rocklea.
- Pre-season industry (ripener, AAL) meeting; 8th May 2013; Woolloongabba.
- Pre-season industry (ripener, retailers, AAL) meeting; 29th May 2013; Gatton.
- Pre-season industry (ripener, retailers, AAL) meeting; 3rd June 2014; Larapinta.
- Post-season industry (ripeners, AAL) meeting; 13th November 2014; Dutton Park.
- Post-season industry (ripener, retailer) meeting; 13th November 2014; Larapinta.

- Post-season industry (ripener, retailer, AAL) meeting; 25th November 2014; Dutton Park.
- Email correspondence (ripener, retailers, AAL) for organizing 2013 project activities.
- One-to-One exchange of information among project team members and with industry and other stakeholders, such as avocado researchers, as discussions, exchange of reports and information (e.g. data) sharing.

Public reports on findings and recommendations relating to bruising and skin spotting

- Milestone reports (101-105) and HIA Ltd. annual industry reports 2012, 2013, and 2014.
- Reporting on AV12009 and AV10019 by Terry Campbell in 2014 and by Noel Ainsworth and Daryl Joyce in 2015 at ongoing Qualicado workshops for growers and wholesalers and ripeners as per AAL's schedule.
- Understanding and managing avocado flesh bruising. The 12th Annual Avocado R&D and Networking Forum 2014. 19 June 2014. Brisbane, Australia.
- Flesh bruising in Hass avocado. The 11th Annual Avocado R&D Forum 2013. 30 July 2013. Brisbane, Australia.
- Reducing flesh bruising and skin spotting in Hass avocado. The 10th Annual Avocado R&D Forum 2012. 4 September 2012. Brisbane, Australia.
- Bruising in Hass avocados. The 9th Annual Avocado R&D Forum, 10 August 2011. South Bank, Brisbane, Australia.

Magazine articles

- Mazhar, M., D. Joyce, P. Hofman, R. Collins. 2015. Low temperature management can reduce bruise expression in avocado cv. 'Hass' fruit flesh. *Talking Avocados*. **25**, 40-43.
- Mazhar, M., D. Joyce, G. Cowin, P. Hofman, I. Brereton, R. Collins. 2013. MRI as a non-invasive research tool for internal quality assessment of 'Hass' avocado fruit. *Talking Avocados*. **23**, 22-25.
- Mazhar, M., D. Joyce, P. Hofman, R. Collins, M. Gupta. 2012. Impact induced bruising in ripening 'Hass' avocado fruit. *Talking Avocados*. **22**, 34-37.

Thesis

- Mazhar, M. Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains: from the ripener to the consumer. PhD Thesis. University of Queensland, Australia.

(Submitted)

Proceeding papers

- Mazhar, M.S., D. Joyce, A. Lisle, R. Collins, and P. Hofman. Comparison of firmness meters for measuring 'Hass' avocado fruit firmness. *Acta Hort.* (Submitted).
- Mazhar, M.S., D. Joyce, L. Taylor, P. Hofman, J. Petty, and N. Symonds. Skin spotting situation at retail level in Australian avocados. *Acta Hort.* (Submitted).

Proceeding abstracts

- Mazhar, M.S., D. Joyce, and R. Collins. 2014. Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains in Queensland Australia: ripener to retailer. *HortScience,* **49** (9): S205. 2014 ASHS Annual Conference. http://hortsci.ashspublications.org/content/suppl/2014/11/13/49.9.DC1/HS-Sept_2014-Conference_Supplement.pdf
- Mazhar, M.S., D. Joyce, P. Hofman, R. Collins, T. Sun., N. Tuttle. 2013. Reducing flesh bruising and skin spotting in 'Hass' avocados. Online abstracts of 5th New Zealand and Australian avocado grower's conference. Tauranga, New Zealand. . http://www.avocadoconference.co.nz/speakers/abstracts

Presentations

- Talks on project AV12009 and AV10019 by project team member Daryl Joyce at Qualicado workshops in Melbourne (2014, wholesalers and ripeners) and in Nambour (2015, growers), Brisbane (2015, wholesalers and ripeners), Sydney (2015, wholesalers and ripeners) and Tweed Northern Rivers (2015, growers).
- Comparison of firmness meters for measuring 'Hass' avocado fruit firmness. International Horticulture Congress 2014. 17 – 22 August 2014, Brisbane, Australia.
- Skin spotting situation at retail level in Australian avocados. International Horticulture Congress 2014. 17 – 22 August 2014, Brisbane, Australia.
- National Science Week 'Show & Tell' event. 15 August 2014. Brisbane Convention Centre, Brisbane.
- Bruising in avocado (*Persea americana* m.) cv. 'Hass' supply chains in Queensland Australia: ripener to retailer. American Society of Horticultural Sciences Annual Conference 28 – 31 July 2014. Orlando, USA.

- Bruising in Queensland 'Hass' avocado fruit supply chains. Mid PhD candidature review; 22 October 2013; University of Queensland, Gatton.
- Bruising in Queensland 'Hass' avocado supply chains from the ripener to the consumers. 5th New Zealand and Australian Avocado Growers' Conference, 9 to 12 September 2013. ASB Baypark Arena, Tauranga, New Zealand.
- Consumer focused bruising management in Queensland 'Hass' avocado fruit supply chains. Confirmation of Candidature seminar; 14th March 2012, School of Agriculture & Food Sciences, The University of Queensland, Gatton. (Oral Presentation and written confirmation document).
- Bruising in the Queensland supply chain of Hass avocado fruit. VII World Avocado Congress 2011. 6 September 2011. Cairns, Australia.

Videos

- The case of the bruised avocados. http://www.youtube.com/watch?v=yDn-4YbV9BE
- Tasty science. Scope TV Australia. http://tenplay.com.au/channel-ten/scope/season-2/episode-159

Newspapers / Blogs / Magazines

- Research may deliver bruise-free avocados. University of Queensland, Australia. http://www.uq.edu.au/news/?article=26485
- Quest for the perfect avocado. Australian Centre for International Agricultural Research. http://aciarblog.blogspot.com.au/2013/09/quest-for-perfect-avocado.html
- Avocado industry takes bruising with squeezers. The Queensland Times, Australia. http://www.qt.com.au/news/avocado-industry-takes-bruising-with-squeezers/1908235/
- Losing the bruising from avocados. ABC Rural, Australia. http://www.qt.com.au/news/avocado-industry-takes-bruising-with-squeezers/1908235/
- New Aussie research looks into avocado bruising. Food Magazine, Australia. http://www.foodmag.com.au/news/new-aussie-research-looks-into-avocado-bruising-vi

4. Outcomes

1. Bruise expression in avocado fruit

The results from the experiments described above in Section 2 are presented below.

4.1.1 Impact energy absorbed by individual fruit

Energy absorbed by firm ripe avocado cv. 'Hass' fruit had significant ($P \leq 0.05$) effects on bruise development (Fig. 4.1). Bruise severity increased with serially increasing fruit drop heights of 25 cm (energy absorbed ~ 0.38 J), 50 cm (~ 0.81 J), and 100 cm (~ 1.67 J), respectively.

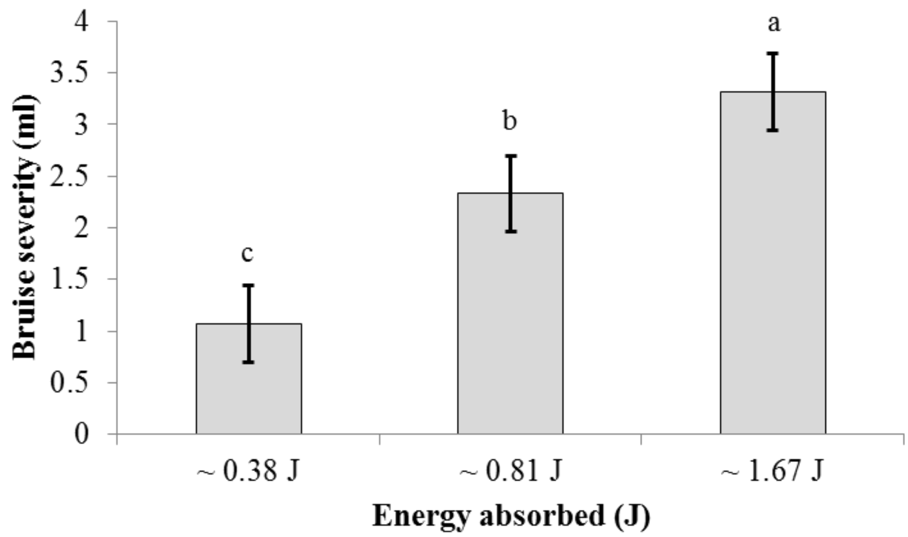

Fig. 4.1 Bruise severity (ml) in avocado cv. 'Hass' fruit (*n* = 10) having absorbed different levels of impact energy. Vertical lines represent standard deviation from the mean. Different letters represent significance differences between treatments by LSD ($P = 0.05$).

4.1.2 Impact forced applied to fruit in trays

Greater tray drop height and greater tray drop angle significantly increased ($P \leq 0.05$) bruise severity in firm ripe avocado cv. 'Hass' within dropped fruit trays. However, while significant ($P \leq 0.05$) for from 50 cm, the tray drop angle effect was not significant in fruit trays dropped from 25 cm (Fig. 4.2).

In the experiment conducted to confirm and expand the findings of the above experiment, all treatments of 15 cm and 0 degrees, 15 cm and 15 degrees, 15 cm and 30 degrees, 25 cm and 0 degrees, 25 cm and 15 degrees, and 25 cm and 30 degrees gave significantly ($P \leq 0.05$) higher bruise severity as compared with the control, which did not show any bruising. The main factor treatment effects of tray drop height (Factor A) and tray drop angle (Factor B) were both significant ($P \leq 0.05$). The interaction effect (A * B) of tray drop height and tray drop angle was not significant ($P > 0.05$) (Table 4.1).

In the experiment conducted to confirm and expand the findings, mapping of average bruise severity in fruit within impacted trays revealed 3.29 ± 3.54 ml per fruit for those at position 1 (proximal to impact point; Fig. 4.3A). The severity was increased significantly ($P \leq 0.05$) to 6.78 ± 3.40 ml per fruit for those at position 5 (distal to the impact point). Bruise severity as mapped across trays is indicated in Fig. 4.3B. The effect of fruit position on bruise severity was significant ($P \leq 0.05$) for both drop heights of 15 and 25 cm and for both drop angles of 15 and 30 degrees. However, fruit position did not have a significant ($P > 0.05$) effect in terms of bruise severity in trays dropped from either height at the 0 degrees (i.e. horizontal) drop angle. The IRD placed in fruit trays measured impact forces in this duplicated experiment. Tray drop height and drop angle both significantly ($P \leq 0.05$) affected the force recorded. For trays dropped at 0 degrees, the IRD recorded higher force as compared with for either of the 15 and 30 degrees drop angles for each of the 15 and 25 cm drop heights (Fig. 4.4).

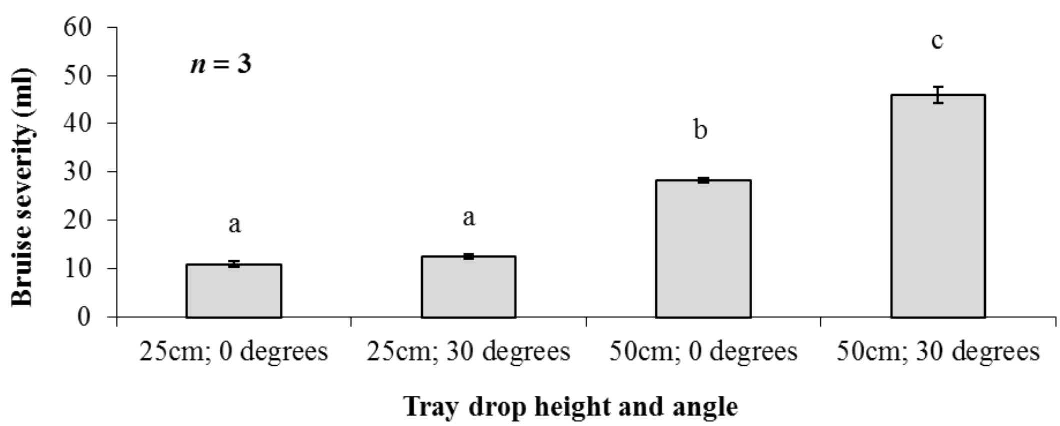

Fig. 4.2 Flesh bruising in individual fruit held in fruit trays (n = 3) dropped from different heights and drop angles. Vertical lines represent standard deviation from the mean. Different letters represent significance differences between treatments by LSD (P = 0.05).

4.1.3 Fruit dry matter at harvest

Dry matter content (%) of fruit harvested from tree 1 (25.6 ± 4.7%) was not significantly different ($P > 0.05$) to that of fruit harvested from tree 2 (26.2 ± 3.4%). The dry matter content

(%), however, increased significantly ($P \leq 0.05$) from 21.5 ± 2.4% at first harvest in May to 33.0 ± 2.4% at the last harvest of the experiment in September (Fig. 4.5). Nonlinear regression analysis ($y = a \cdot e^{bx}$ and $n_{x,y} = 10$) for correlating change in dry matter content (%) over the fortnightly harvest treatments yielded: dry matter content (%) = 19.65 . $\exp^{(0.048 \text{ x time (fortnight)})}$, with a goodness of fit (R^2) value of 95.3% and $P \leq 0.05$.

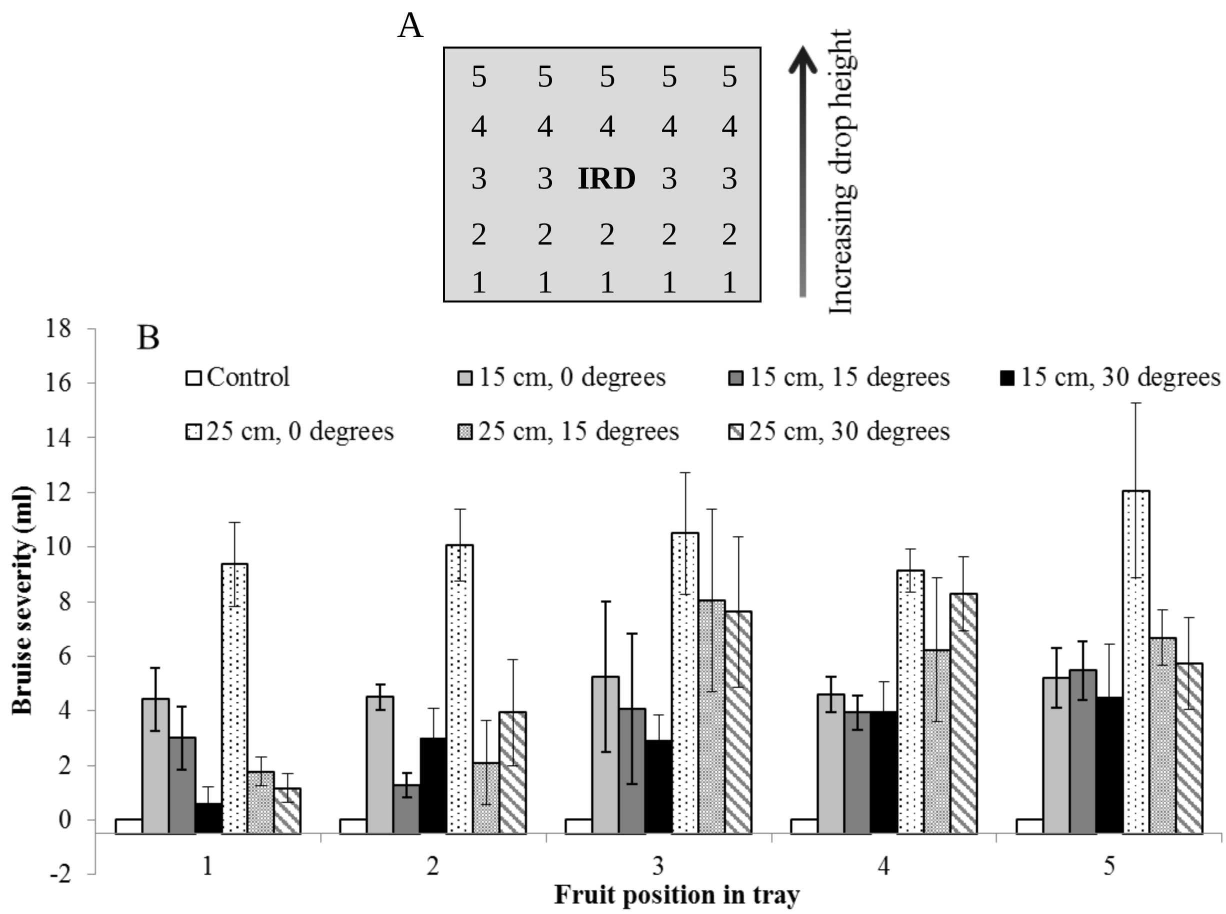

Fig. 4.3 A: Arrangement of avocado cv. 'Hass' fruit in a tray for mapping of bruise severity in response of tray drops from different heights and angles. Fruit in row number 1 were closer to the ground (i.e. proximal to the impact point) and fruit in row 5 were away from the ground (i.e. distal to the impact point) in trays dropped from an angle. B: Distribution of flesh bruising in fruit trays (n = 3) dropped from different heights and drop angles. Vertical lines represent standard deviation from the mean. Different letters represent significance differences between treatments by LSD (P = 0.05).

Table 4.1 Effects of tray drop heights and drop angles on resultant bruise severity in avocado cv.

'Hass' fruit in trays impacted from different drop heights and angles at firm ripe stage of hand firmness (± SD).

Factors/treatments	Number of fruit in tray	Number of trays (replications)	Bruise severity (ml)
Tray drop height (Factor A)			
0 cm	24	3	0
15 cm	24	3	3.6 ± 1.1 b
25 cm	24	3	7.3 ± 2.8 a
Tray drop angle (Factor B)			
0 degrees	24	3	7.5 ± 3.3 a
15 degrees	24	3	4.7 ± 2.6 b
30 degrees	24	3	4.1 ± 1.3 b
Factor A x Factor B			
Tray drop height of 15 cm			
0 degrees	24	3	4.8 ± 0.8 a
15 degrees	24	3	3.0 ± 0.3 b
30 degrees	24	3	3.0 ± 0.8 b
Tray drop height of 25 cm			
0 degrees	24	3	10.2 ± 2.1 a
15 degrees	24	3	6.4 ± 2.7 b
30 degrees	24	3	5.3 ± 0.1 b
Statistical probability (*P*)			
Factor A			0.000
Factor B			0.005
Factor A * Factor B			0.212

$P < 0.05$ = significant, $P > 0.05$ = non-significant. Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at $P = 0.05$.

Bruise severity in fruit harvested from tree 1 (14.6 ± 3.5 ml) was not significantly different by 95% confidence interval (CI) from the bruise severity in fruit harvested from tree 2 (14.7 ± 3.5 ml). However, it was significantly different between fortnightly harvest time treatments by the 95% CI level (Fig. 4.5). Linear regression analysis ($n_{x,y} = 10$) yielded: bruise volume (ml) = 16.9 – 0.403 x time (fortnight) with $R^2 = 88.7\%$ and $P \leq 0.05$. The hue angle of bruised flesh did not change ($P > 0.05$) over the harvest period (Table 4.2). However, chroma significantly reduced ($P \leq 0.05$), i.e. bruise darkness increased with increasing dry matter content (%), over the time of fortnightly harvest periods (Table 4.2). The linear regression equation correlation ($n_{x,y} = 10$) was: chroma = 25.4 – 0.390 x time (fortnight) with $R^2 = 88.9\%$ and $P \leq 0.05$. The linear regression analysis between dry matter content and bruise volume in fruit over the times of fortnightly harvest periods ($n_{x,y}$ = 10) was: bruise volume (ml) = 22.2 – 0.29 x mean dry matter content (%) with R^2 = 78.1% and $P \leq 0.05$.

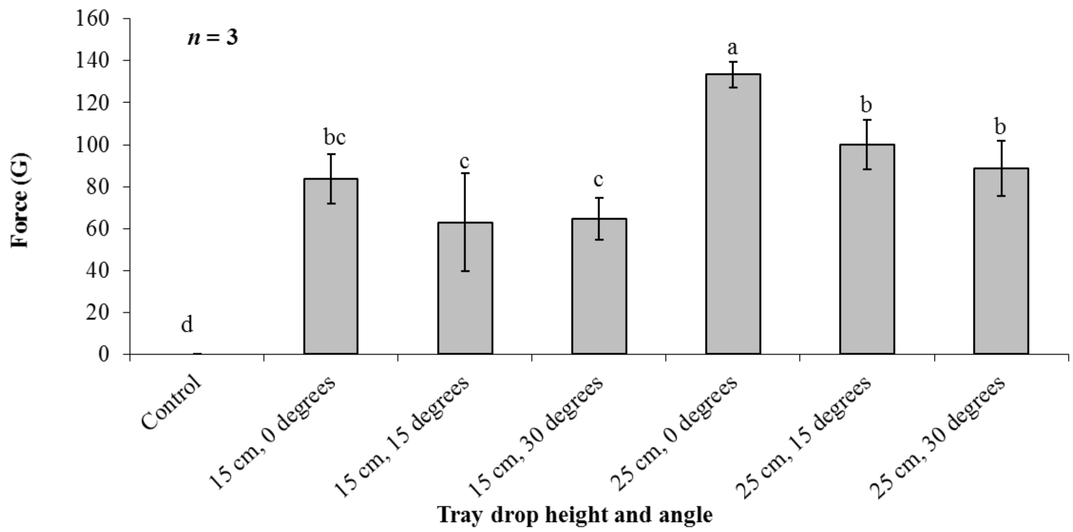

Fig. 4.4 Impact forces recorded by an IRD placed in fruit trays (*n* = 3) of avocado cv. 'Hass' fruit. Treatments were different combinations of tray drop height and angle. Vertical lines represent standard deviation from the mean. Different letters represent significance differences between treatments by LSD (*P* = 0.05).

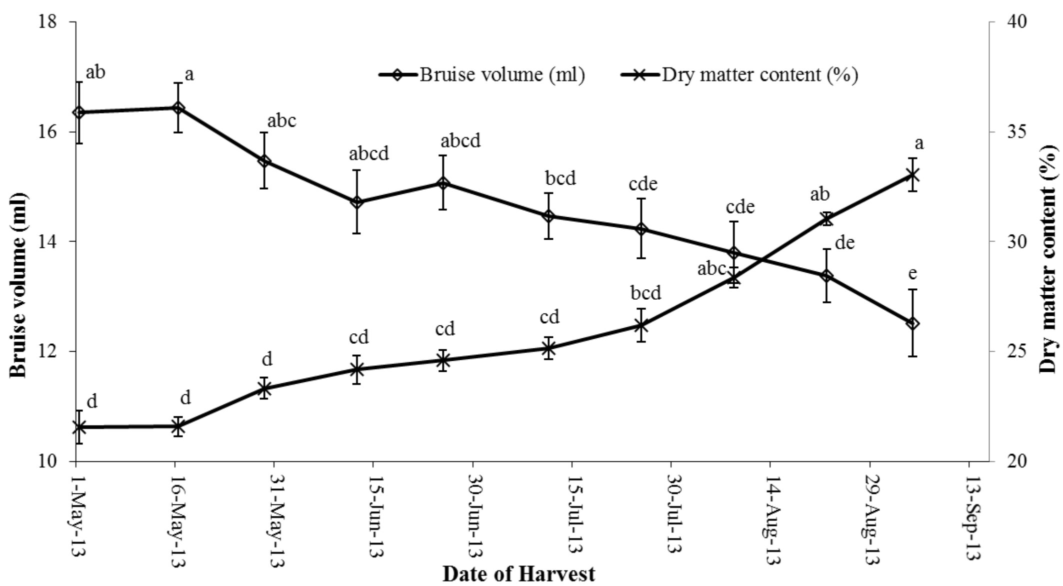

Fig. 4.5 Relationships of fruit dry matter content (%) and bruise volume (ml) with time of harvest. The horizontal axis presents dates over the period of harvest. The vertical axis on the right hand side presents dry matter content (%) in fruit (*n* = 5). The vertical axis on left hand

side presents bruise volume (ml) in impacted avocado cv. ‘Hass’ fruit (*n* = 20). Perpendicular bars on the lines presenting data on dry matter contents (%) and bruise volume (ml) show the mean standard errors of the treatments. Letters on the data points represent the difference between the treatments. Different letters represent significance differences between treatments by LSD (*P* = 0.05).

Table 4.2 Effect of fortnightly harvest time of avocado cv. ‘Hass’ fruit (*n* = 20) impacted at firm ripe stage of hand firmness from 50 cm drop height and held for 48 h before destructive bruise assessment through the fruiting season on hue angle and chroma of bruised flesh (±SE).

Harvest time	Hue angle	Chroma
T1 (1 May 2013)	85.5 ± 1.4 a	24.9 ± 0.3 a
T2 (16 May 2013)	82.2 ± 1.4 a	24.8 ± 0.3 a
T3 (31 May 2013)	82.9 ± 1.4 a	24.3 ± 0.3 ab
T4 (15 June 2013)	83.8 ± 1.4 a	24.1 ± 0.3 ab
T5 (30 June 2013)	82.6 ± 1.4 a	23.4 ± 0.3 abc
T6 (15 July 2013)	83.0 ± 1.4 a	22.5 ± 0.3 bc
T7 (30 July 2013)	81. 3 ± 1.4 a	22.8 ± 0.3 bc
T8 (14 August 2013)	81.6 ± 1.4 a	22.2 ± 0.3 c
T9 (29 August 2013)	79.9 ± 1.4 a	21.9 ± 0.3 c
T10 (13 September 2013)	79.9 ± 1.4 a	21.7 ± 0.3 c

Values not sharing the same letter differ significantly from each other by Tukey’s LSD test at *P* = 0.05.

4.1.4 Fruit firmness

Mature green hard avocado cv. ‘Hass’ fruit impacted from 50 cm and 100 cm did not show visible symptoms of bruising over the 15 days assessment period. However, at the time of assessment, body rots were noticed incidentally at the impact site. The proportion of fruit developing body rots at the impact site from d 7 after impact was 7.3%, this being significantly higher ($P \leq 0.05$) as compared with no rot in control fruit. Rot incidence on fruit impacted from the two different drop heights did not differ significantly (P > 0.05) (Fig. 4.6).

In the experiment with the ripening fruit, the bruise severity in response to impact of softening fruit from 50 cm drop height was significantly lower ($P \leq 0.05$) as compared with firm ripe and soft ripe fruit, which were not significantly different from one another (P > 0.05) (Fig. 4.7). Hue angle and chroma of bruised flesh in all three treatments of softening, firm ripe and soft ripe fruit did not differ significantly (P > 0.05) (Table 4.3).

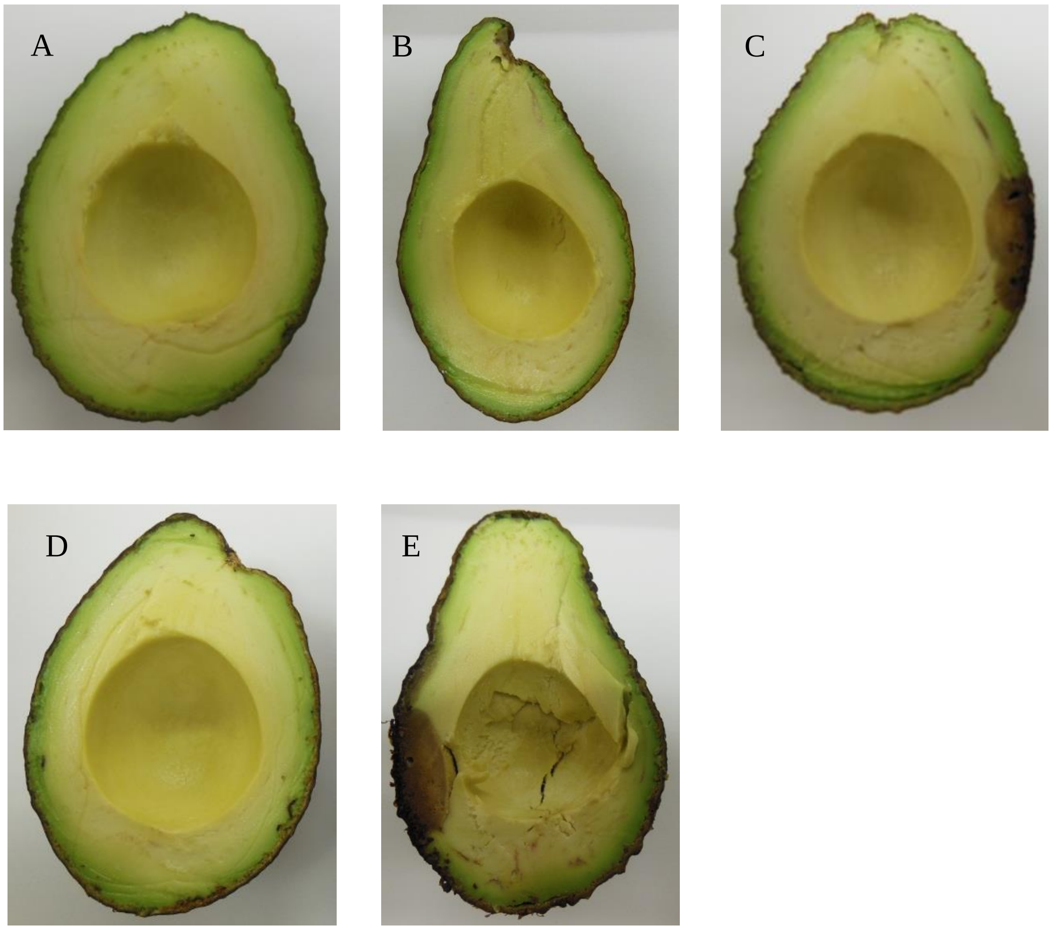

Fig. 4.6 Images of a typical control fruit without any internal fruit quality problems symptoms (A), a fruit impacted from 50 cm drop height that did not develop any rotting until 15 d after impact (B), a fruit impacted from 50 cm drop height that developed rotting on d 7 after impact (C), a fruit impacted from 100 cm drop height that did not yield any internal quality problems until 15 d after impact (D), and a fruit impacted from 100 cm drop height that produced rotting on d 8 after impact (E).

Table 4.3 Avocado cv. 'Hass' fruit (n = 10) firmness and hue angle and chroma values for bruised flesh (±SD). The fruit were impacted from 50 cm drop height and bruise assessment was conducted destructively.

Hand firmness stage	Hue angle	Chroma

Softening	90.9 ± 4.2 a	26.9 ± 3.2 a
Firm ripe	91.1 ± 5.0 a	26.9 ± 5.3 a
Soft ripe	86.8 ± 3.9 b	25.2 ± 2.1 a

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at *P* = 0.05.

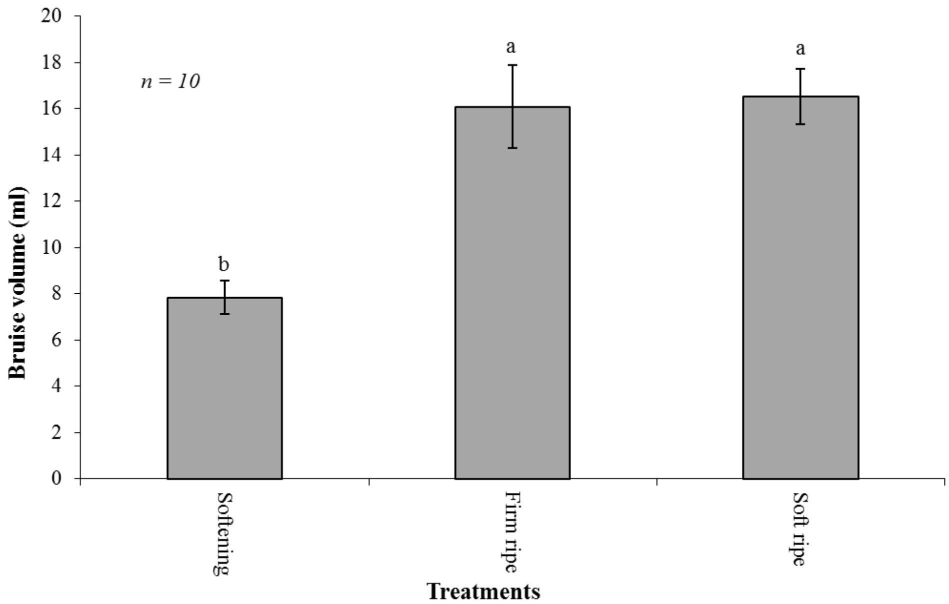

Fig. 4.7 Firmness of avocado cv. 'Hass' fruit (n = 10) (horizontal axis) and bruise severity (vertical axis) upon impact from 50 cm drop height. Vertical lines present the mean standard error of bruise volume in 10 fruits. Different letters represent significance differences between treatments by LSD (P = 0.05).

4.1.5 Pre-ripening fruit holding duration

Longer pre-ripening fruit holding durations significantly ($P \leq 0.05$) increased bruise severity in avocado cv. 'Hass' fruit impacted from 50 cm drop height. Fruit which were not held after harvest had significantly ($P \leq 0.05$) low bruising as compared with the other treatments. Also, a temporal increase was recorded in bruise severity with increasing pre-ripening holding duration treatments (Fig. 4.8). Linear regression analysis ($n_{x,y}$ = 6) yielded: bruise volume (ml) = 11.3 + 0.64 x time (weeks) with R^2 = 16.1% and $P \leq 0.05$. Fruit holding duration treatment did not statistically significantly affect the hue angle at 95% CI. However, chroma values were significantly ($P \leq 0.05$) lower at week 5, the end of the experiment (Table 4.4).

Table 4.4 Effect of pre-ripening holding duration of avocado cv. 'Hass' fruit (*n* = 20) impacted from 50 cm drop height at firm ripe stage of hand firmness and destructively assessed at 48 h after impact on hue angle and chroma of bruised flesh (±SD).

Holding duration (weeks)	Hue angle	Chroma
Control (no holding)	81.1 ± 4.4 a	22.4 ± 1.2 a
Week 1	81.5 ± 2.2 a	22.8 ± 1.7 a
Week 2	81.7 ± 6.9 a	22.8 ± 4.6 a
Week 3	81.2 ± 4.8 a	22.4 ± 1.7 a
Week 4	79.8 ± 5.4 a	21.8 ± 2.0 ab
Week 5	78.6 ± 5.8 a	20.2 ± 2.8 b

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at *P* = 0.05.

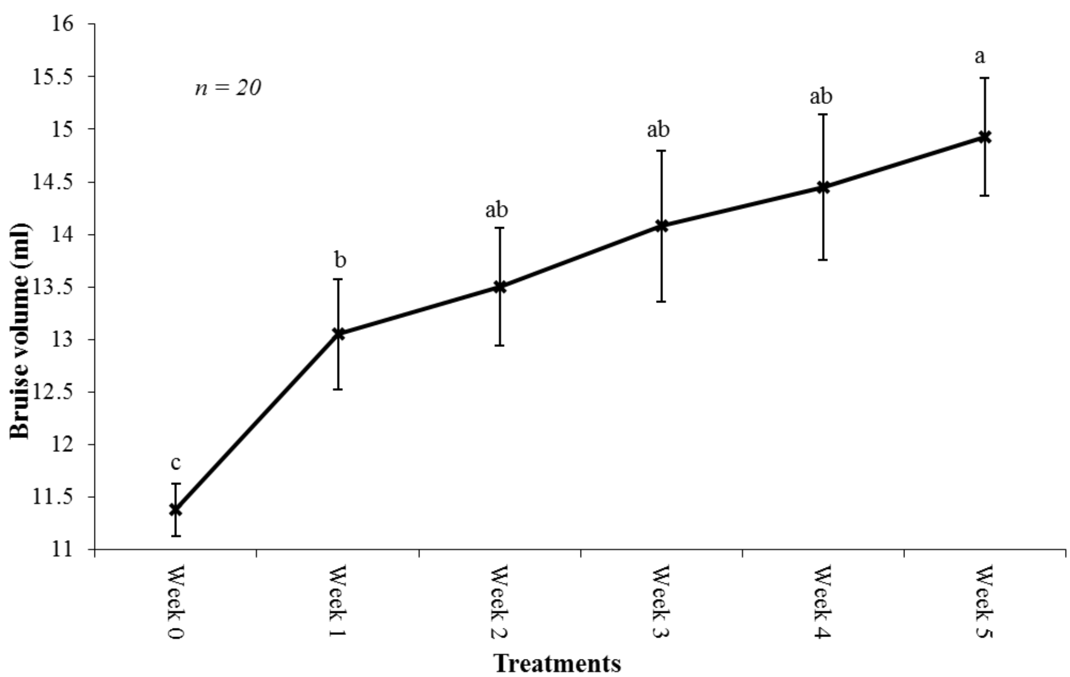

Fig. 4.8 Effect of fruit holding duration (x-axis) on bruise volume (ml; y-axis) is presented for fruit (*n* = 20) held after harvest at 5 °C and removed weekly followed by ripening and impact treatment from 50 cm drop height. Perpendicular lines on the line presenting data of bruise volume (ml) show the mean standard errors of the treatments. Different letters represent significance differences between treatments by LSD (*P* = 0.05).

4.1.6 Post-impact fruit holding duration

Bruise severity, hue angle and chroma were significantly affected ($P \leq 0.05$) by post-impact fruit holding duration (Table 4.5). Visible bruise symptoms first appeared at 12 h after impact and continued to increase thereon until last assessment at 96 h. Hue angle and chroma also started to change as the visible bruising darkened over the assessment period.

Table 4.5 Effect of post-impact holding duration on bruise severity, hue angle and chroma of bruised flesh of avocado cv. 'Hass' fruit (*n* = 20) impacted from 50 cm drop height at firm ripe stage of hand firmness and destructively assessed after 48 h of impact (±SE).

Holding duration (hours)	**Bruise severity (ml)**	**Hue angle**	**Chroma**
T1 (0 h)	0	99.8 ± 2.1 a	38.8 ± 0.5 ab
T2 (2 h)	0	99.8 ± 2.6 a	39.5 ± 0.5 a
T3 (4 h)	0	102.4 ± 1.9 a	39.1 ± 0.5 ab
T4 (8 h)	0	100.9 ± 2.9 a	39.6 ± 0.5 a
T5 (12 h)	1.0 ± 0.7 d	100.2 ± 5.2 a	37.1 ± 0.5 b
T6 (24 h)	4.8 ± 0.7 c	93.8 ± 4.4 bc	39.0 ± 0.5 ab
T7 (48 h)	7.6 ± 0.7 b	92.0 ± 4.7 c	26.1 ± 0.5 c
T8 (72 h)	8.5 ± 0.7 ab	83.1 ± 2.7 d	23.1 ± 0.5 d
T9 (96 h)	10.9 ± 0.7 a	79.2 ± 2.8 e	21.5 ± 0.5 d
Control (no impact assessed at 96 h)	0	95.8 ± 1.2 b	37.2 ± 0.5 ab

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at $P = 0.05$.

In a confirmatory and expanded experiment, firm ripe fruit impacted from 50 cm drop height expressed visible bruising from d 1 that was significantly ($P \leq 0.05$) higher as compared with the un-impacted control (Fig. 4.9). Bruise severity increased significantly ($P \leq 0.05$) over the assessment period from d 0 to d 7. The hue angle of the flesh of control fruit was significantly ($P \leq 0.05$) higher than that of the impacted fruit assessed from day 4 onwards (Table 4.6). Chroma of the flesh of un-impacted control fruit was significantly ($P \leq 0.05$) higher than that of the impacted fruit assessed from day 2 onwards (Table 4.6). About 20% fruit started showing rots at the impact site from d 4. The proportion of fruit with rots rose to 60% on d 7.

Table 4.6 Effect of post-impact holding duration on hue angle and chroma of bruised flesh of avocado cv. ‘Hass’ fruit (n = 10) impacted at firm ripe stage from 50 cm drop height and subjected to destructive bruise assessment after 48 h after impact (±SD).

Holding duration (days)	**Hue angle**	**Chroma**
T1 (Day 0)	102.8 ± 2.6 a	41.2 ± 4.8 a
T2 (Day 1)	102.6 ± 2.5 a	36.6 ± 3.7 ab
T3 (Day 2)	93.6 ± 8.2 b	32.4 ± 11.0 bc
T4 (Day 3)	89.0 ± 14.2 bc	29.5 ± 9.5 bcd
T5 (Day 4)	88.8 ± 7.3 bc	28.4 ± 7.8 cd
T6 (Day 5)	88.2 ± 9.6 bc	26.6 ± 8.4 cd
T7 (Day 6)	87. 3 ± 7.8 bc	24.0 ± 8.8 d
T8 (Day 7)	84.2 ± 8.8 c	24.2 ± 9.5 d
Control (no impact assessed on day 7)	94.2 ± 1.3 b	36.8 ± 3.4 ab

Values not sharing the same letter differ significantly from each other by Tukey’s LSD test at P = 0.05.

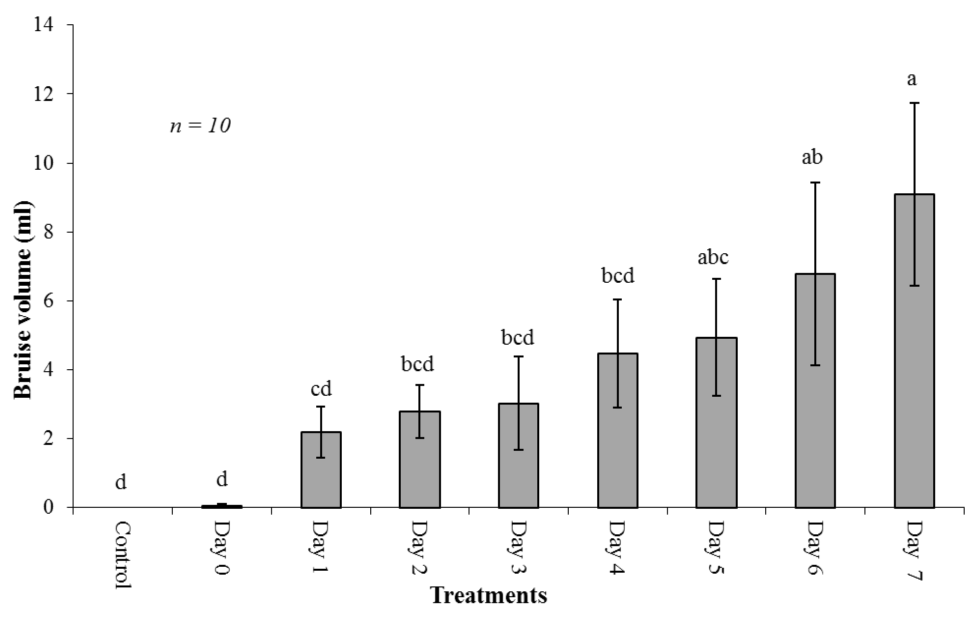

Fig. 4.9 Bruise volume (ml; y-axis) developed over time (x-axis) in firm ripe avocado cv. ‘Hass’ fruit (n = 10) as compared with the control treatment (firm ripe fruit, no impact). Vertical lines on the bars presenting the bruise volume (ml) present the mean standard errors of the treatments. Letters on the data points represent the difference between the treatments. Treatments not sharing letters differ significantly from each other.

4.1.7 Pre- and post-impact fruit holding temperature

Post impact fruit holding temperature had a significant ($P \leq 0.05$) effect on bruise incidence, bruise severity, and bruise intensity in terms of hue angle and chroma over holding temperatures of 5 °C, 15 °C and 25 °C. Bruising was not obvious in even a single fruit held at 5 °C post-impact. However, 90% and 95% of impacted fruit held at 15 °C and 25 °C respectively, expressed visible bruise symptoms. Although fruit held at 5 °C post-impact temperature did not produce any visible bruising, ~ 60% of the fruit held at 5 °C showed cracks in their flesh at the impact site. However, the crack volume (0.2 ± 0.2 ml) was significantly ($P \leq 0.05$) less than the bruised flesh volumes in fruit held at 15 °C (1.9 ± 1.0 ml) and 25 °C (2.2 ± 1.1 ml), which were on par statistically. Bruise intensity, in terms of hue angle and chroma of bruised flesh, reduced significantly ($P \leq 0.05$) consistently with the increase of the post-impact fruit holding temperature (Table 4.7). No bruising was recorded in the flesh of non-impacted control fruit after 48 h holding period at all three temperatures. The change in hue angle and chroma of the flesh of firm ripe avocado fruit in control (viz., not impacted and assessed with the impacted fruit at 48 h after their being impacted) of the three post-impact fruit holding temperature treatments was not significant ($P > 0.05$).

Table 4.7 Effect of post-impact holding temperature on hue angle and chroma of bruised flesh of avocado cv. 'Hass' fruit ($n = 20$) impacted from 25 cm drop height at firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Holding temperature	Hue angle	Chroma
5 °C	105.7 ± 3.7 a	37.8 ± 1.9 a
15 °C	102. 0 ± 4.9 b	33.6 ± 3.3 b
25 °C	94.7 ± 5.6 c	29.2 ± 4.9 c

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at $P = 0.05$.

The results of the experiment conducted to assess the effect of fruit holding temperature on hue angle and chroma of bruised flesh confirmed that the hue angle and chroma of the impacted flesh of firm ripe avocado cv. 'Hass' fruit changed significantly ($P \leq 0.05$) over the 48 h holding period. Hue angle changed from 1.2 fold at 1.2 °C to 1.29 fold at 29 °C (Fig. 4.10A). Chroma changed ($P \leq 0.05$) from 1.9 fold at lowest temperature of 1.2 °C up to 1.60 fold at highest temperature of 29 °C (Fig. 4.10B). Regression analysis of the hue angle and chroma measured at the time of impact and 48 h after impact ($n_{x,y} = 25$) established correlations for generalised prediction of hue angle and chroma based on post-impact fruit holding temperature. For hue angle, the model yielded: hue angle at 48 h after impact = hue angle at the time of impact - 2.94 - 0.779 x (post-impact fruit holding temperature) with R^2 = 79.3% and $P \leq 0.05$. For chroma, the model yielded: chroma at 48 h after impact = chroma at the time of impact - 10.6 - 0.404 x (post-impact fruit holding temperature) with R^2 = 85.7% and $P \leq 0.05$.

In the experiment conducted to assess bruising in fruit at different stages of firmness held at different post-impact temperature, bruise severity was not significantly ($P > 0.05$) affected by the softening and firm ripe hand firmness stages in fruit held at 5 °C. However, bruise severity in firm ripe stage fruit was significantly ($P \leq 0.05$) higher than that in the softening fruit held post-impact at 25 °C (Table 4.8). There were no significant ($P > 0.05$) implications of fruit firmness (viz., softening and firm ripe) on bruise intensity in fruit held at either of the 5 °C or 25 °C post-impact fruit holding temperatures (Table 4.9). No visible bruising was recorded in the flesh of non-impacted control fruit subjected to assessment with the impacted fruit after the 48 h holding period in any of the firmness and post-impact fruit holding temperature treatments. Similarly, there were no significant ($P > 0.05$) effects in terms of any change in hue angle or chroma of the flesh of firm ripe avocado fruit in controls for the firmness and post-impact fruit holding temperature treatments.

Table 4.8 Effect of firmness and post-impact holding temperature on bruise severity of avocado cv. 'Hass' fruit (*n* = 20) impacted from 25 cm drop height at firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Firmness and holding temperature	Bruise severity (ml)
Softening, 5 °C	0.1 ± 0.1 b
Firm ripe, 5 °C	0.1 ± 0.1 b
Softening, 25 °C	0.3 ± 0.6 b
Firm ripe, 25 °C	0.7 ± 1.0 a

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at $P = 0.05$.

Table 4.9 Effect of firmness and post-impact holding temperature on hue angle and chroma of bruised flesh of avocado cv. 'Hass' fruit (*n* = 20) impacted from 25 cm drop height at softening and firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Firmness and holding temperature	Hue angle	Chroma
Softening, 5 °C	103.2 ± 2.3 a	36.1 ± 2.1 a
Firm ripe, 5 °C	101.3 ± 2.7 ab	35.9 ± 2.6 a
Softening, 25 °C	100.9 ± 6.4 ab	35.3 ± 5.6 a
Firm ripe, 25 °C	100.0 ± 5.9 b	35.0 ± 3.5 a

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at *P* = 0.05.

Impacted fruit held at 5 °C for the initial 8 h and then held at 25 °C for the subsequent 40 h expressed significantly low bruising ($P \leq 0.05$) as compared with the bruise severity when the post impact fruit holding temperature was 25 °C during the initial 8 h after impact followed by holding the fruit at 5 °C for the subsequent 40 h (Fig. 4.10C). The non-impacted control fruit held at the two combinations of post-impact fruit holding temperature did not express any bruising. The difference between the two treatments of switching the post-impact fruit holding temperature was significant ($P \leq 0.05$) for hue angle, but was not significant ($P > 0.05$) for chroma (Table 4.10). However, flesh hue angle and chroma values obtained on the impacted part of the fruit were significantly ($P \leq 0.05$) lower than those in control fruit which were not subjected to impact. The hue angle and chroma of the control fruit was not different for the two sets of post-impact fruit holding temperature (Table 4.8).

Table 4.10 Effect of switching the post-impact holding temperature on hue angle and chroma of bruised flesh of firm ripe avocado cv. 'Hass' fruit ($n = 20$) impacted from 25 cm drop height at firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Treatment	Hue angle	Chroma
Impacted, 5 °C for 8 h and 25 °C for 40 h	98.0 ± 5.3 b	32.5 ± 3.1 b
Impacted, 25 °C for 8 h and 5 °C for 40 h	93.4 ± 7.1 c	31.9 ± 5.1 b
Non-impacted, 5 °C for 8 h and 25 °C for 40 h	100.5 ± 2.6 ab	35.7 ± 3.4 a
Non-impacted, 25 °C for 8 h and 5 °C for 40 h	101.3 ± 2.6 a	36.0 ± 2.6 a

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at *P* = 0.05.

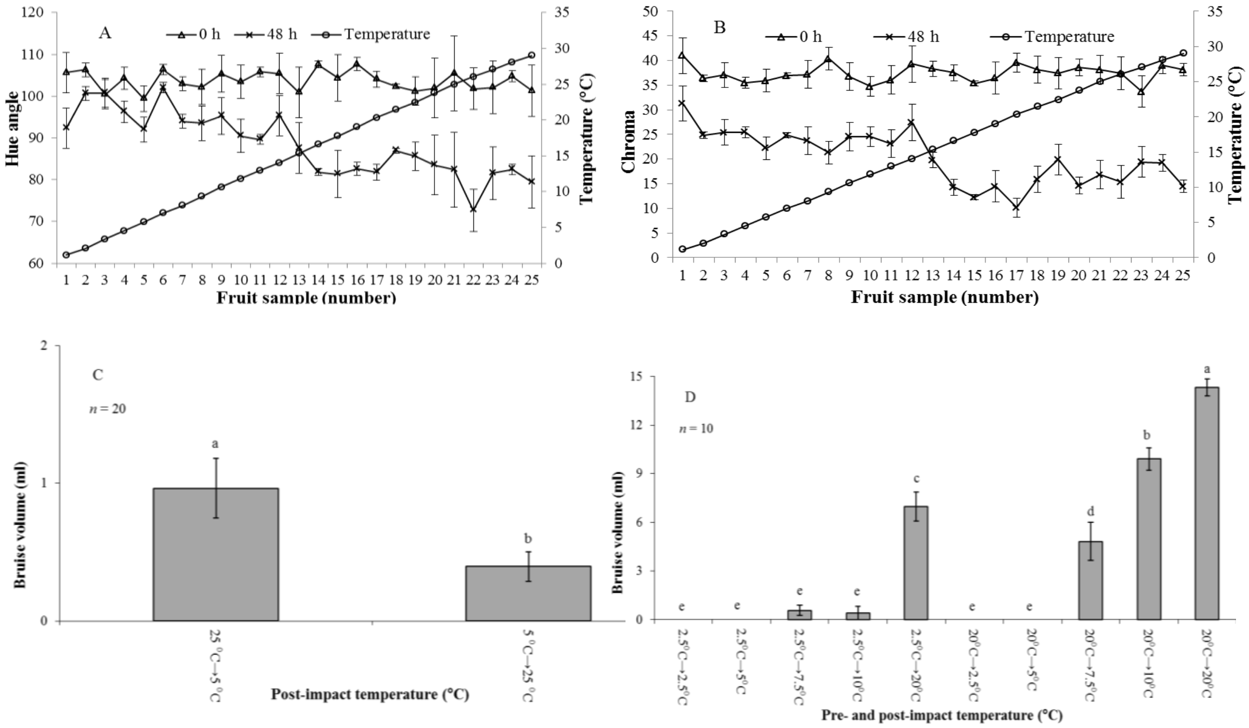

Fig. 4.10 A: Effect of post-impact fruit holding temperature on hue angle (left vertical axis) of the bruised flesh of firm ripe avocado cv. 'Hass' fruit (n = 25) (horizontal axis) impacted from 50 cm drop height. The data line at the top (i.e. upper) represents the hue angle measured immediately after impact and the bottom (i.e. lower) parallel line represents the hue angle measured 48 h after impact. The sloped line represents the temperature gradient (right vertical axis). Vertical lines on the lines representing hue angle present the mean standard errors. B: Chroma value (left vertical axis) of avocado cv. 'Hass' fruit (horizontal axis) as affected by the post-impact fruit holding temperature. The upper or top line is the measure of chroma value immediately after impact. The lower or bottom line is the measure of chroma value at 48 h after impact. The sloped line represents the range of temperature (right vertical axis). Vertical lines on the lines representing hue angle present the mean standard errors. C: Effect of switching the post-impact fruit holding temperature (x-axis) on bruise severity (y-axis) in firm ripe avocado cv. 'Hass' fruit (n = 20) impacted from 25 cm drop height. Vertical lines on the bars of bruise volume (ml) present the mean standard errors. Letters on the data points represent the difference between the treatments. Treatments not sharing letters differ significantly from each other. D: Effect of different combinations of pre- and post-impact fruit holding temperature (x-axis) on bruise volume (ml) (y-axis) in firm ripe avocado cv. 'Hass' fruit (n = 10) impacted from 50 cm drop height. Vertical lines on the bars of bruise volume (ml) present the mean standard errors. Letters on the data points represent the difference between the treatments. Treatments not

sharing letters differ significantly from each other.

Fruit impacted at the flesh temperature of 2.5 °C and held at any of 2.5 °C, 5 °C, 7.5 °C, and 10 °C, and the fruit impacted at flesh temperature of 20 °C and held post-impact at 2.5 °C, and 5 °C developed significantly ($P \leq 0.05$) low bruise volumes. The other treatments combinations of pre- and post-impact fruit holding temperatures were significantly ($P \leq 0.05$) different from each other, and the maximum bruise volume was in fruit impacted and held post-impact at 20 °C (Fig. 4.10D). The hue angle of the bruised flesh in fruit impacted and held at 2.5 °C was significantly ($P \leq 0.05$) higher (no visible bruising) than the hue angle of bruised flesh of all other treatments. That of the fruit impacted and held at 20 °C was significantly ($P \leq 0.05$) lower than all other treatments of pre- and post-impact fruit holding temperature (Table 4.11). Similarly, the chroma of the bruised flesh in fruit impacted at 2.5 °C and held at any of 2.5 °C, 5 °C, 7.5 °C, and 10 °C and that impacted at 20 °C and held at 2.5 °C was significantly ($P \leq 0.05$) higher than chroma of bruised flesh for all other treatments of pre- and post-impact fruit holding temperature. The lowest chroma was recorded for fruit impacted and held at flesh temperature of 20 °C, while chroma of the fruit impacted and held at 2.5 °C was highest (Table 4.11).

Table 4.11 Effect of pre- and post-impact fruit holding temperature on hue angle and chroma of bruised flesh of avocado cv. 'Hass' fruit (n = 10) impacted from 50 cm drop height at firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Pre- and post-impact flesh temperature	Hue angle	Chroma
Impacted at 2.5 °C and held at 2.5°C	104.9 ± 2.2 a	38.5 ± 1.9 ab
Impacted at 2.5 °C and held at 5°C	100.0 ± 2.7 bc	39.9 ± 3.3 a
Impacted at 2.5 °C and held at 7.5°C	102.0 ± 1.8 b	38.6 ± 1.7 a
Impacted at 2.5 °C and held at 10°C	98.2 ± 1.7 cd	39.3 ± 1.2 a
Impacted at 2.5 °C and held at 20°C	90.2 ± 3.7 f	28.3 ± 4.4 e
Impacted at 20 °C and held at 2.5°C	96.9 ± 2.7 de	38.2 ± 2.3 abc
Impacted at 20 °C and held at 5°C	96.9 ± 2.2 de	36.2 ± 1.4 cd
Impacted at 20 °C and held at 7.5°C	94.9 ± 2.7 e	35.7 ± 2.0 d
Impacted at 20 °C and held at 10°C	95.7 ± 2.3 e	36.4 ± 2.3 bcd
Impacted at 20 °C and held at 20°C	82.5 ± 3.4 g	23.9 ± 1.6 f

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at P = 0.05.

The experiment conducted to confirm and expand the assessment of bruising due to pre and post-impact fruit holding temperature regimes confirmed that fruit held at a low post-impact fruit holding temperature developed significantly ($P \leq 0.05$) lower bruise volumes (Table 4.12). The hue angle and chroma of bruised flesh of fruit impacted and held at 5 °C were both significantly ($P \leq 0.05$) higher and that of the fruit impacted and held at 20 °C was significantly ($P \leq 0.05$) lower than for all other treatments lying in between; i.e. impacted at 5 °C and held at 10 °C, impacted at 5 °C and held at 20 °C, impacted at 20 °C and held at 5 °C, impacted at 20 °C and held at 10 °C (Table 4.12).

Table 4.12 Effect of pre and post-impact holding temperature on bruise severity, hue angle and chroma of bruised flesh of avocado cv. 'Hass' fruit (n = 20) impacted from 25 cm drop height at firm ripe stage of hand firmness and bruise assessment conducted after 48 of impact (±SD).

Firmness and holding temperature	**Bruise severity (ml)**	**Hue angle**	**Chroma**
Impacted and held at 5 °C	0.8 ± 1.7 c	98.1 ± 3.5 a	33.3 ± 3.0 a
Impacted at 5 °C, held at 10 °C	11.2 ± 3.4 b	93.4 ± 7.2 bc	26.9 ± 3.7 b
Impacted at 5 °C, held at 20 °C	13.7 ± 3.4 a	87.2 ± 6.6 d	24.1 ± 2.2 c
Impacted at 20 °C, held at 5 °C	1.4 ± 2.5 c	93.6 ± 4.6 b	35.0 ± 2.6 a
Impacted at 20 °C, held at 10 °C	11.3 ± 1.8 b	90.0 ± 5.8 cd	27.7 ± 2.9 b
Impacted and held at 20 °C	15.0 ± 3.4 a	81.3 ± 5.7 e	24.5 ± 3.3 c

Values not sharing the same letter differ significantly from each other by Tukey's LSD test at P = 0.05.

4.1.8 Application of magnetic resonance imaging for bruising assessment in avocado fruit

The exocarp, flesh, vasculature, endocarp (testa), and seed morphological features of ripening avocado cv. 'Hass' fruit were clearly distinguishable in ^{1}H-MRI images (Fig. 4.11A and 4.11B). The pericarp, except the vasculature, of fruit appeared relatively hyperintense. The vasculature and seed appeared hypointense. Pixel intensity values for the exocarp, the transition zone between the exocarp and flesh, the flesh, and the seed of the firm ripe fruit were recorded separately over time up until d 3 following impact on d 0 (Fig. 4.12). The pixel intensity values of the exocarp (398 to 453 counts) and the transition zone between exocarp and flesh (689 to 600 counts) did not change significantly ($P > 0.05$) relative to the dark (i.e., black) background (air space) reference (16 to 18 counts). However, pixel intensities for the flesh (416 to 463 counts) and seed (163 to 223 counts) increased significantly ($P \leq 0.05$) over time.

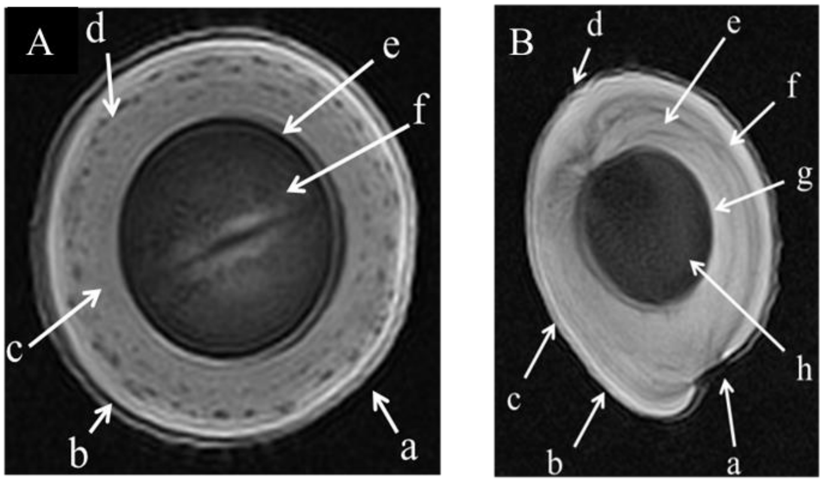

Fig. 4.11 A: Transverse section image of a ripe avocado cv. 'Hass' fruit acquired with ^{1}H-MRI. The internal morphology of the avocado fruit discerned non-destructively was: (a) exocarp (skin), (b) transition zone, (c) flesh, (d) vasculature, (e) endocarp (seed coat), and (f) seed. B: Longitudinal section image of a ripe avocado cv. 'Hass' fruit acquired with ^{1}H-MRI showing: (a) stem scar, (b) exocarp, (c) transition zone, (d) distal fruit tip, (e) flesh, (f) vasculature, (g) endocarp (seed coat), and (h) seed.

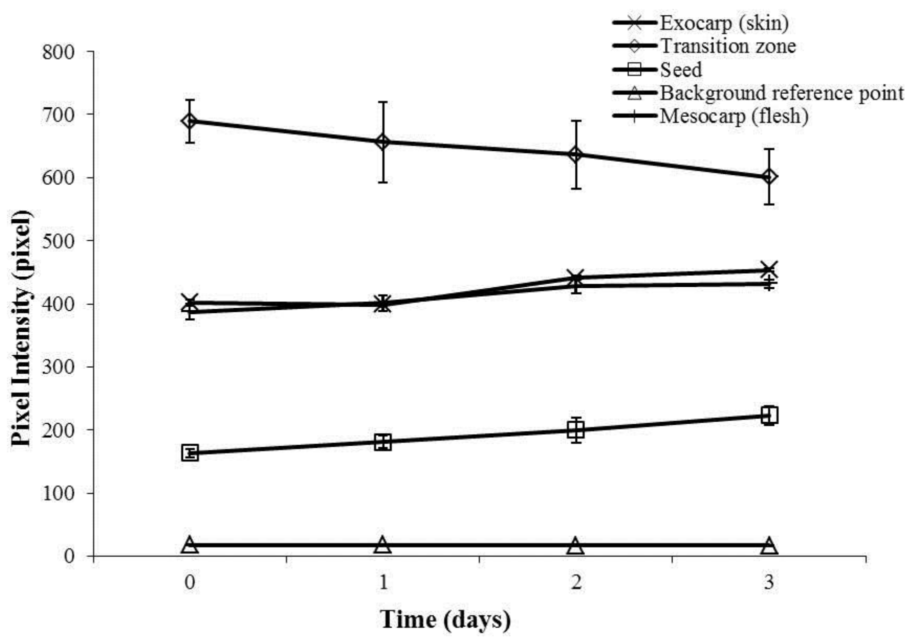

Fig. 4.12 Pixel intensity values (pixel) along the vertical axis for exocarp, transition zone, flesh, and seed regions of T_2 weighted spin echo ^{1}H-MRI images of a ripe avocado cv. 'Hass' fruit as

acquired over 3 days and compared to the pixel intensity of a dark background reference point. Vertical bars represent the standard error of the mean values.

Damage to the flesh at the site of impact was not visible immediately upon destructive assessment of firm ripe avocado cv. ‘Hass’ fruit impacted from 50 cm drop height (Fig. 4.13A). In contrast, ^{1}H-MRI non-destructively visualised the initial effect of impact energy at the site of impact (Fig. 4.13B). The image contrast for the flesh at the site of impact was clearly distinguished from the surrounding flesh in T_2 TSE ^{1}H-MRI images.

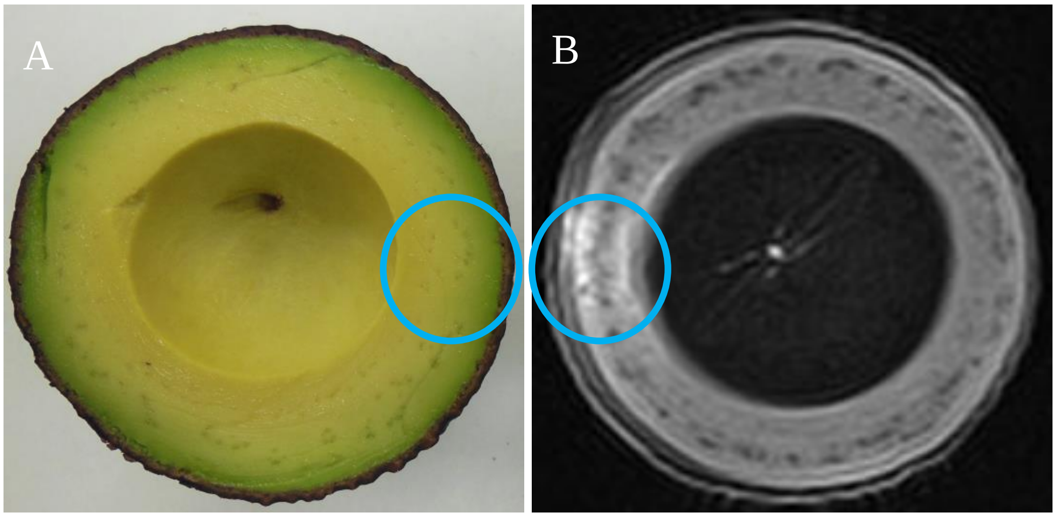

Fig. 4.13 A: Image of a transverse destructive cross section through a firm ripe avocado cv. ‘Hass’ fruit impacted from 50 cm drop height (0.81 J energy absorbed). The impacted fruit flesh marked with a circle was not visually distinguishable from the non-impacted flesh immediately after impact. B: T_2 weighted ^{1}H-MRI image of a firm ripe avocado cv. ‘Hass’ fruit impacted from 50 cm drop height (0.81 J energy absorbed). The impact site, marked with a circle, was non-destructively visualised immediately after impact and the impacted flesh appeared hyperintense as compared with the surrounding flesh.

Destructive assessment of firm ripe avocado cv. ‘Hass’ fruit impacted from drop heights of 25 and 50 cm (energy absorbed ~ 0.38 J and ~ 0.81 J, respectively) did not reveal symptoms of bruising in the flesh at the impact site on d 0. Thereafter, the visible bruise volume increased over time until ≥ d 3. In contrast, the destructive assessment of hard fruit impacted from 100 cm drop height (energy absorbed ~ 1.68 J) did not reveal any visible symptoms of bruising over the 3 day assessment period (Fig. 4.14). Nonetheless, contrast was evident in T_2 weighted TSE ^{1}H-

MRI images of both impacted firm ripe and hard fruit at the site of impact and the surrounding flesh from d 0 (Fig. 4.15).

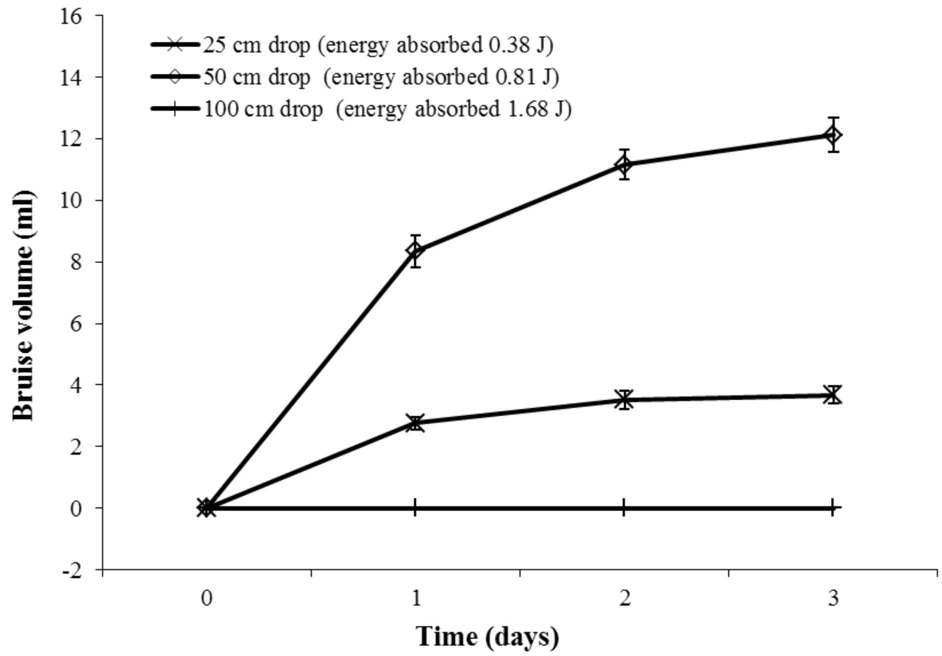

Fig. 4.14 Destructive assessment of bruise development over time until d 3 following impact in avocado cv. 'Hass' fruit impacted from 25 cm and 50 cm drop heights (0.38 and 0.81 J energies absorbed, respectively) at the firm ripe stage and from 100 cm drop height (1.68 J energy absorbed) at the hard stage. Where the bruise volume in firm ripe fruit increased over time until d 3 following impact, the bruised flesh was not visible in destructive assessments of hard fruit. Vertical bars represent the standard error for the mean values.

The bruised flesh in firm ripe fruit impacted from 25 and 50 cm drop heights appeared hyperintense on d 0 and the affected area increased up to d 3. Some of the hyperintense bruised flesh region transformed into a hypointense area from d 2. This change was visually evident as a cavity or crack in destructive assessment of the same fruit at the end of the assessment period. The impact site in hard green mature fruit was visible on d 0 in T_2 TSE ^{1}H-MRI images. It appeared hyperintense on d 0 and then became relatively hypointense over the period of assessment to d 3 without any obvious increase in the affected area. The pixel intensity value of the flesh in the area of the fruit that was impacted, as compared with the pixel intensity of a standard background reference point, was dependent on time of assessment for both the firm ripe and the hard green mature fruit (Fig. 4.16). The change in pixel intensity value of the flesh over time for firm ripe fruit impacted from 25 cm drop height was not significant ($P > 0.05$) (427 to

350 counts;). However, the changes were significant ($P \leq 0.05$) for firm ripe fruit impacted from 50 cm drop height (567 to 485 counts) and hard green mature fruit impacted from 100 cm drop height (433 to 284 counts).

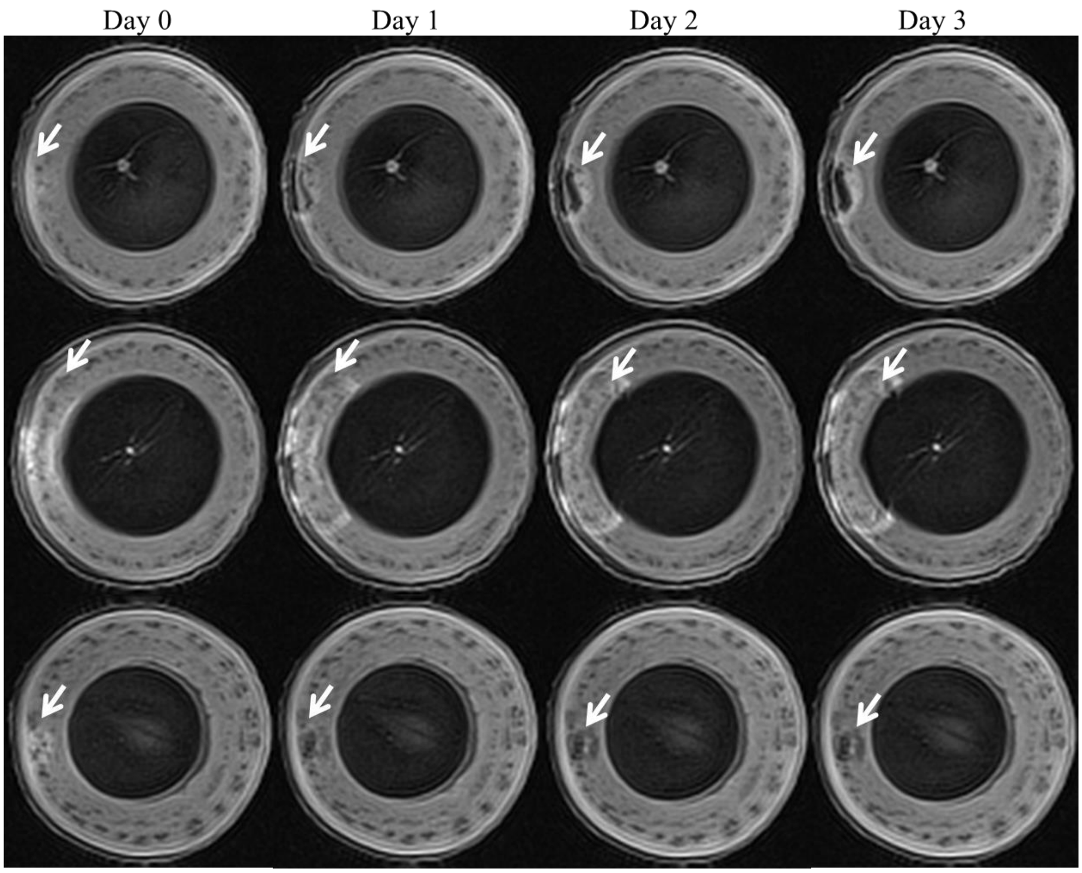

Fig. 4.15 Serial T_2 weighted ^{1}H-MRI images of bruise development over time for softening avocado cv. 'Hass' fruit impacted from 25 cm drop height (0.38 J energy absorbed) and 50 cm drop height (0.81 J energy absorbed) at the firm ripe stage and from 100 cm drop height (1.68 J energy absorbed) at the hard stage. Arrows indicate the flesh adjacent to impact sites. The impacted flesh in firm ripe avocados appeared hyperintense on d 0 and increased until d 3. The hypointense regions adjacent to impact site in firm ripe avocados reveals cracking as a result of impact. The impacted flesh in hard fruit was hyperintense on d 0 and did not expand over time.

T_2 weighted TSE ^{1}H-MRI images of firm ripe avocado cv. 'Hass' revealed hyperintense regions at the distal end of the fruit, spatially away from impact points. This high contrast in distal regions increased progressively over the 3 day experiment assessment period (Fig. 4.17).

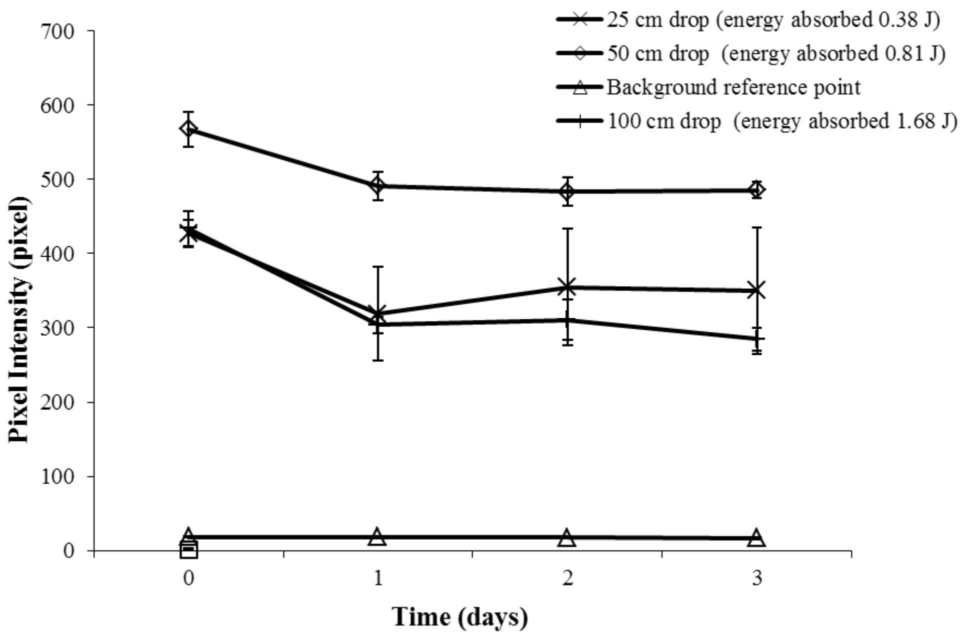

Fig. 4.16 Pixel intensity for bruised regions, acquired through T_2 weighted ^{1}H-MRI images of avocado cv. 'Hass' fruit, of firm ripe fruit impacted from 25 cm and 50 cm drop heights (0.38 and 0.81 J energies absorbed, respectively) and of hard fruit impacted from 100 cm drop height (1.68 J energy absorbed) relative to a background reference point until d 3 following impact. Vertical bars represent the standard error for the mean values.

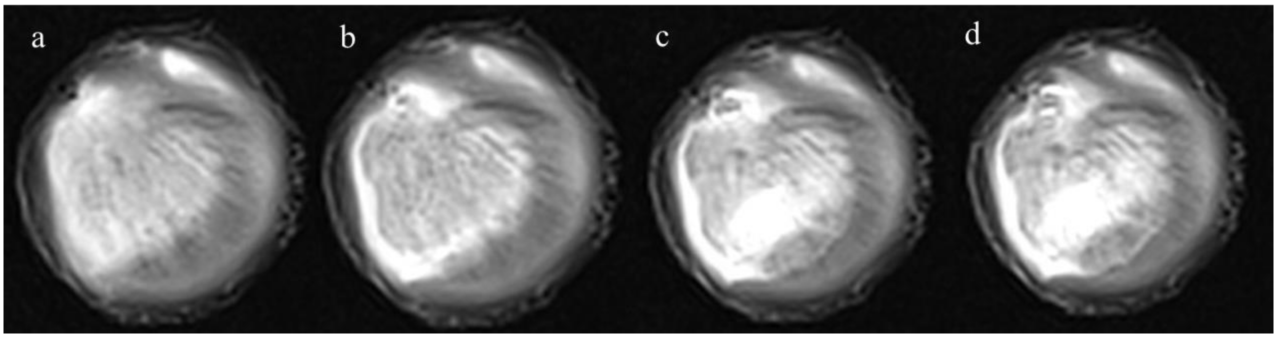

Fig. 4.17 Serial T_2 weighted ^{1}H-MRI images of pathogen affected flesh of firm ripe avocado cv. 'Hass' fruit over 3 days. The increasingly hyperintense distal region suggests that the pathogen affected flesh volume degenerated and expanded representing progressive decay over time.

4.2 Sampling through the supply chain

4.2.1 Sampling from the ripener to the retail display

Flesh bruise severity increased ($P \leq 0.05$) from sampling point 1 (ripener arrival) to sampling point 6 (retail store display) for the cumulative data of the two supermarket supply chains (Fig. 4.18) in the first experiment. Mean bruise severity increased from 0.2 ± 1.1 ml at sampling point 1 to 1.0 ± 3.6 ml at sampling point 4. Bruise severity rose to 3.5 ± 7.4 ml at sampling point 5 and reached 7.7 ± 12.5 ml at sampling point 6.

The same pattern of increasing bruising from ripener to retail display was observed in the results of the individual supermarket chains (Table 4.13). Mean bruise severity in supply chain 1 increased from 0.1 ± 0.4 ml at sampling point 1 to 6.7 ± 12.3 ml at sampling point 6. Similarly, mean bruise severity in supply chain 2 was 0.2 ± 1.4 ml at sampling point 1 and increased to 9.9 ± 12.3 ml at sampling point 6. The bruise severity averaged across all sampling points were significantly different ($P \leq 0.05$) between the two supply chains. Mean flesh bruising in supply chain 1 was 2.6 ± 6.8 ml whereas that in supply chain 2 was 3.9 ± 8.6 ml (Fig. 4.19).

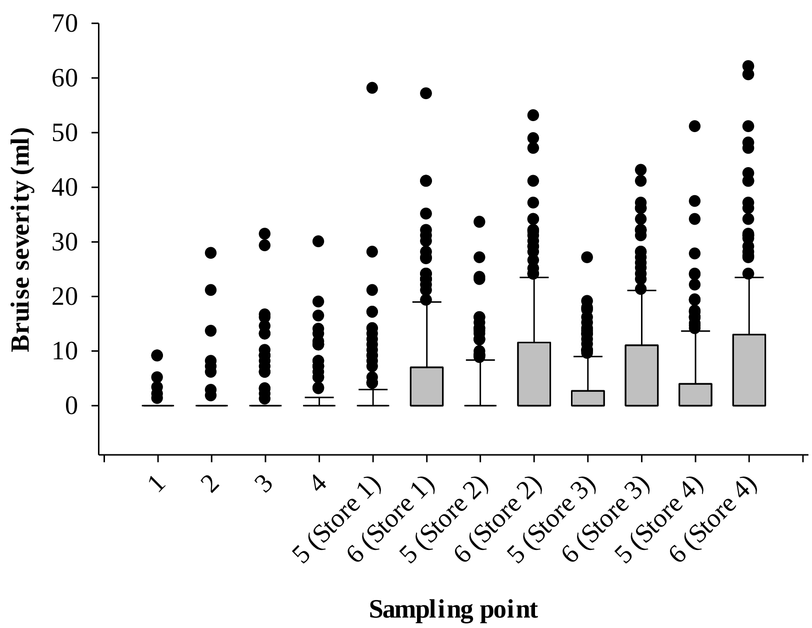

Fig. 4.18 Boxplot of bruise severity in avocado cv. 'Hass' fruit sampled from six serial sampling points of two supermarket retail store chains and subjected to destructive bruising assessment. 1 = ripener arrival, 2 = ripener dispatch, 3 = distribution center arrival, 4 = distribution center dispatch, 5 = retail store arrival, 6 = retail store dispatch. Four stores of each supermarket supply chain participated in this study. Bottom boundaries of the bars in this figure represent the first quartile and the median of the data. Upper boundaries of the bars represent the third quartile of data sets. Lower terminal points of the lines without bars represent the minimum range of the data, and top terminal points of the lines with and / or without bars represent the maximum range

of the data. Black dots represent the outlier values of the data sets.

Table 4.13 Bruise severity in avocado cv. 'Hass' fruit sampled from six serial sampling points of two supermarket retail store supply chains and subjected to destructive bruising assessment (±SD).

Sampling point	**Bruise severity (ml)**	
	Supply chain 1	**Supply chain 2**
Ripener arrival	0.1 ± 0.4 f	0.2 ± 1.4 d
Ripener dispatch	0.5 ± 3.4 f	0.4 ± 2.4 d
DC arrival	1.0 ± 4.8 def	1.0 ± 3.1 cd
DC dispatch	1.0 ± 4.2 def	1.0 ± 2.8 cd
Store 1 arrival	0.2 ± 0.6 f	2.6 ± 7.6 c
Store 1 display	2.6 ± 7.5 cd	7.5 ± 10.7 b
Store 2 arrival	2.2 ± 5.3 de	1.8 ± 4.8 cd
Store 2 display	4.5 ± 9.1 b	9.9 ± 12.3 a
Store 3 arrival	2.2 ± 4.0 cde	2.2 ± 5.0 cd
Store 3 display	4.0 ± 6.6 bc	9.7 ± 12.4 ab
Store 4 arrival	4.8 ± 8.6 b	2.2 ± 5.9 cd
Store 4 display	6.7 ± 12.3 a	8.8 ± 12.6 ab

DC = distribution centre. Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at P = 0.05.

The effect for individual participating supermarket retail stores was also significant ($P \leq 0.05$) (Table 4.13). For example the bruise severity at sampling point 6 of a store in supply chain 1 was 2.6 ± 7.5 ml and the bruise severity at sampling point 6 in another store of the same supply chain was 6.7 ± 12.3 ml. In addition, not all consignments monitored in a supply chain showed the same degree of flesh bruising. In supply chain 2, mean bruise severity varied from 1.6 ± 4.6 ml in one consignment to 6.8 ± 11.9 ml in another (Table 4.14). The effect of assessing bruise severity at two different hand firmness stages of softening or firm ripe was also significant ($P \leq 0.05$) for bruise severity (Fig. 4.20). Bruise severity in softening fruit was 2.6 ± 6.2 ml and the average bruise severity in firm ripe fruit was 4.0 ± 9.1 ml.

Fig. 4.19 Comparison of bruise severity in avocado cv. 'Hass' fruit sampled from two supermarket retail store chains and subjected to destructive bruising assessment is presented in this boxplot. Horizontal lines of the data sets in each treatment in this figure represent the minimum range, first quartile, the median, and the third quartile of the data. Top terminal points of the perpendicular lines represent the maximum range of the data. Black dots represent the outlier values of the data sets.

Table 4.14 Bruise severity in avocado cv. 'Hass' fruit sampled from six serial sampling points of five consignments for each of two supermarket retail store supply chains and subjected to destructive bruising assessment (±SD).

Consignment	Bruise severity (ml)	
	Supply chain 1	**Supply chain 2**
1	2.9 ± 7.0 ab	3.3 ± 7.0 b
2	3.5 ± 8.3 a	1.6 ± 4.6 c
3	2.2 ± 6.7 b	4.2 ± 8.6 b
4	2.4 ± 6.4 ab	3.9 ± 8.6 b
5	2.0 ± 5.3 b	6.8 ± 11.9 a

Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at $P = 0.05$.

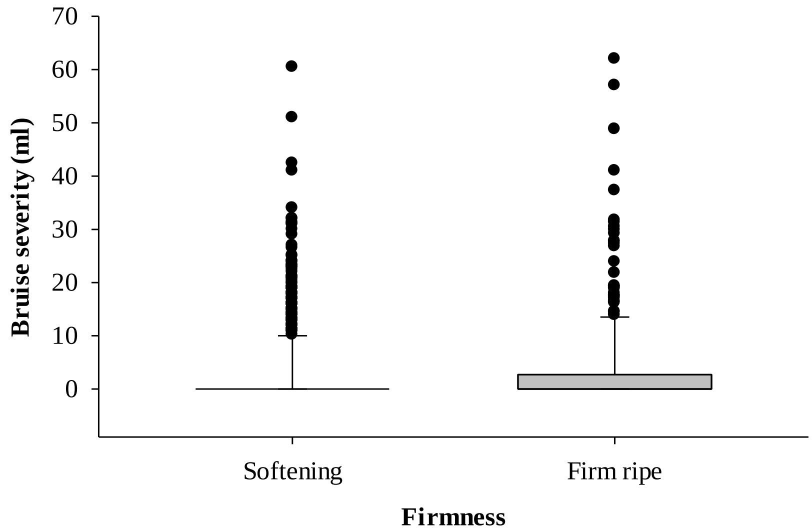

Fig. 4.20 Boxplot of bruise severity in avocado cv. 'Hass' fruit at softening and firm ripe stage of firmness sampled from two supermarket retail store chains and subjected to destructive bruising assessment. Bottom boundaries of the bar in this figure represent the first quartile and the median of the data. Upper boundaries of the bar represent the third quartile of data sets. Lower terminal points of the line without bar represent minimum range, first quartile, the median, and the third quartile of the data. Top terminal points of the perpendicular lines with and / or without bar represent the maximum range of the data. Black dots represent the outlier values of the data sets.

The second experiment with sampling from a tagged consignment reinforced the findings of the first experiment (Table 4.15). Bruise severity increased significantly ($P \leq 0.05$) from 0.1 ± 0.7 ml at sampling point 1 to 7.7 ± 10.0 ml at sampling point 6 for the cumulative data of the two supply chains. The mean value of bruise severity in supply chain 1 (1.9 ± 5.2 ml) was significantly ($P \leq 0.05$) less than in supply chain 2 (2.7 ± 6.8 ml). Bruise severity in fruit from individual stores was also significant ($P \leq 0.05$) with supply chain 2 (Table 4.16). Flesh bruise severity at sampling point 6 in one store was 6.2 ± 9.8 ml and it was 10.2 ± 11.6 ml at the sampling point 6 in the other store of the same supply chain. The consignment effect on bruise severity was significant ($P \leq 0.05$) for supply chain 1 (Table 4.17). Mean bruise severity in one consignment was 1.0 ± 3.2 ml and it was 3.1 ± 6.6 ml in another consignment.

Table 4.15 Bruise severity in avocado cv. 'Hass' fruit sampled from serial sampling points of two supply chains and subjected to destructive bruise assessment (±SD).

Sampling point	Bruise severity (ml)
Ripener arrival	0.1 ± 0.7 e
Ripener dispatch	0.1 ± 0.9 e
Distribution centre arrival	0.2 ± 0.8 e
Distribution centre dispatch	0.3 ± 1.2 de
Store 1 arrival	1.4 ± 3.2 cd
Store 1 retail display	7.8 ± 10.0 a
Store 2 arrival	2.5 ± 4.9 c
Store 2 retail display	6.2 ± 9.5 b

Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at P = 0.05.

Table 4.16 Bruise severity in avocado cv. 'Hass' fruit sampled from six serial sampling points of two supermarket retail store supply chains and subjected to destructive bruising assessment (±SD).

Sampling point	Bruise severity (ml)	
	Supply chain 1	**Supply chain 2**
Ripener arrival	0.1 ± 0.3 c	0.2 ± 0.9 d
Ripener dispatch	0.0 ± 0.3 c	0.2 ± 1.2 d
DC arrival	0.2 ± 0.7 c	0.2 ± 0.9 d
DC dispatch	0.3 ± 1.0 c	0.3 ± 1.4 d
Store 1 arrival	1.4 ± 2.9 bc	1.3 ± 3.4 cd
Store 1 display	5.3 ± 7.4 a	10.2 ± 11.6 a
Store 2 arrival	2.2 ± 4.3 b	2.8 ± 5.4 c
Store 2 display	6.3 ± 9.4 a	6.2 ± 9.8 b

DC = distribution centre. Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at P = 0.05.

Table 4.17 Bruise severity in avocado cv. 'Hass' fruit sampled from six serial sampling points of four consignments for each of two supermarket retail store supply chains and subjected to destructive bruising assessment (±SD).

Consignment	Bruise severity (ml)

	Supply chain 1	Supply chain 2
1	1.0 ± 3.2 b	2.2 ± 5.6 a
2	1.8 ± 4.9 b	3.0 ± 7.1 a
3	3.1 ± 6.6 a	2.9 ± 7.6 a
4	1.9 ± 5.2 b	2.7 ± 6.7 a

Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at $P = 0.05$.

Overall, bruise incidence in the two supply chains across and six sampling points increased as the fruit passed through each stage in the chain. The proportion (%) of fruit with no bruising reduced from 95.6% at sampling point 1 to 61.6% at sampling point 6 (Table 4.18). In fruit sampled from retail displays, 28.1% of fruit showed 10-25% bruise severity and 5.9% of fruit showed 25-50% bruise severity. In contrast, bruise severity did not exceed 10% of fruit flesh up to the point of dispatch from the DC.

Table 4.18 Incidence of flesh bruising in avocado cv. 'Hass' fruit sampled from six serial sampling points of two supermarket supply chains.

Sampling point	Number of samples	Incidence of flesh bruising				
		No bruising	Up to 10%	10 - 25%	25 - 50%	> 50%
Ripener arrival	*n* = 160	95.6	4.4	0.0	0.0	0.0
Ripener dispatch	*n* = 160	97.5	2.5	0.0	0.0	0.0
Distribution center arrival	*n* = 160	93.8	6.3	0.0	0.0	0.0
Distribution center dispatch	*n* = 160	92.5	7.5	0.0	0.0	0.0
Retail store arrival	*n* = 320	78.1	15.6	6.3	0.0	0.0
Retail store display	*n* = 320	61.6	4.4	28.1	5.9	0.0

4.2.2 Retail store staff contribution to flesh bruising

Retail store staff handling significantly ($P \leq 0.05$) increased the bruise severity in avocado cv. 'Hass' fruit as compared with unhandled control fruit (Fig. 4.21). Fruit from both retail supply chains developed significantly ($P \leq 0.05$) different levels of flesh bruising severity due to retail staff handling practices. Mean flesh bruising for retailer 1 was 2.7 ± 4.7 ml and that for retailer 2 was 1.2 ± 6.3.4 ml.

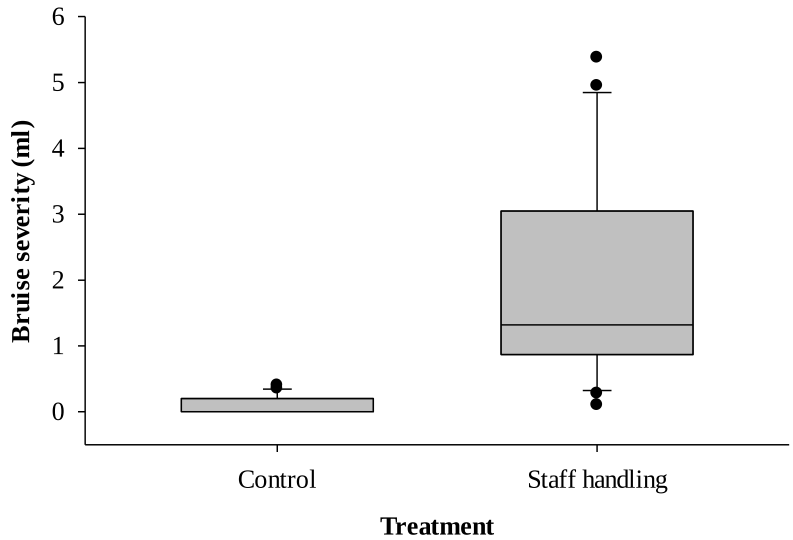

Fig. 4.21 Comparison of bruise severity in avocado cv. 'Hass' fruit subjected to staff handling practices in two supermarket retail store chains at the firm ripe stage of hand firmness and subjected to destructive bruising assessment after 48 h of collection with the control. Two retail stores of each supermarket supply chain participated in this study. Bottom boundaries of the bars in this figure represent the first quartile and the median of the data. Central horizontal line in the bar represents the median of the data. Upper boundaries of the bars represent the third quartile of data sets. Lower terminal points of the lines without bars represent the minimum range of the data, and top terminal points of the lines with bars represent the maximum range of the data. Black dots represent the outlier values of the data sets.

Bruise incidence in control fruit was also less than that in fruit subjected to store staff handling practices (Table 4.19). Bruise incidence varied between retail stores and among the four replications of the experiment.

Table 4.19 Incidence of flesh bruising in avocado cv. 'Hass' fruit due to the store staff handling practices compared with control.

Sampling point	**Number of samples**	**Incidence of flesh bruising**				
		No bruising	Up to 10%	10 - 25%	25 - 50%	> 50%
Control	*n* = 80	95.0	5.0	0.0	0.0	0.0

Store staff handling	*n* = 720	62.8	35.8	1.3	0.1	0.0

4.2.3 Flesh bruising in avocado fruit displayed in independent and supermarket retail stores

Bruise severity in the avocado cv. 'Hass' fruit on display in independent retail stores (5.0 ± 4.2 ml per fruit) was significantly ($P \leq 0.05$) higher than that in fruit on display in supermarket retail stores (1.0 ± 1.5 ml) (Fig. 4.22). Bruise severity in fruit in the four independent and supermarket retail stores was not significantly ($P > 0.05$) different (Table 4.20).

Table 4.20 Bruise severity in avocado cv. 'Hass' fruit sampled from four each of independent and supermarket retail stores and subjected to destructive bruising assessment (±SD).

Store	**Bruise severity (ml)**	
	Independent	**Supermarket**
1	3.8 ± 3.4 a	1.2 ± 1.3 a
2	6.2 ± 6.4 a	0.2 ± 0.1 a
3	5.4 ± 4.1 a	2.7 ± 2.0 a
4	4.6 ± 3.9 a	0.6 ± 0.8 a

Bruise severity values sharing the same letter do not differ significantly from each other by Tukey's LSD test at $P = 0.05$.

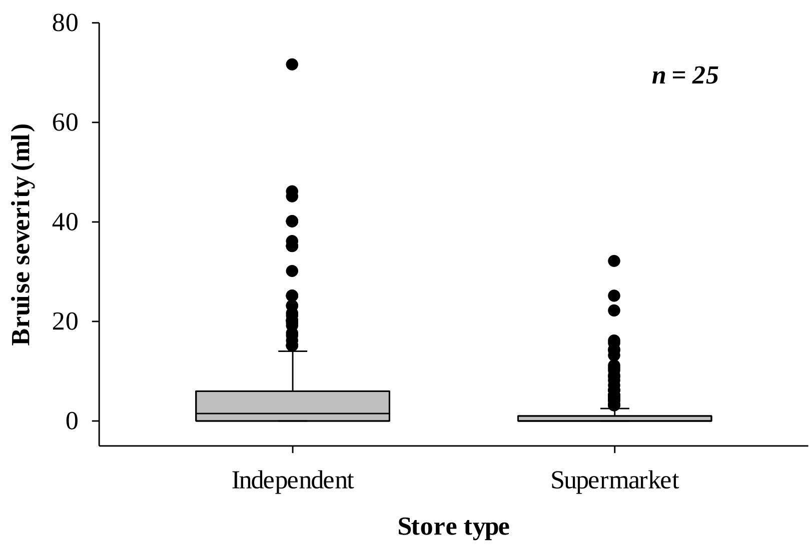

Fig. 4.22 Boxplot of bruise severity in avocado cv. 'Hass' fruit sampled from supermarket retail stores (n = 4) and the independent retail stores (n = 4). Fruit (n =25) collected four times from each store and subjected to destructive bruising assessment after 48 h of collection. Bottom

boundary of the bar representing supermarket retail store shows the first quartile and the median of the data. Central horizontal line in the bar representing independent retail store shows the median of the data. Upper boundaries of the bars represent the third quartile of data sets. Top terminal points of the lines with bars represent the maximum range of the data. Black dots represent the outlier values of the data sets.

The incidence of flesh bruising in the independent and supermarket retail stores was different. In independent retail stores, 30.9% of fruit had no bruising, 55.6% had up to 10% of the flesh with bruising, 9.1% had 10-25% bruising, 3.4% had 25-50% bruising, and 0.9% had > 50% bruising. In the supermarket retail stores, 58.4% of fruit had no bruising, 39.4% had up to 10% bruising, 1.3% had 10-25% bruising, and 0.9% had 25-50% bruising (Table 4.21).

Table 4.21 Incidence of flesh bruising in avocado cv. 'Hass' fruit on display in independent and supermarket retail stores.

Sampling point	**Number of samples**	**Incidence of flesh bruising**				
		No bruising	Up to 10%	10 - 25%	25 - 50%	> 50%
Independent retail store	*n* = 320	30.9	55.6	9.1	3.4	0.9
Supermarket retail store	*n* = 320	58.4	39.4	1.3	0.9	0.0

4.3 Evaluation of Impact Recording Device, ShockLog and impact indicator clips

Both IRD and ShockLog devices detected and recorded data on the number and magnitude of impact events throughout the supply chain. The highest impact recorded by the IRD was 85.9 G, while the ShockLog recorded 89.5 G for the same event in run 2 of supply chain 1 (Fig. 4.22 and 4.23). This and other major impact events recorded by both the IRD and ShockLog devices occurred at the DC. The IRD and ShockLog recorded 15 and 16 impact events, respectively, through the supply chain in run 2 of supply chain 1. The intensity of most impact events recorded by both devices was below 30 MaxG. This magnitude of impact is comparatively lower than the impact force recorded with the IRD (~ 60 G) in fruit trays dropped from 15 cm at either of 15 degrees or 30 degrees (Fig. 4.4). It implies that the magnitude of most impacts events through the supply chain do not cause bruising in the fruit in trays. The ShockLog device also recorded the temperature regime through the supply chain. Temperatures ranged through 15 °C at ripener arrival, to 19.7 °C during ripening, down to 3.5 °C when the fruit arrived at DC and to 23.4 °C at the retail store display. None of the 5G, 10G, 25G, 35G, and 50G ShockWatch impact indicator clips changed colour from transparent to bright red in any of the monitored consignments.

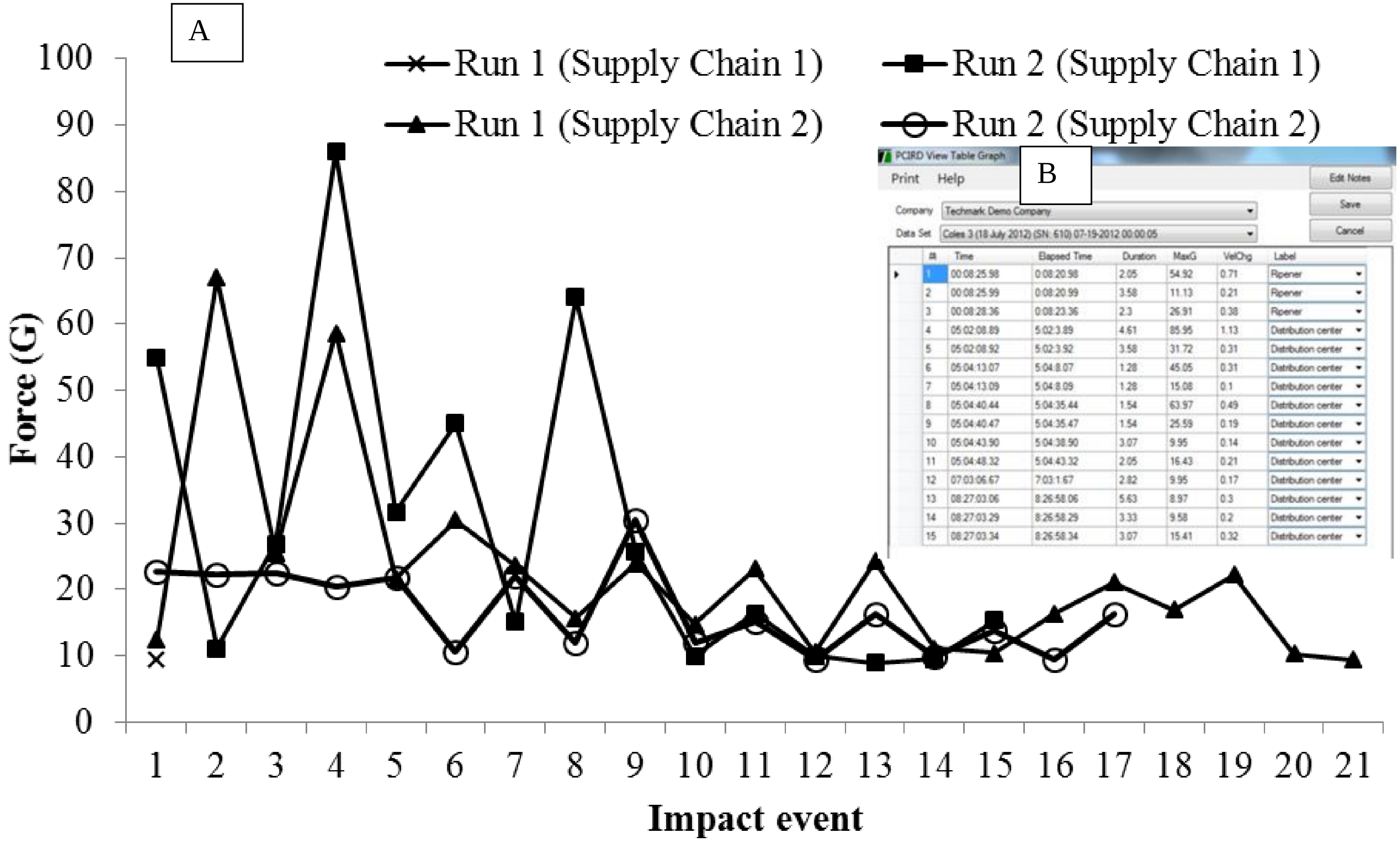

Fig. 4.22 A: Incidence and magnitude of impact events in two supply chains recorded with an Impact Recording Device® placed in the middle of the fruit tray at first sampling point (ripener arrival) and removed at the last sampling point (retail store display). B: Actual data with the detail of impacts happened to a monitored supply chain as screenshot is presented along with the line graph.

Fig. 4.23 Incidence and magnitude of impact events in an avocado supply chain monitored from the ripener arrival to the retail store display. The impact events and their magnitude were recorded with a ShockLog device placed in an avocado fruit tray in a tagged consignment at ripeners' arrival and taken out at the retail store display. The figure presents the consignment details (red square), data of all the impacts recoded on X, Y, and Z axes (green square), the temperature regime through the duration of data acquisition (blue square), a bar graph of all the impact events (yellow square), and a line graph of the largest impact event (purple square).

4.4 Skin spotting

Wholesalers (*n* = 3) and retailers (*n* = 69) reported that fruit with SS ratings of 3 (26 - 50 %) and 4 (> 50 %) are not acceptable (Fig. 4.24). In limited surveys, wholesalers (*n* = 3), retailers (*n* = 69), and shoppers (*n* = 5) reported that the severity of skin spotting affects purchase decisions, and sale price and / or sale volume (Fig. 4.25).

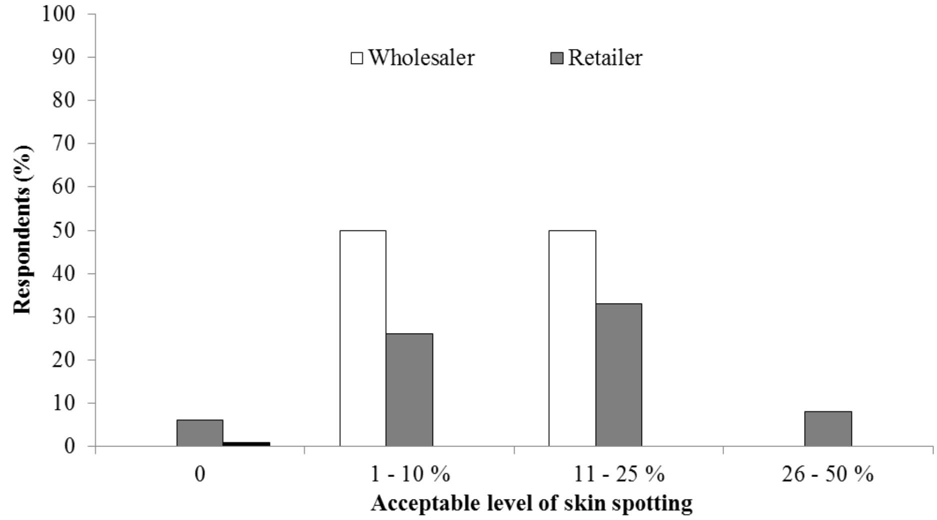

Fig. 4.24 Feedback of wholesalers (*n* = 3) and retailers (*n* = 69) on the acceptance of avocado cv. 'Hass' fruit with different levels of severity of skin spotting. 0 = no skin spotting, subsequent categories (0 - 10 % SS, 11 - 25 %, 26 - 50 %) represent the surface area of fruit affected by skin spotting.

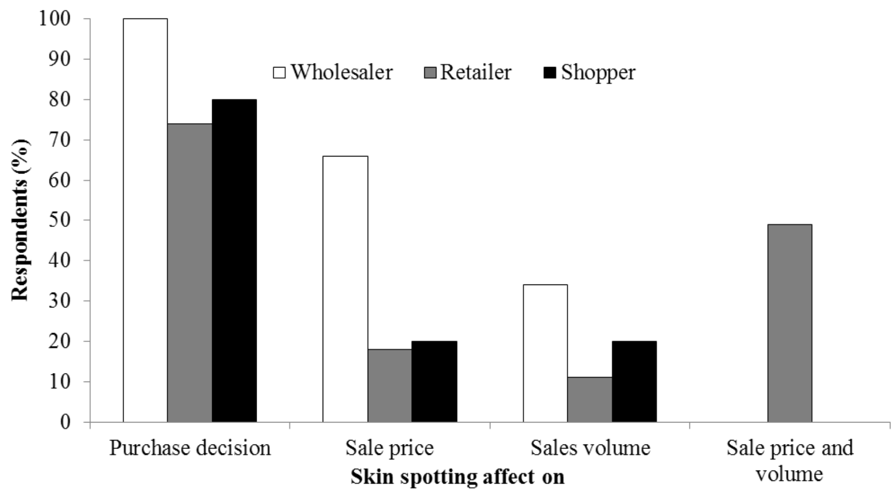

Fig. 4.25 Effect of skin spotting on the purchase decision and sale price and sale volume as

advised by wholesalers (*n* = 3), retailers (*n* = 69) and shoppers (*n* = 5) to a survey conducted by Avocado Australia Limited and Department of Agriculture and Fisheries, Queensland.

Most SS in the unacceptable levels range (> 26% of skin surface affected) was recorded for avocado cv. 'Hass' fruit sampled in New South Wales (Sydney; 34.5%) (Fig. 4.26). SS was markedly less in fruit samples in Queensland (Brisbane; 6.4%), Western Australia (Perth; 3.0%) and Victoria (Melbourne; 2.7%). The pattern of SS incidence varied markedly throughout the year (Fig. 4.27). However, there was no clear pattern of incidence versus time. SS was relatively more in the supermarket retail store as compared with the independent retail stores (Fig. 4.28).

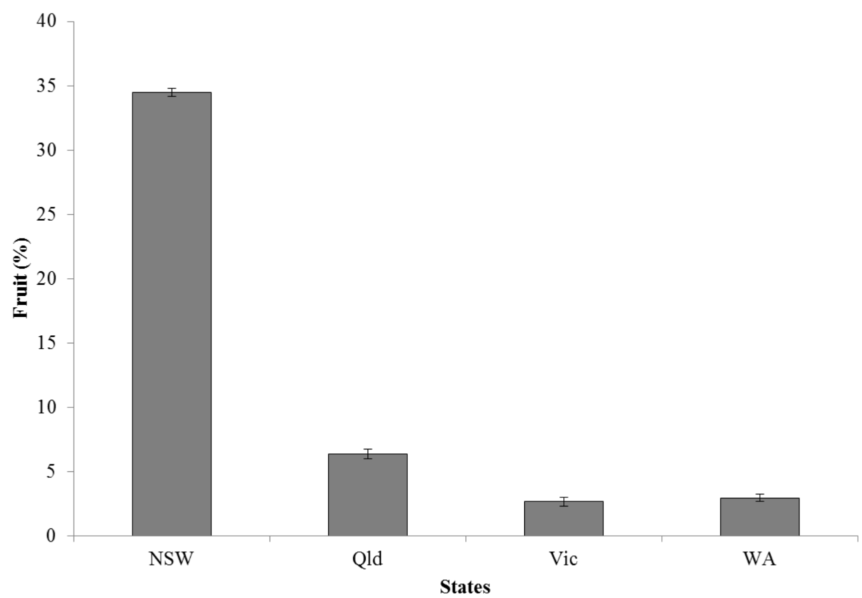

Fig. 4.26 The proportional incidence (%) of avocado fruit with unacceptable skin spotting levels (>26% of skin surface affected) as found in sampling at retail store level and assessment of avocado cv. 'Hass' fruit (*n* = 15). The sampling as assessment was conducted by trained staff appointed by Avocado Australia Limited from September 2011 to May 2014. These data were collated for 16 independent and supermarket retail stores in the States of New South Wales (Sydney, NSW), Queensland (Brisbane, Qld.), Victoria (Melbourne, Vic.), and Western Australia (Perth, WA).

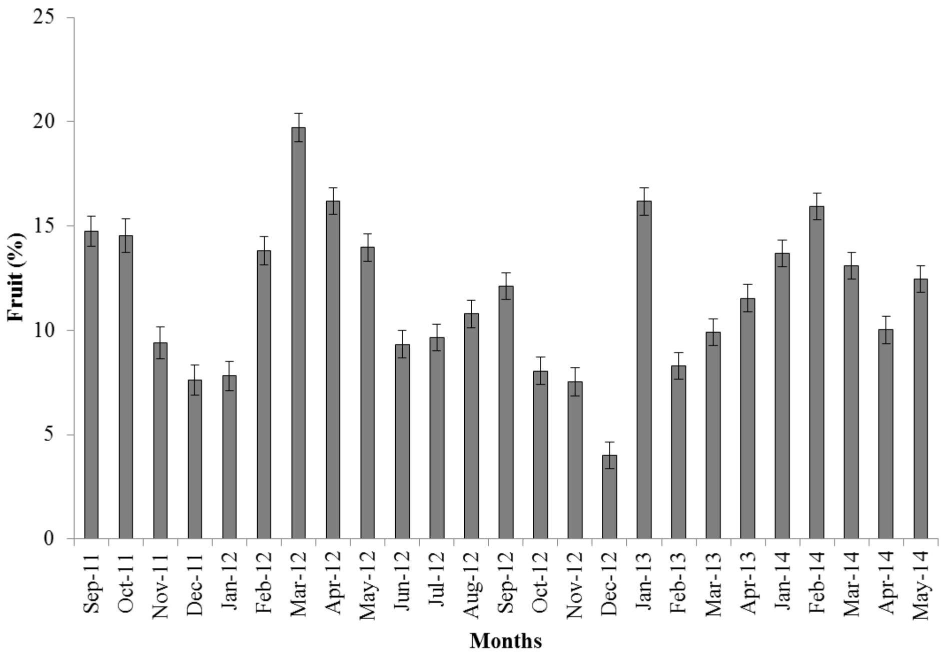

Fig. 4.27 The incidence of avocado fruit with unacceptable skin spotting (>26% of fruit surface) through the period from September 2011 to May 2014. These main factor data were collated for sampling and assessment of fruit (n = 15) at 16 independent and supermarket retail level in the States of New South Wales (Sydney), Queensland (Brisbane), Victoria (Melbourne), and Western Australia (Perth). Vertical lines in the histogram show the standard error of mean.

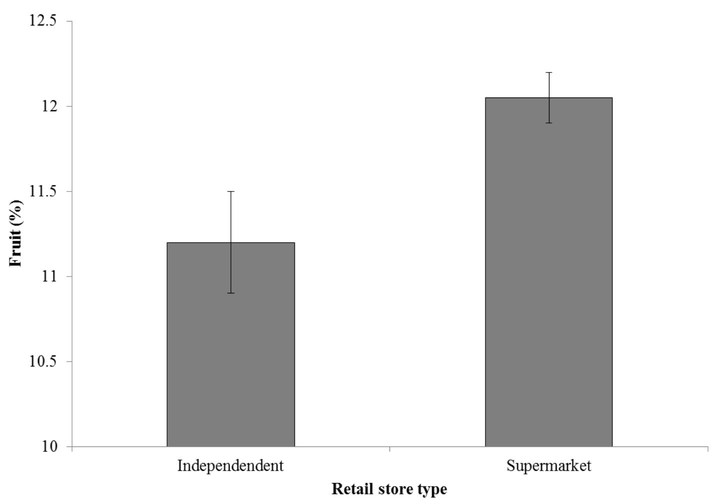

Fig. 4.28 The incidence of avocado fruit with unacceptable levels skin spotting (>26% of fruit surface) in independent and supermarket retail stores. These data were collated for monthly sampling and assessment of fruit (n = 15) from September 2011 to May 2014 at retail stores (n =

8) of each of the independent and supermarkets chains in the States of New South Wales (Sydney, Queensland (Brisbane), Victoria (Melbourne), and Western Australia (Perth). Vertical lines in the histogram show the standard error of mean.

5. Evaluation and Discussion

In the course of AV10019, project activities were prioritised in consultation with industry and institutional stakeholders, particularly the AAL. The supply chain studies were planned in conjunction and conducted in collaboration with the two major supermarket retail store chains of Australia. Besides this liaison, growers and / or ripener - wholesalers were engaged in refining each experiment plan, as appropriate and relevant. Pre-season meetings were conducted at the beginning of each season to share the annual activity plan and to receive inputs from stakeholders. Post-season meetings were conducted at the end of each avocado season to share the findings for each year's work with the stakeholders. Accordingly, project findings were readily available for industry stakeholders to consider in relation to their everyday avocado fruit handling practices. In the course of the project, findings were also shared widely to a broad industry and public audience through a YouTube video, print, electronic, and social media, and presentations at conferences.

Project activities were organized in four researchable areas:

5.1 Bruise expression in avocado fruit

In this project, previously little understood relationships between avocado fruit handling and flesh bruising were relatively comprehensively explored for the first time. For example, the relationship between avocado fruit tray drop height and drop angle and fruit bruising. Novel insights such as this are readily applied as insight into when bruising occurs and when bruise expression peaks relative to causal events in the supply chain. Greater understanding supported by more sampling for bruise assessment can, in turn, be applied to inform and facilitate effective bruise reduction practices in commercial avocado supply chains. For the future, it is proposed that this solid foundation research be expanded to ultimately fully inform best management and continual improvement practices for avocado supply chain stakeholders; in particular, for retailers, shoppers and consumers – such as through informed education materials and fruit selection for purpose decision or decision aid tools. This being said, the information is also important to all value chain players from 'paddock to plate', including growers, transporters and, particularly, ripener – wholesalers.

Visible symptoms of flesh bruising are the result of two processes (Van linden et al., 2006). Initially, cell walls and membranes of the fruit tissue experience plastic deformation when an external impact or compression force exceeds their bio-yield threshold. Thereupon, subsequent polyphenoloxidase (PPO) enzyme activity at the impact or compression site results in browning of the affected flesh. Bruise expression can be mediated by various factors. For example, as has been clearly demonstrated in the current project, tissue discolouration can be reduced markedly at low temperature. Better low temperature management throughout the supply chain, as and where appropriate and possible, is proposed as one practical or doable approach to limit bruising expression in fruit that experience impact and / or compression events.

Other factors in addition to fruit holding temperature (Ahmadi et al., 2010) that can affect bruise expression include fruit maturity at harvest (Arpaia et al., 1987), fruit firmness (Baryeh, 2000), and fruit holding duration (Marques et al., 2009). In the course of the present work, controlled experiments explored associations between flesh bruising and these modulating factors for avocado cv. 'Hass' fruit. Bruise severity increased with low dry matter content at harvest, low firmness, and with longer holding duration in fruit exposed to an impact or compression event. Industry stakeholders are advised to harvest fruit at and, ideally, above the minimum recommended dry matter content (viz. 23% for 'Hass'), to maintain stringent low temperature management, including at retail, and to rapidly handle fruit through the supply chain such as to minimize 'time in the chain' to reduce potential risk to bruising events.

As a potential tool to non-destructively monitor bruising and bruise expression, MRI was shown to have real present and great future potential in research and applications contexts respectively, for example, in non-destructively revealing bruise development over time. Moreover, MRI also non-destructively discerned the onset and expansion of fruit rot in avocado fruit in real time. Thus, MRI represents an efficacious tool to assess internal bruise and decay developments in 'Hass' avocado fruit. Immediate and broader advantages of MRI over destructive assessments include avoiding the need to dissect many fruit over time, greater efficiency in measurements in terms of both 2D and 3D visualization of internal fruit quality defects and accuracy of their measurement, more precision due to avoiding fruit to fruit variability in respect to maturity and structural composition (e.g. seed size in individual fruit), and choices as to different imaging modes to inform greater understanding of physicochemical bruise mechanisms. Based on the present study, more in-depth MRI research is warranted; including on various different combinations of fruit firmness and impact energy in green mature through to ripe avocado fruit. MRI could also be applied for non-destructive bruising assessments that evaluate the incremental progression in bruising (and decay) as fruit travel through the supply chain. Fruit quality assessment based on MRI technologies is approaching the market ready stage (McCarthy et al., 2014).

5.2 Sampling through the supply chain

Bruise severity increased as the fruit travelled through the supply chain. It was evident that susceptibility to bruising increased in concert with decreasing fruit firmness. As ripening avocado fruit travel from ripener through DC to retail store, and as mechanical handling of fruit unitised in trays on pallets moved by forklifts is replaced by manual handling of individual fruit trays and indeed individual fruit by retailers, shoppers and consumers, more intensive handling coincides with greater bruise susceptibility.

5.3 Evaluation of Impact Recording Device, ShockLog and impact indicator clips

Several commercially available approaches, including two devices, were evaluated as tools to help fruit handlers identify if and where potentially damaging impacts occur in the supply chain from farm to retail store. The IRD was, relatively, the most promising device in terms of detecting and recording comparatively more impacts. Nonetheless, based on concomitant laboratory studies using controlled forces, the recorded shock events were not of sufficient magnitude to cause fruit bruising. However, this observation would benefit from further wider field testing. It is generally advisable that producers, handlers, and marketers integrate available agro-technologies, such as the IRD, into supply chain evaluations to monitor and manage activities (Oke et al., 2013).

5.4 Skin spotting

In the course of this project, it was affirmed that the severity of SS on cv. 'Hass' avocado fruit in the supply chain, including at retail level, is still problematic for stakeholders in Australia. The extent of the problem varied with time over the marketing season and regionally across the Australian State capital cities wherein sampling was carried out. Differences in SS severity across Sydney, Brisbane, Melbourne and Perth may possibly be associated with different durations and / or conditions of transport. A difference in SS incidence and severity for independent versus supermarket retail stores was also discerned in the data. This intriguing observation also suggests that a better understanding of the SS issue in terms of underlying causal factors, modulators and practices to minimise the problem in Australia is warranted. Overall, it is evident that comprehensive structured research is needed to accurately assign reasons for both apparently consistent trends (e.g. independent versus supermarket stores) and also for inconsistency (e.g. variability over time) in SS incidence and severity in Australian marketplaces.

HIA Project AV12009

An allied HIA project, AV12009, further investigated the role of shoppers and consumers in causing unsightly bruising in cv. 'Hass' avocado fruit. In concert with that project, a set of draft education materials were developed towards mitigating flesh bruising problems such that consumers realise perceived value for money and increase avocado purchasing and repeat purchases. The draft material, along with a prototype decision aid tool to assist consumers in choosing fruit without bruising them, are presented within the final report of HIA Project AV12009.

6. Recommendations

The following recommendations are presented for consideration in conjunction with those made in the complimentary partner HIA project, AV12009.

6.1 General recommendations based on the research findings

- Fruit should be harvested at or, ideally, above the minimum recommended dry matter content. The lower the dry matter content of the fruit at harvest, the higher will be the bruise severity in fruit impacted at a given force level.

- Fruit should be handled carefully, both individually and in trays. The higher the impact energy absorbed by the fruit, the greater will be the resultant bruise severity.

- Fruit should be passed through the supply chain as time efficiently as possible. Longer holding periods before ripening or following an impact or compression event will increase bruise severity in the fruit impacted at a given force level.

- Temperatures throughout the supply chain should be managed to effectively reduce bruise expression by slowing bruised tissue browning (i.e. symptom expression) in the fruit. Although not currently used, refrigerated display cases should not be discounted out of hand.

- Advanced technologies, like the instrumented sphere (IRD) device, and even more advanced technology, like magnetic resonance imaging (^{1}H-MRI), should be co-opted to help monitor and manage impact events and their consequences through supply chain.

6.2 Future research, development and extension

The findings of this project suggest a good many opportunities for future research, development and extension to better understand the processes of mesocarp bruising in 'Hass' avocados and to better manage the issue in cool, supply and value chain contexts.

6.2.1 Specific recommendations concerning extension of the current research

- The current research has shown that low temperature management at ~ 5 °C can reduce bruise expression. However, the effect of maintaining cool chain conditions whenever practical from plantation to plate on bruise symptoms expression needs to be realised in terms of integration with current practices.

- Independent retailers were found to have five times greater bruise severity as compared with the supermarket retail chains. Independent retail operations should be monitored or mapped for incidence and severity of mesocarp bruising with a view to better understanding the causes of greater bruise severity and to develop strategies to reduce this bruising.

- Decision aid tools (i.e. devices involving the shopper in testing to determine fruit firmness in the context of fitness for purpose) or decision tools (i.e. determining fitness for purpose without involving the shopper in process of determination) might be identified, made, modified, and/or otherwise optimised to support consumers in making more objective fruit selection decisions with little or no risk of contributing to bruising in avocados. Devising and / or adapting existing and / or new technologies in this regard could potentially massively reduce mesocarp bruising in avocados as experienced at the time of fruit consumption. Satisfied consumers underpin the further growth of industries, including of the avocado industry.

- MRI was proved to be a useful tool for non-destructive assessment of internal avocado fruit quality. Further research is recommended to use ^{1}H-MRI to follow the condition of individual pieces of fruit through the supply chain from ripener to consumer or even from harvest to consumer. This process of non-destructive physicochemical photo documentation (imaging) would proffer understanding of fruit physiological development from harvest maturity to senescence and concomitantly inform and encourage adoption of improved practices through critical points in the supply chain.

6.2.2 Adjunct empowering research opportunities

- Rot development in impacted hard green mature and firm ripe fruit at the site of impact was discerned in the current research as possibly being of a direct effect (viz., early rotting) of an identified cause (i.e. mechanical force). Further research should explore this possible cause and effect association, including in regard to managing the onset and process of decay.

- Mesocarp bruising expresses due to PPO activity, which is dependent on cell and tissue variables like pH of the fruit mesocarp and fruit firmness as well as the presence and levels of enzymes and substrates. Comparative elucidation (e.g. 'Hass' versus a green skin cultivar, like 'Sheppard') of the bio-chemistry of browning in the mesocarp of hard green, ripening and bruised fruit is recommended. This knowledge could be applied in informing improved postharvest management (e.g. treatments, environment conditions) towards reduced expression of bruise symptoms.

- The cumulative (viz., industry wide) and segregated (viz., based on independent and supermarket retail store chains) levels of economic losses due to bruising in avocado supply chains should ideally be dissected. The findings could be applied in setting priorities for the industry in terms of guiding future research and development.

Scientific Refereed Publications

- Mazhar, M., Joyce, D., Cowin, G., Brereton, I., Hofman, P., Collins. R., Gupta, M., 2015. Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea americana* M.) cv. Hass. *Postharvest Biology and Technology*, **100**: 33-40.

IP/Commercialisation

No commercial IP was generated in the course of this project.

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Appendices

A: Definitions of terminology.

B: Thesis **-** Mazhar, M. Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains: from the ripener to the consumer. PhD Thesis Abstract. University of Queensland, Australia. (Submitted)

C: Scientific publication - Mazhar, M., Joyce, D., Cowin, G., Brereton, I., Hofman, P., Collins. R., Gupta, M., 2015. Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea americana* M.) cv. Hass. *Postharvest Biology and Technology,* **100**: 33-40.

D: Magazine article 1 - Mazhar, M., D. Joyce, P. Hofman, R. Collins. 2015. Low temperature management can reduce bruise expression in avocado cv. 'Hass' fruit flesh. *Talking Avocados*. **25**, 40-43.

E: Magazine article 2 - Mazhar, M., D. Joyce, G. Cowin, P. Hofman, I. Brereton, R. Collins. 2013. MRI as a non-invasive research tool for internal quality assessment of 'Hass' avocado fruit. *Talking Avocados*. **23**, 22-25.

F: Magazine article 3 - Mazhar, M., D. Joyce, P. Hofman, R. Collins, M. Gupta. 2012. Impact induced bruising in ripening 'Hass' avocado fruit. *Talking Avocados*. **22**, 34-37.

G: Proceedings paper 1 - Mazhar, M.S., D. Joyce, A. Lisle, R. Collins, and P. Hofman. Comparison of firmness meters for measuring 'Hass' avocado fruit firmness. Acta Hort. (Submitted).

H: Proceedings paper 2 - Mazhar, M.S., D. Joyce, L. Taylor, P. Hofman, J. Petty, and N. Symonds. Skin spotting situation at retail level in Australian avocados. Acta Hort. (Submitted).

I: Presentation 1 - Comparison of firmness meters for measuring ‘Hass’ avocado fruit firmness. International Horticulture Congress 2014. 17 – 22 August 2014, Brisbane, Australia.

J: Presentation 2 - Skin spotting situation at retail level in Australian avocados. International Horticulture Congress 2014. 17 – 22 August 2014, Brisbane, Australia.

K: Presentation 3 - Minimizing risks to avocado quality: Handling and temperature control. Qualicado workshops by project team member Daryl Joyce at Qualicado workshops in Melbourne (2014, wholesalers and ripeners), Nambour (2015, growers), Brisbane (2015, wholesalers and ripeners), Sydney (2015, wholesalers and ripeners), and Tweed Northern Rivers (2015, growers).

L: Presentation 4 - Bruising in avocado (*Persea americana* M.) cv. ‘Hass' supply chains in Queensland Australia: ripener to consumer. Qualicado workshops by project team member Daryl Joyce at Qualicado workshops in Melbourne (2014, wholesalers and ripeners), Nambour (2015, growers), Brisbane (2015, wholesalers and ripeners), Sydney (2015, wholesalers and ripeners), and Tweed Northern Rivers (2015, growers).

M: Skin spotting survey questionnaires.

Appendix A: Definitions of terminology

Bruise	Mechanical damage caused to mesocarp of fruit due to impact or compression. Typical dark-grey symptom of bruising is the result of oxidation of phenolic compounds in the cytoplasm by polyphenol oxidase enzyme, provided the pH of the substrate and other factors (e.g., temperature) are suitable for the enzymatic activity.
Bruising event	An impact or compression event with the potential to cause bruising.
Bruise susceptibility	Likelihood of fruit to get bruised.
Bruise expression	Appearance of symptom of a bruise at the site of impact or compression.
Bruise incidence	Proportion of fruit that express bruising in a given number of fruit samples.
Bruise severity	Mesocarp of fruit affected by bruising. Bruise severity is measured in bruise volume in this study and is used interchangeably.
Bruise intensity	Colour parameters i.e., darkness of bruised mesocarp measured in terms of hue and chroma.
Hue	Name of a specific / pure colour. Each hue has a different wavelength in the spectrum.
Chroma	Saturation of the colour identified by hue. It determines the brightness or darkness of the pure colour
Maturity	It refers to horticultural maturity. This is a phase of fruit development when the fruit has achieved all the necessary growth stages and is ready for commercial purpose.
Ripening	Process of biochemical changes taking place in fruit that alter the fruit composition and make it ready for consumption
Impact	Collision of two objects for a short time.

Compression	Pressing or squeezing an object by making a closer contact.
Force	Force is the product of mass and acceleration. Its units are $kg.m.sec^{-2}$ or N. Also, force is an action of change in the state of motion of an object.
G	Gravitational force. It's a constant force and is 9.8 $m.sec^{-2}$.
Pressure	Force applied per unit area. Its units are $kg.m^{-1}.sec^{-1}$ or $N.m^{-2}$ or P.
Energy	Ability of force or pressure to perform work. Its units are $kg.m^{2}.sec^{-2}$ or J.
Stress	An objects' internal response to the external impact or compression force. Used in the same context as of pressure.
Strain	Deformation in shape, size, or volume of an object due to stress caused by an external force or pressure.
Elastic deformation	Deformation in an object which is recoverable on removal of the stress. Force and deformation relationship progresses in a linear fashion.
Plastic deformation	Deformation in an object which is irreversible on removal of the stress. Cells start to fail. Force and deformation relationship transforms into non-linear.
Bio-yield	In the force and deformation relationship, the point where more deformation starts to happen without increase in stress.
Shopper	Person who has the power to make a purchase decision.
Consumer	End user of a product.

Appendix B: Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains from the ripener to the consumer (Abstract of PhD Thesis)

Bruising of fruit mesocarp (flesh) is a major concern of avocado industries around the world. Bruising, when evident in avocado fruit at the time of consumption, results in consumer dissatisfaction with the quality of fruit available at retail level. In this regard, a consumers' intention to repeat purchase is negatively affected. This study evaluates the proposition that product handling practices throughout the supply chain from the ripener to the point of consumption are the predominant causes of mesocarp bruising in 'Hass' avocados.

Initially, magnetic resonance imaging (MRI) was assessed for its potential application in the non-destructive assessment of bruise development in avocado fruit. Hard green mature and firm ripe avocado fruit were impacted by drops against a solid metal surface from various heights. Non-destructive MRI and complementary destructive fruit assessments revealed progressive post-impact growth in bruise volume for up to 96 hours in firm ripe avocado fruit. No visual bruising was observed in avocado fruit impacted at the hard green mature stage. Nonetheless, MRI did distinguish, by relative signal intensity, the mesocarp tissue at the impact site from the surrounding non-impacted mesocarp.

Avocado fruit at different stages of firmness were subjected to controlled impact or compression forces under laboratory conditions to assess how increasing applied forces affected bruise severity. Incidence and severity of consequent bruising were quantified. Increased levels of force and decreased levels of fruit firmness led to predictably heightened mesocarp bruise severity.

The effects of fruit harvest maturity, duration for which the fruit were stored pre-ripening and post-impact, and pre- and post-impact fruit holding temperatures on mesocarp bruising were investigated. Bruise severity in avocado fruit increased with less mature fruit (harvested at low level of dry matter content) and with longer periods of holding before ripening and after impact events. Avocado fruit held at the post-impact fruit holding temperature of 5 °C expressed less bruising as compared with the higher holding temperatures of 7.5 °C, 10 °C, 15 °C, 20 °C, and 25 °C. Moreover, 'Hass' avocado fruit held at 5 °C for 8 hours after an impact event and then held at 25 °C for another 40 hours developed less bruising as compared with fruit held at 25 °C for 8 hours after impact event and then held at 5 °C for another 40 hours.

Serial supply chain studies involving both random and tracked sampling of fruit from the ripener to retailers were undertaken to quantify relative bruise incidence and severity at different stages of the supply chain. Of six serial sampling stages of ripener arrival and dispatch, distribution centre arrival and dispatch, retail store arrival, and retail shelf, the incidence and severity of mesocarp bruising was found to be highest at the retail shelf sampling stage. Accordingly, the effect of fruit handling practices of retail-store staff on bruise severity was examined. Also, the difference in bruise severity in 'Hass' avocado fruit displayed by independent retailers and by supermarket retailers was determined. The bruise severity in 'Hass' avocado fruit displayed at independent retail stores was about 5 times greater than in those displayed by supermarkets.

An Impact Recording Device® (IRD) and a ShockWatch® ShockLog that record impact events and magnitude were employed as decision aid tools to potentially inform decision making in the supply chain. ShockWatch® impact indicator clips of 5 G (acceleration due to gravity), 10 G, 25 G, 35 G, and 50 G were also tested. The IRD and the ShockLog devices recorded 15 and 16 impact events, respectively, in a supply chain from ripener to retail shelf. The highest impact recorded by IRD was 85.9 G, while the ShockLog recorded 89.5 G for the same event. The ShockWatch® impact indicator clips did not discern any of the impacts.

The role played by shoppers in bruising the fruit by squeezing it to determine its firmness was investigated. Depending on the stage of fruit firmness, forces exceeding ~ 10 N could result in bruising. Using the Grip™ pressure sensors, the part/s of hand used by the shoppers for assessment of fruit firmness was/were identified. The most used parts of the hand for firmness assessment were the combination of thumb and index finger (28%) or the thumb and middle finger (26%). About 20% of participants used only the thumb. Shoppers' involvement in fruit bruising was confirmed by observing their practices of squeezing avocado fruit presented on retail shelves. Of 257 shoppers observed, the average purchase was one piece of fruit per shopper. The maximum time spent on the display was 41 seconds and the highest number of fruit handled by a shopper was 15.

The part played by consumers in bruising avocado cv. 'Hass' fruit was determined by two approaches that involved providing avocado fruit to consumers to take home. Half of the numbers of fruit were collected back from the consumers' homes and subjected to bruise assessment. Diary notes questionnaires allowed the consumers to record the level of their satisfaction and intention or otherwise to repeat purchase. Of 244 consumer diary notes, 16% indicated negative intentions to repeat purchase because of mesocarp bruising. On the other hand, 16% of the 84% consumers who said their intention to repeat purchase had not been negatively impacted by their purchase and consumption experience, had experienced up to 25% cumulative bruise severity in a fruit, comprising of small bruises closer to the exocarp of the fruit.

This study affirms that mesocarp bruising remains problematic for the ‘Hass’ avocado industry. Most mesocarp bruising results from fruit squeezing by shoppers on retail display. In view of the experimental findings, a ‘first generation’ in-store decision aid tool was prototyped with a view to assist avocado shoppers in selecting fruit at their desired stage of firmness from the retail display. Also, through-chain and point of sale avocado fruit handling guides were mocked up as potential education tools to inform supply chain stakeholders, including consumers, with a view to minimising and even avoiding mesocarp bruising in ripening ‘Hass’ avocado fruit.

Appendix C: Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea Americana* M.) cv. Hass (Abstract)

Bruising of the mesocarp in avocado fruit is an important postharvest issue for the industry. Proton magnetic resonance imaging (^{1}H-MRI) was used as a non-destructive tool to monitor bruise expression over time in avocado cv. Hass fruit. ^{1}H-MRI clearly discerned fruit morphological features and bruised mesocarp. The pixel intensity value of T_2 weighted spin echo ^{1}H-MRI images of avocado fruit pericarp changed over time with fruit softening. Bruised mesocarp tissue in impacted fruit appeared relatively hyperintense (brighter) in T_2 weighted ^{1}H-MRI images. For firm ripe fruit impacted from 25 cm drop height (0.38 J ± 0.004) and for firm ripe fruit impacted from 50 cm drop height (0.81 J ± 0.011), hyperintensity in the mesocarp beneath the impact point was evident immediately after impact. However, visible symptoms of bruising in the form of flesh browning did not appear in parallel serial destructive assessments until after day 1 following impact on day 0. The brown, bruised mesocarp volume in ripe fruit increased progressively over the assessment period of 3 days. This trend was evident in destructive assessments as well as in ^{1}H-MRI images. In mature hard fruit impacted from 100 cm drop height (1.68 J ± 0.020), contrast between mesocarp tissue beneath the impact site and surrounding sound mesocarp was evident in T_2 weighted ^{1}H-MRI images from day 0. However, no bruise symptoms were evident as flesh browning upon serial destructive assessments of fruit over the 3 days assessment period. The average pixel intensity values at the impact site in T_2 weighted ^{1}H-MRI images for both firm ripe and hard fruit decreased over the period of assessment. In contrast, the pixel intensities in the T_2 weighted ^{1}H-MRI images of diseased flesh increased over time.

- Mazhar, M., Joyce, D., Cowin, G., Brereton, I., Hofman, P., Collins. R., Gupta, M., 2015. Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea americana* M.) cv. Hass. *Postharvest Biology and Technology*, **100**: 33-40.

Appendix D: Low temperature management can reduce bruise expression in avocado cv. 'Hass' fruit flesh.

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Background

Fresh produce holding temperatures play an important role in postharvest quality management (Hofman et al., 2010). Temperature mediates physiological and biochemical activities in fruit tissues. For example, respiration rates and ripening enzyme activities decrease at lower holding temperatures (Eaks, 1978). As a consequence, the shelf life of produce is typically lengthened (Lee and Young, 1984). Conversely, at relatively high holding temperatures, fruit physiological activities are higher and shelf life is usually shorter.

Avocado farming and marketing is a major fresh produce industry in Australia. Importantly, the industry is growing progressively over time through increases in both production and consumption. Nonetheless, negative consumer feedback on the quality of avocado fruit from retail displays of supermarkets and independent green grocers has continued over the years (Dermody, 1990; Embry, 2009). As high as 80% of the fruit on retail display is reported to have internal fruit quality issues, mainly in the forms of flesh bruising and body rots (Hofman, 2011).

The primary reasons for flesh bruising are impact and compression pressures on the fruit. Applied force can immediately damage cell walls. Attendant polyphenol oxidase (PPO) enzyme activity can bring about browning of the flesh at and around injury sites (Linden and Baerdemaeker, 2005). Browning enzyme activity is associated with fruit holding temperature. For example, in apple (Toivonen et al., 2007) and peach (Ahmadi et al., 2010), increasing fruit holding temperature led to increased bruise expression in terms of both bruise severity and intensity. Marques et al. (2009) reported that low temperature storage at 5 °C significantly improved avocado fruit quality by reducing the incidence of body rots. However, to date no study has reported the relationship between flesh bruising and holding temperature for avocado cv. 'Hass' fruit. Flesh bruising in avocado cv. 'Hass' fruit typically increases with decreasing fruit firmness at the time of impact or compression (Arpaia et al., 1987). However, the interaction effect with bruise expression of fruit firmness and post-impact fruit holding duration is not yet reported.

Avocado fruit quality and disease susceptibility can be influenced by the growing location (Thorp et al., 1997). Pre-harvest orchard management practices and tree factors, like yield and mineral concentration, are known to affect the postharvest quality of fruit (Hofman et al., 2002). Gamble et al. (2010) recognised the role of growing region in determining postharvest quality of avocado fruit. They argued a case for independent study to compare and contrast quality of avocado fruit harvested from different growing regions. However, despite high levels of consumer concern over flesh bruising in avocado fruit, bruise expression in response to mechanical stress of avocado cv. 'Hass' fruit sourced from different origins is not yet characterised.

Experiments were conducted to determine the effects of pre- and post-impact temperature management on bruise severity in firm ripe avocado cv. 'Hass' fruit. Also evaluated was whether avocado fruit at softening versus firm ripe stages responded differently to impact bruising when the fruit were held at various different temperatures post-impact. Additionally assessed was the influence of fruit origin on bruise severity.

Influences of pre- and post-impact fruit holding temperatures on bruise severity

Hard green mature avocado cv. 'Hass' fruit were sourced from a commercial orchard near Cairns. They were transported to a commercial ripener at the Brisbane Markets in Rocklea. The fruit were collected from there and transported to a postharvest laboratory at the University of Queensland Gatton (UQG) Campus. They were ripened by a dip treatment in ethephon (1000 $\mu L.L^{-1}$) followed by holding at 20 °C. When they reached the firm ripe hand firmness stage (White et al., 2009), they were divided in two lots. The flesh temperature of one lot was maintained at 5 °C. That of the other lot was maintained at 20 °C. Fruit (n = 20) were impacted against a hard metal surface using a mechanical swing-arm device. Each fruit was secured into a holder at the end of the swing-arm. They were allowed to free fall from 50 cm drop height such that the average energy absorbed was ~ 0.8 J. The point of impact on individual fruit was marked. Each of the two initial lots of fruit was then further divided into three sub-lots for different post-impact fruit holding temperature regimes. All sub-lots were then placed post-impact into specific temperatures for 48 h before their destructive bruising assessment was conducted. The treatments (T) were: T1 = pre-impact 5 °C and post-impact 5 °C, T2 = pre-impact 5 °C and post-impact 10 °C, T3 = pre-impact 5 °C and post-impact 20 °C, T4 = pre-impact 20 °C and post-impact 5 °C, T5 = pre-impact 20 °C and post-impact 10 °C, and, T6 = pre-impact 20 °C and post-impact 20 °C.

For destructive assessment of flesh bruising, fruit were cut into two pieces with a sharp smooth-bladed knife along their longitudinal axis and through the impact site. The flesh was visually inspected for bruising observed as browned flesh. Where present, the volume of affected flesh was measured by a volume displacement method (Rashidi et al., 2007). Briefly, affected flesh was removed from the surrounding sound flesh and placed into water in a measuring cylinder in order to record the volume change. When present, impact-induced cracks were filled with water from a calibrated syringe. The crack volume was added to the displacement bruise volume to record the total bruise volume. Data for this and the following experiments were subjected to analysis of variance (ANOVA) with Minitab® 16. Images of bruised fruit were taken with a Nikon Coolpix digital camera.

Fruit impacted with flesh temperatures of 5 °C and 20 °C and held post-impact at 5 °C developed significantly less bruising at the impact site as compared with those held post-impact at either 10 °C or 20 °C. Flesh bruising in fruit impacted at 5 °C and held at 5 °C was 0.8 ± 1.7 ml (~2% flesh affected), in fruit impacted at 5 °C and held at 10 °C was 11.2 ± 3.4 ml (~15% flesh affected), and, in fruit impacted at 5 °C and held at 20 °C was 13.7 ± 3.4 ml (~20% flesh affected). Sequentially, flesh bruising in fruit impacted at 20 °C and held at 5 °C was 1.5 ± 2.5 ml (~5% flesh affected), in fruit impacted at 20 °C and held at 10 °C was 11.3 ± 1.8 ml (~15% flesh affected), and in fruit impacted at 20 °C and held at 20 °C was 15.0 ± 3.4 ml (~25% flesh affected) (Fig. 1). Qualitative assessments of visible bruise expression confirmed the quantitative measures. Bruise expression was minor and light brown in colour for fruit impacted and held at 5 °C. In contrast, bruises were distinct and dark brown in fruit impacted and held at

20 °C. Bruise expression in all intermediate treatments ranged across the two colour extremes of light to dark brown flesh at the impact point (Fig. 2).

Influence of fruit firmness on bruise severity

Avocado cv. 'Hass' fruit at the hard green mature stage were harvested near Cairns and transported to the Brisbane markets at Rocklea. They were collected from the markets and transported to the lab at UQG. The fruit were ripened by dipping in ethephon solution (1000 $\mu L.L^{-1}$) and holding at 20 °C until they reached the softening or the firm ripe stages of hand firmness. Fruit (*n* = 20) at these stages of firmness were impacted with the mechanical swing arm device from 25 cm drop height for an average energy absorbed of ~ 0.38 J. They were then held at post-impact fruit holding temperatures of 5 °C and 20 °C for 48 h. These fruit were subjected to destructive bruise assessment.

Flesh bruising in avocado cv. 'Hass' fruit held post-impact at 5 °C was 0.1 ± 0.1 ml (~1% flesh affected) in softening fruit and 0.1 ± 0.1 ml (~1% flesh affected) in firm ripe fruit. That in fruit held post-impact at 25 °C was 0.7 ± 0.9 ml (~2% flesh affected) in softening fruit and 0.3 ± 0.6 ml (~2% flesh affected) in firm ripe fruit (Fig. 3). Thus, whether the fruit are softening or firm ripe did not affect bruise severity at either 5 °C or 20 °C.

Influence of fruit origin on bruise severity

Avocado cv. 'Hass' fruit harvested at horticultural maturity from a commercial orchard near Toowoomba in Queensland and from another orchard near Busselton in Western Australia were collected from two different ripeners at the Brisbane Markets in Rocklea. These fruit were transported to the laboratory at UQG and given a ripening initiation treatment of dipping into 1000 $\mu L.L^{-1}$ ethephon solution. They were ripened to the firm ripe stage in a shelf life room set at 20 °C. The fruit (*n* = 20) were then impacted from 50 cm drop height with the mechanical swing arm device. The average energy absorbed was ~ 0.8 J. The fruit were then held at 20 °C for 48 h for bruising to express. Destructive bruising assessment was conducted as described above.

Average bruising severity in avocado cv. 'Hass' fruit harvested in Queensland, impacted from 50 cm drop height at the firm ripe stage, and held at 20 °C post-impact holding temperature was

12.1 ± 2.7 ml (~15% flesh affected) as compared with 12.9 ± 2.5 ml (~15% flesh affected) average bruising severity in fruit harvested in Western Australia (Fig. 4). The regionally diverse origin of the avocado fruits, thus, did not influence bruising severity. It is possible that fruit from any origin might be equally susceptible to flesh bruising if the impact energy and the fruit holding temperature regime were in common. However, the present experiment was limited to only two different sources. Therefore, further research is likely warranted into possible pre-harvest influences on bruise susceptibility.

Conclusion

Pre-impact fruit temperatures of 5 °C and 20 °C and post-impact fruit holding temperature of 5 °C significantly reduced bruise expression as compared with that in fruit held at higher post-impact fruit holding temperatures of 10 °C and 20 °C. Accordingly, where technically possible, managing fruit temperature at 5 °C through the supply chain should reduce bruise expression in mechanically impacted or compressed fruit. On the other hand, fruit at different stages of firmness held post-impact at different temperatures and fruit sourced from different origins held at different post-impact fruit holding temperatures were not differentially affected in terms of bruise expression.

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Fig. 1.

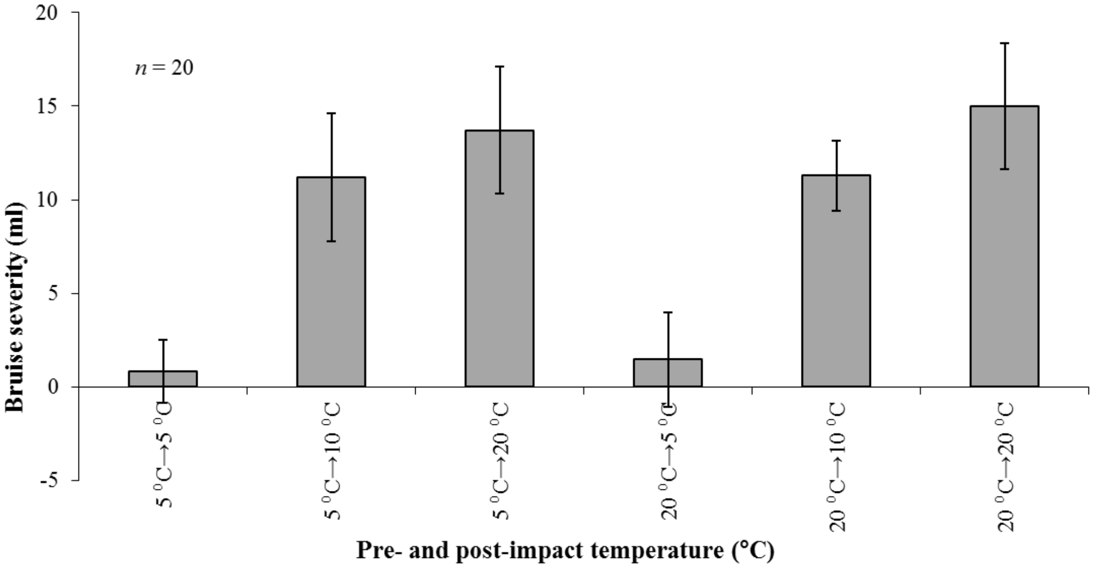

Fig. 1. Effect of pre- and post-impact fruit holding temperatures on flesh bruising in avocado cv. 'Hass' fruit (n = 20). Destructive bruising assessment was conducted after the fruit were held at treatment specific post-impact temperatures for 48 hours. Vertical lines represent the SD (standard deviation) of the means.

Fig. 2.

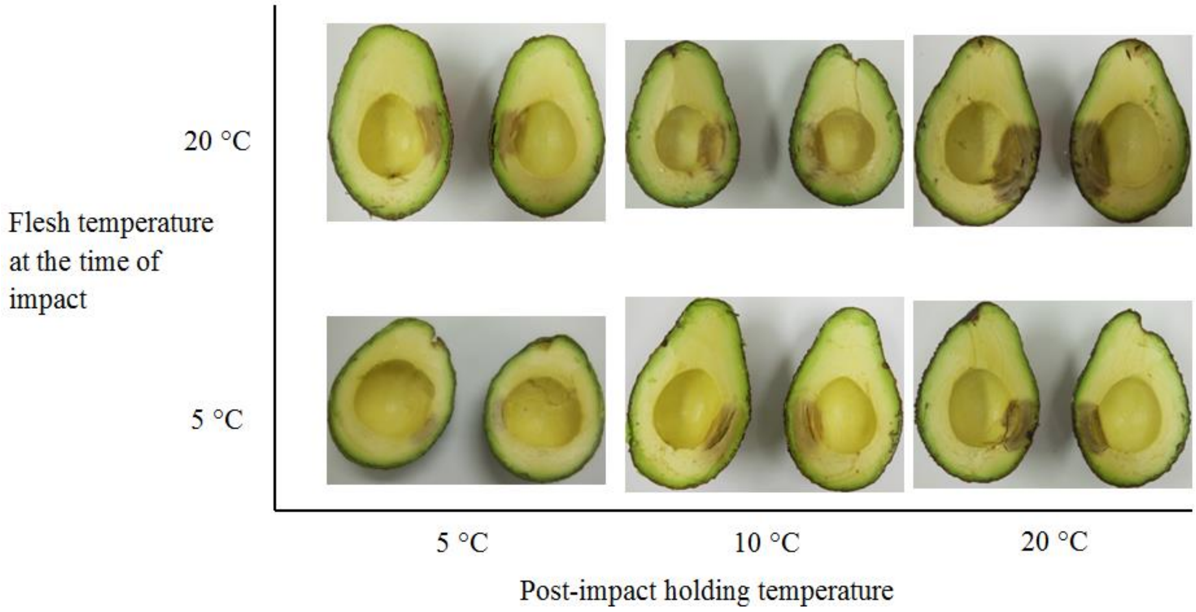

Fig. 2. Visual bruising expression in avocado cv. 'Hass' fruit impacted at flesh temperatures of 5 °C and 20 °C and held post-impact at 5 °C, 10 °C, and 20 °C for 48 hours before destructive bruising assessment.

Fig. 3.

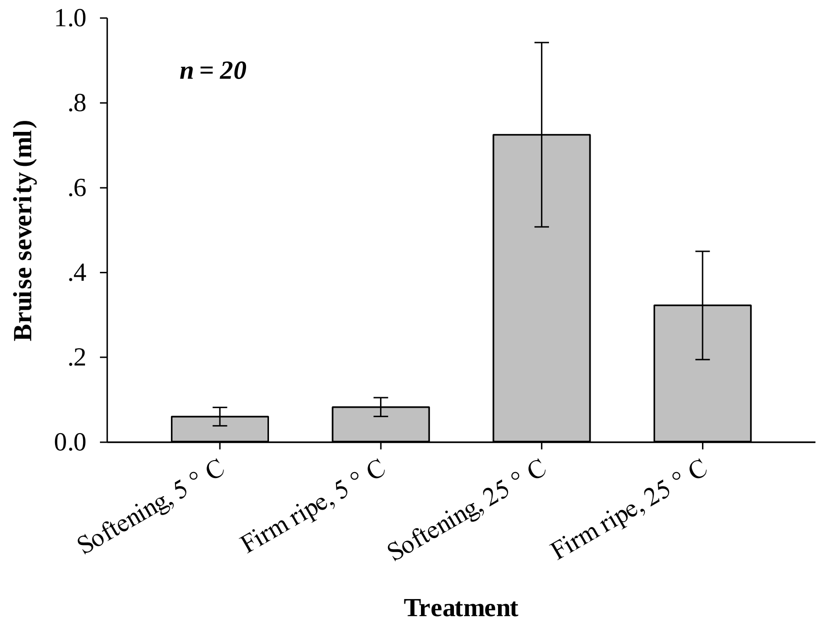

Fig. 3. Effect of fruit firmness and post-impact fruit holding temperature on bruise severity in avocado cv. 'Hass' fruit (n = 20). Vertical lines represent the SD of the means.

Fig. 4.

Fig. 4. Effect of fruit origin on bruise severity in avocado cv. 'Hass' fruit (*n* = 20). Vertical lines represent the SD of the means.

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Appendix E: MRI as a non-invasive research tool for internal quality assessment of 'Hass' avocado fruit.

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Introduction

Magnetic Resonance Imaging (MRI) is known for its efficacy in medicine and medical research for non-destructively revealing the morphological features of internal organs, including those that are diseased. Its application in studies on plant organs, including for avocado fruit, has been investigated in the past. However, its full potential for internal quality and defect assessment of avocado fruit has not been fully explored. This article briefly introduces MRI and describes its application for defect assessment in 'Hass' avocado fruit. Our recent research into impact bruising of green mature and firm ripe fruit is discussed along with the potential of MRI for future avocado postharvest research.

The avocado industry continues to expand in Australia, with 'Hass' being the leading cultivar. Avocado production and consumption growth has increased despite research over about two decades indicating general consumer dissatisfaction due to poor internal fruit quality (Harker and Jaeger, 2007; Embry, 2008). Compromised avocado fruit quality at retail level is nonetheless an important supply chain issue (Hofman, 2011). Bruising and flesh rot are the main reasons for poor internal avocado fruit quality (Hofman and Ledger, 2001).

Bruising in 'Hass' avocado fruit is the result of physicochemical changes in the flesh due to impact energy absorbed by the fruit (Ledger and Barker, 1995; Arpaia et al., 2005). Factors that affect the development of flesh bruising include the stage of fruit ripeness (softening) and time and temperature after impact (Hyde et al., 2001). Rots reflect the activity of pathogens that mostly infect fruit in the field and remain dormant until the fruit start ripening (Everett and Pushparajah, 2008).

Various approaches to minimize both bruising and rots have been devised. The measures to reduce rots in particular include utilising appropriate rootstocks, practicing good orchard hygiene, applying postharvest fungicides (Willingham et al., 2006; Everett et al., 2007) and bruising can be reduced by handling fruit less ripe, and using protective packing (Arpaia et al., 2005). In most research, bruising and rots in avocado fruit flesh are measured by destructive assessments. However, bruise and rot progression vary from fruit to fruit. To better understand the development of these disorders, either large numbers of fruit need to be destructively sampled or a non-destructive technique needs to be developed that allows serial observation of bruise and rot development in the same fruit.

MRI potentially represents a non-invasive research tool for internal quality assessment of 'Hass' avocado fruit. MRI's use in plant science has been investigated in a range of different plant organs (Clark et al., 1997), including avocado fruit (Sanches et al., 2003). ^{1}H-MRI imaging detects changes in the magnetic environment of the nucleus of hydrogen, one of the atoms in water. The nucleus of hydrogen can be envisaged as a bar magnet. When placed in the large magnetic field of a superconducting MRI magnet, the nuclei align with the magnetic field similar to a compass facing north. In addition to being aligned with the magnetic field, the nuclei also rotate at a frequency dependent on the magnetic field. When a magnetic field gradient is applied across the sample, the frequency of the spinning nucleus changes dependent on where it is within the applied magnetic field gradient. This response allows for positional information to be obtained. A radiofrequency pulse of energy then rotates the nuclei perpendicular to the MRI magnetic field, which permits the spinning magnetic field of the nuclei to be detected by a receiver coil as nuclei realign with the MRI magnetic field. The signal contains spatial information and can be converted to an image or map of the atomic components of the water molecule according to their density and other properties. The rate at which the nuclei realign with the MRI magnetic field is dependent on the freedom of the water, the chemical environment of the water and the tissue structure that contains the water. In the case of living organisms, including for avocado fruit, this all occurs without any damage to the tissues. Accordingly, normal avocado flesh should give rise to different image intensity than would abnormal (e.g. bruised) tissue. As the tissue structure changes during bruise development, changes in the avocado images should be evident. The image acquisition process can be repeated many times in order to follow the development of a bruise in a single fruit without additional damage, as opposed to cutting the avocado fruit open.

In this work, the effects of impact bruising were investigated by MRI for green mature and firm ripe 'Hass' avocado fruit. Opportunistically, images of fruit rots were also obtained.

Methods

The experiment was comprised of two treatments: a green mature fruit dropped from 100 cm height onto a hard surface and two firm ripe fruit dropped from 50 cm height onto the same surface. The 'Hass' avocado fruit for both treatments were collected from a ripener at the Brisbane Markets. The green mature treatment fruit was used on the day of collection from the ripener. The firm ripe treatment fruit were triggered to ripen by dipping into ethephon solution. They were then held at 20^{o}C until firm ripe. The fruit were individually impacted by dropping in a pendulum swing arm device against a solid surface. The impacted fruit were then held in a foam rubber lined wooden sandwich frame which was inserted into a head coil for imaging in a 3T clinical MRI system. The fruit were impacted on a Friday afternoon, placed immediately in the MRI, scanned every 30 minutes over the weekend, and then every day during the following week. T2 weighted turbo spin echo (TSE) images were acquired. Additional fruit were collected and treated in the same way. These fruit were then cut at serial intervals of time to track the visible development of bruising manifested as browning and flesh cracking symptoms.

Findings

MRI was able to effectively and non-invasively visualise internal avocado fruit morphological features. These features included the skin (i.e. exocarp), a thin layer of cells under the skin (i.e. mesocarp), strands in the flesh (i.e. vascular bundles), and the flesh (i.e. endocarp) *per se* of the fruit (Plate A). Visualising the different parts of fruit tissue non-destructively can inform an understanding of the physiology, microbiology and pathology of 'Hass' avocado fruit.

The energy absorbed by the firm ripe avocado fruit upon impact caused damage to the flesh in the forms of bruising and cracking. Immediately after impact the MRI showed bright (hyperintense) areas around the location of the impact (Plate B). This appearance suggested disruption of cell membranes allowing greater motional freedom of water as it leaked into cell wall spaces. Nonetheless, the parallel destructive sampling revealed that visual symptoms of bruising did not become obvious until at least 8 hours after impact (Mazhar et al., 2011; Plate C). This delay may be the time required for the enzymes in the affected area to react with relatively small phenolic molecules and start producing brown-coloured polyphenols. The area of the hyperintense region increased for up to 72 hours during the period of post-impact serial imaging (Plate D). The destructive assessment at about 72 hours after impact of the firm ripe fruit used for MRI confirmed the presence of bruised flesh at the site of impact and which corresponded to the hyperintense area in the MRI images.

Visual symptoms of bruising in impacted green mature fruit were not obvious, even after 72 hours from impact. Hofman (2002) observed very little bruising in green mature fruit sampled from the end of the packing line after it was very carefully handled and ripened to minimise any additional bruising. These findings suggest that firm hard fruit do not develop bruise symptoms. Nonetheless, the MRI did reveal changes in water partitioning characteristics near the impact site that potentially reflect transient tissue damage (Plate E). Thus, visualization by MRI of transient bruising in hard green fruit suggests a capacity to repair the initial damage. This interesting observation merits more detailed investigation.

As the avocado fruit aged through ripening and senescence, they began to decay. Disease-affected areas were noted during destructive assessment. They typically appeared as hyperintense regions in the MRI images (Plate F). The image intensity and tissue volume affected by disease progressively increased over the 72 hour assessment period. The non-invasive visualization of decay affected regions demonstrates additional utility of MRI technology in postharvest pathogenicity studies on ripening ‘Hass’ fruit.

Overall, this study has shown that MRI can be used as a research tool to non-destructively assess internal bruise and decay development in ‘Hass’ avocado fruit. The advantages of MRI over destructive assessments include avoiding the need to dissect many fruit over time, greater efficiency in measurements, more precision due to avoiding fruit to fruit variability, and optional choices of different MRI imaging modes that potentially provide additional knowledge about the physicochemical mechanisms of bruising. Following this preliminary study, there is a need for more in-depth MRI research on various different combinations of fruit firmness and impact energy in green mature through to ripe avocado fruit. MRI could also be applied for non-destructive bruising assessments that evaluate the incremental progression in bruising (and decay) as fruit travel through the supply chain.

Acknowledgements

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Figure legends:

Plate A: Transverse MRI section of a firm ripe 'Hass' avocado fruit that has not been deliberately impacted.

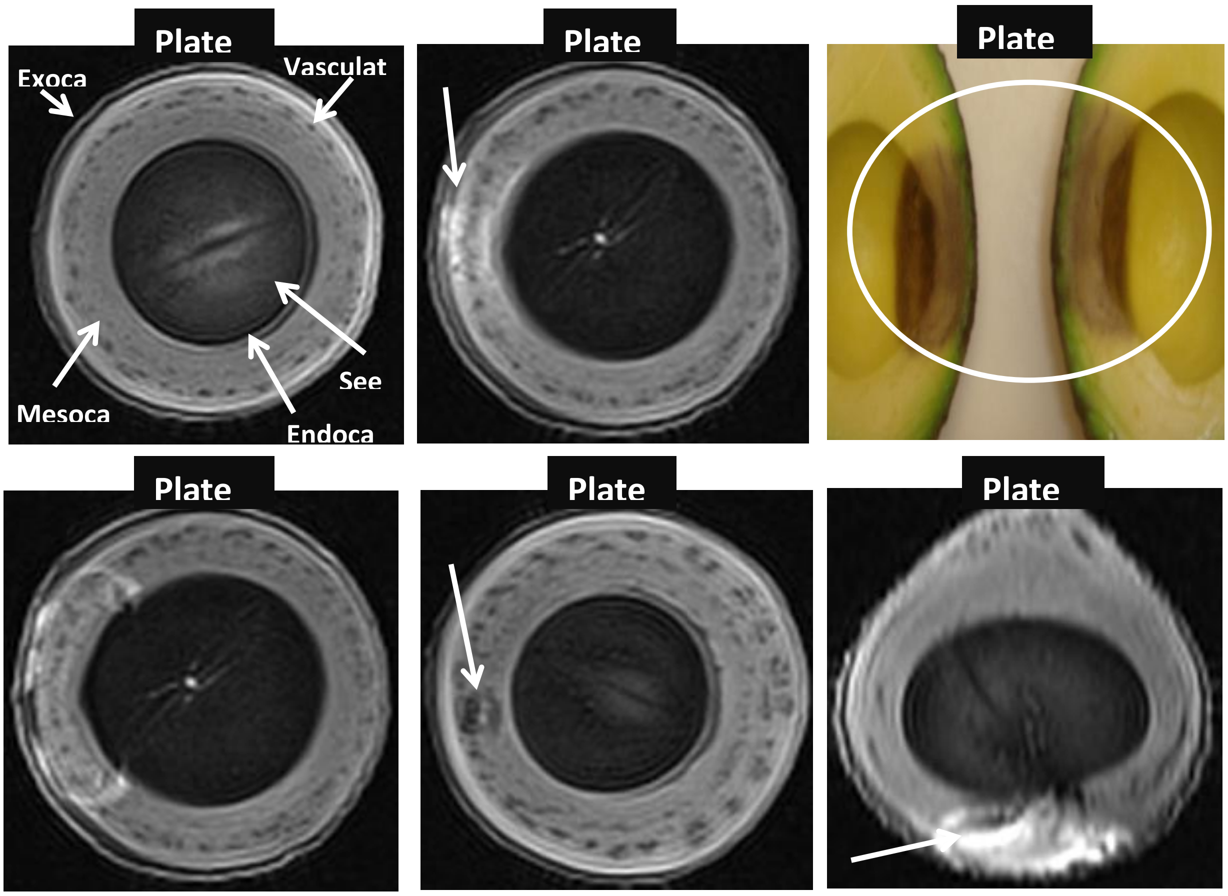
Plate B: MRI of a firm ripe 'Hass' avocado fruit immediately after impact by dropping from 50 cm height. The arrow indicates the site of impact. The brighter (hyperintense) area indicates water that is less constrained in likely association with damaged or broken cell membranes and release of water into cell wall spaces.

Plate C: MRI of a firm ripe 'Hass' avocado fruit 72 hours after impact from 50 cm drop height. The arrow indicates the impact point and the hyperintense area indicates the increased area of flesh affected by the impact over the 72 hours (*cf*. Plate B).

Plate D: Image of a bruised 'Hass' avocado fruit impacted from 50 cm drop height at the firm ripe stage. The circled area indicates the damaged flesh.

Plate E: MRI of a green mature fruit immediately after being impacted from 100 cm drop height. The arrow indicates the site of impact which was visible immediately after impact.

Plate F: MRI of a firm ripe 'Hass' avocado fruit impacted from 50 cm drop height showing the diseased area of the fruit. The arrow indicates decaying flesh at the distal end of the fruit.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Appendix F: Impact induced bruising in ripening 'Hass' avocado fruit.

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Introduction

Matching consumer demand with supply relies on consistently providing appropriate quality and quantity, and at the right price. This is particularly important as supply continues to increase. The consumer is the final "judge" of quality and value, so quality should be assessed in fruit sampled from the retail shelf, and when the fruit are ready to eat. Retail surveys over the last 20 years (Smith et al, 1990; Hofman and Ledger 2001; Harker and Jaeger, 2007) have shown significant problems with flesh quality, for example 40-50% of consumers having bad purchase experiences because of poor internal quality. Recent consumer research suggested that consumer's intentions to repeat purchase will be negatively affected if more than 10% of the flesh volume is discoloured (Gamble et al, 2010). A suitable benchmark in relation to flesh defects was for no more than one in 10 fruit to have no more than 10% of the flesh affected. Results from the HAL project on 'Avocado Retail Quality Surveys' (AV07018) in 2008 indicated that 63% of the fruit had flesh defects and that 29% of these fruit had more than 10% of the flesh volume with defects.

The retail surveys indicate that flesh diseases and bruising are the two major causes of flesh discolouration. Considerable research has been undertaken to minimise flesh diseases, but little is understood about bruising. Project AV10019 was commissioned by Avocados Australia Ltd (AAL) to fill this knowledge gap and provide guidance toward commercial practices to minimise bruising.

A bruise can be defined as an area of damage within a fruit that is typically caused by either compression or impact injury (Arpaia et al. 2005). Bruises in avocado fruit flesh are typically dark grey in colour and confined to a well defined area that is usually close to the site of injury. Other forms of bruising, such as light coloured discolouration often associated with hairline cracking of the flesh, have been observed in avocado fruit sampled from the end of the packing line (Hofman 2002).

Previous work has shown that only about 0.6% of Hass fruit sampled from the end of the packing line have significant bruising, and usually this bruising is of lighter colour and less obvious (Hofman 2002; project AV02015). Also, avocado flesh is more easily bruised as fruit soften (Arpaia et al. 2005), and the bruise severity typically increases with increasing impact energy, e.g. drop height (Brusewitz et al. 1992). This suggests that fruit are more likely to be bruised during and after ripening. Very preliminary work within the AvoCare project (Hofman and Ledger, 2001: project AV99007) indicated that fairly extensive sampling may be required to identify causes of bruising during ripening and distribution, which may require methodology development and testing.

The current research project entitled 'AV10019 - Reducing Flesh Bruising and Skin Spotting in 'Hass' Avocado' was initiated with a primary focus on reducing flesh bruising in ripening avocado fruit to provide better quality fruit to consumers. It is not clear when bruising symptoms first appear after a bruising event happens. Moreover, it is not known how the symptoms of bruising worsen over time. Gaining an insight into when bruise expression peaks relative to the causal event would enable more informed bruise assessment and, thereby, facilitate monitoring and bruise reduction practices in commercial avocado supply chains. This article presents the results from a preliminary experiment to determine the time to bruise expression after controlled impacts to single ripening fruit. The treatments used were various combinations of fruit firmness and drop heights.

Methodology

'Hass' avocado fruit at the green hard stage were collected from a ripener's premises in the Brisbane Markets at Rocklea, Queensland. The fruit were carefully transported to a Postharvest Research Laboratory at Gatton. There, they were initiated to ripen by a dip treatment in 1000 $\mu L.L^{-1}$ ethephon (an ethylene releasing compound) plus 0.01% Tween 80 (a wetter / spreader compound) for 10 min. The fruit were then air dried and kept in a darkened shelf life evaluation room at 20°C and 85% RH until they variously reached firmness levels 3, 4 and 5 (White et al., 2009; Table 1). Fruit were sorted on the basis of hand firmness and assigned to impact treatments on a matched (e.g. for size, shape) sample basis. Individual fruit were labelled using a white marker pen. They were weighed individually with a digital balance.

Table 1. Avocado hand firmness guide (White et al. 2009).

0	Hard, no 'give' in the fruit.
1	Rubbery, slight 'give' in the fruit.
2	Sprung, can feel the flesh deform by 2-3 mm. under extreme thumb force.
3	Softening, can feel the flesh deform by 2-3 mm. with moderate thumb pressure.
4	Firm ripe, 2-3 mm deformation achieved with slight thumb pressure. Whole fruit deforms with extreme hand pressure.
5	Soft ripe, whole fruit deforms with moderate hand pressure.
6	Over ripe, whole fruit deforms with slight hand pressure.
7	Very over ripe, flesh feels almost liquid.

Fruit were individually impacted by dropping in a pendulum device from heights of 25, 50 and 100 cm against a solid surface. Pendulum based impact devices have been used previously (e.g. Mohsenin 1986). The average impact energies absorbed by the fruit were 0.38, 0.81 and 1.67 N (newtons) for the drop heights of 25, 50 and 100 cm, respectively. The impact area on each fruit was traced using a white marker pen. The fruit were then held at 20ºC for evaluations at 8, 24 and 48 h. The fruit flesh around the stone was then halved through the impact site using a sharp and smooth knife. The bruise volume was quantified in the two halves using a volume displacement method. Briefly, the bruise affected area of the fruit was carefully removed and dipped into water within a calibrated measuring cylinder (Rashidi et al., 2007). The increase in volume of the water plus bruised flesh was recorded. The volume of cracks that also resulted from impact was estimated separately by filling the cracks with a calibrated medical syringe. The crack volume was added to the volume of bruise to calculate the full bruise volume caused by an impact. Bruise volume was, thus, the quantitative measure of 'bruise severity'. The experiment was conducted as a 3 x 3 x 3 factorial randomised complete block design. The data were statistically analysed with Minitab software.

Results and discussion

The severity of visible flesh bruising in the avocado fruit worsened with increasing time after the impact event (Figure 1). Tissue discolouration was not obvious until 24 hours after impact for 'Hass' avocado fruit impacted at hand firmness stages 3, 4 and 5 from 25, 50 and 100 cm heights. The damage appeared initially in the form of cracks and then became more voluminous as damaged flesh tissue changed colour to brown. The data suggests that bruises continued to grow in volume even beyond 48 hours, particularly with intermediate drop heights.

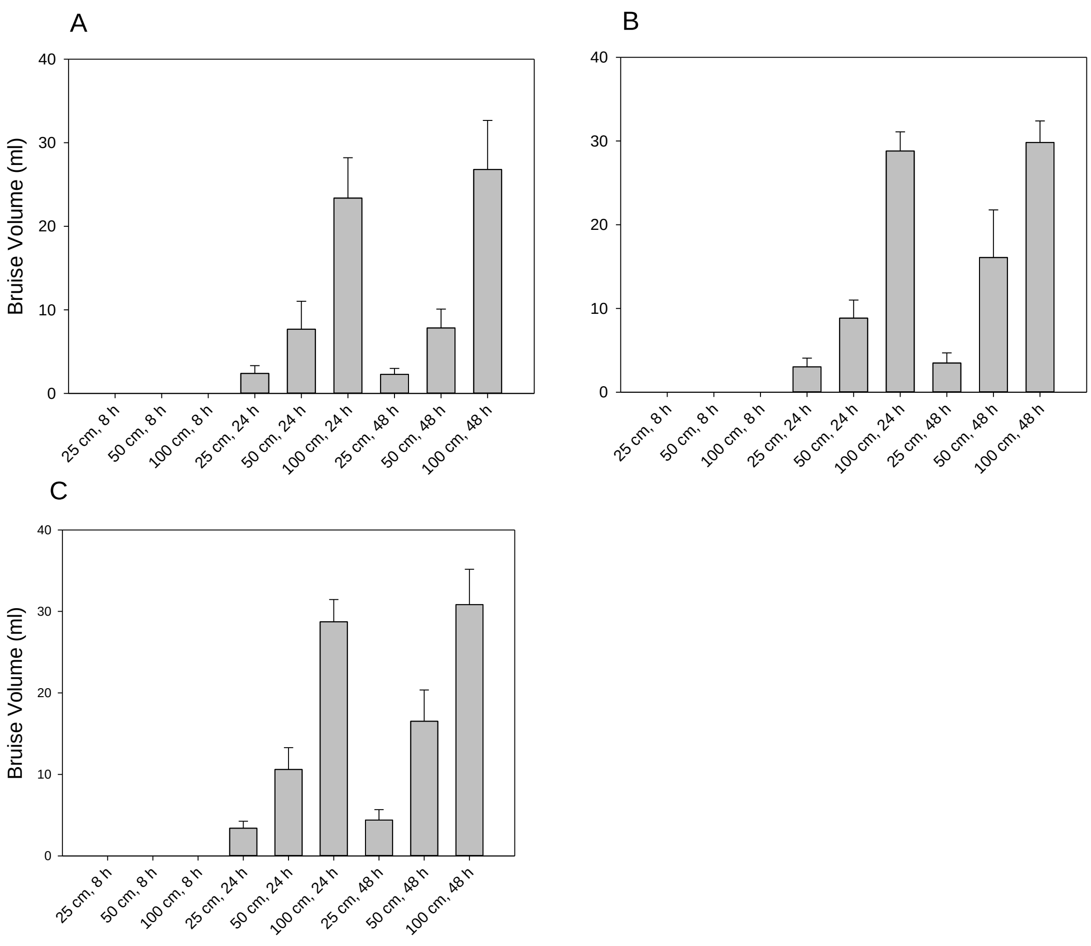

Figure 1. Changes in the bruise volumes over time after 8, 24 and 48 hours in 'Hass' avocado fruit (n = 10) impacted from 25, 50 and 100 cm drop heights at hand firmness stages 3 (A), 4 (B) and 5 (C).

Trends in the data also suggest that at similar times after impact for already softening avocado fruit, any of the three drop heights tested more or less equally damaged the flesh tissues, reflecting only a small affect of firmness of ripening avocado fruit. The bruises at 24 hours after impact in 'Hass' avocado fruit for different stages of firmness and for impacts from different drop heights are depicted in Figure 2.

Figure 2. Bruising of 'Hass' avocado fruit at 24 hours after impact for three different stages of hand firmness and three different drop heights.

This experiment has enhanced our understanding of the bruise severity response over time for individual 'Hass' avocado fruit treated at different stages of ripening with various levels of impact energy caused by dropping fruit from several heights. The improved understanding will be applied in ongoing supply chain experiments to determine exactly where, when and why 'Hass' avocado fruit become bruised from the ripener onwards. It will also be applied to better understand bruise symptom development in ripening 'Hass' avocado fruit. The collective findings will used by industry, research and service personnel, including assessors who monitor avocado quality in the supply chain. In the value chain context, it is particularly important to conduct internal quality assessments that reflect the consumers experience; namely, when bruise expression has peaked.

Acknowledgements
This preliminary study was conducted as part of the project entitled 'AV10019 - Reducing Flesh Bruising and Skin Spotting in 'Hass' Avocado' which is funded by Horticulture Australia Limited (HAL) using the Avocado Industry levy and matched funds from the Australian Government. The authors thank other DEEDI and UQ staff members for their advice and assistance. They also thank commercial supply chain stakeholders, particularly Coles, Murray Brothers and Woolworths, for their cooperative support.

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Appendix G: Comparison of firmness meters for measuring 'Hass' avocado fruit firmness.

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Keywords: Analogue firmness meter, Anderson electronic firmometer, bruising, non-destructive, Sinclair iQ firmness tester

Abstract

Quality control in the avocado supply chain involves the monitoring of fruit firmness. The temporal passage of fruit through the supply chain and the selection of consumable fruit by shoppers depend primarily upon fruit firmness. Traditionally, fruit firmness measuring methods, like Effegi and conical probes, are relatively inefficient and destructive. Simple, accurate and non-damaging methods of measuring fruit firmness are ideally required to help assure eating quality to the consumer without fruit wastage. The firmness of 'Hass' avocado fruit at a range of ripening stages was measured with the various different firmness measuring techniques of the Sinclair iQ Firmness Tester (SIQFT), the Electronic Firmometer (EF), the Analogue Firmness Meter (AFM) and hand squeezing. Measurements were made by each method at different points on the same fruit. Destructive bruise assessment was performed 48 h later, thereby allowing sufficient time for fruit to express any bruising resulting from the act of firmness measurements. Non-linear relationships were determined between fruit firmness values measured with the different techniques. The adjusted R^2 for the relationship between the SIQFT and the EF was 91.6%. For the SIQFT and the AFM, the adjusted R^2 was 73.7%. It was 77.7% for the SIQFT and hand squeezing. A significantly high incidence of bruising was associated with firmness assessment by the EF as compared with either the SIQFT or the AFM ($P < 0.05$). Among the methods compared, the SIQFT was non-damaging compared with the EF and relatively efficient for measuring the firmness of ripening 'Hass' avocado fruit. This instrument merits consideration as a quality control tool of choice in 'Hass' avocado supply chains.

INTRODUCTION

The quality control (QC) system along the typical fruit supply chain incurs loss of at least 5% of the initial quantity in order to assure that quality according to standards is delivered to buyers (FreshPlaza, 2009). Fruit firmness measurement is a very basic and important parameters by which to ascertain the stage of fruit ripening (White et al., 1997). However, measuring fruit firmness is challenging for researchers and the industry alike (García-Ramos et al., 2005). Various instruments and alternative methods for the determination of avocado fruit firmness have been reported.

The Effegi probe has been used for destructive measurement of avocado fruit firmness (Arpaia et al., 1987). The probe of standard diameter, 8 or 11 mm, is penetrated 8 mm deep into the fruit and the pressure is measured. The pressure values, however, often changes when a different operator uses the same instrument on the same product (Abbott et al., 1976). Similarly, conical probes have also been used for destructive assessment of fruit firmness (Kojima et al., 1991). This method involves penetration of a probe of a specific length and angle in the fruit. Meir et al. (1995) used this method to measure the firmness (N) of 'Hass' avocado fruit.

Swarts (1981) purposively developed the South African Firmometer for non-destructive measurement of avocado fruit firmness. This instrument, designed on the principle of lever, measured fruit firmness by applying an indirect force on fruit through a 17 mm diameter button for 10 s. The displacement of the button gave the fruit firmness value, which increased as the fruit softened. This 'manually operated' instrument was upgraded to 'The Electronic Firmometer (EF)' (White et al., 1997), which works on the same basic principle with greater operational efficiency and accuracy.

An Analogue tomato Firmness Meter (AFM) was used to non-destructively measure the firmness of tomato and mango (Macnish et al., 1997). The AFM has also been used by us to measure the firmness of avocado (Mazhar et al., 2011) and other fresh produce (e.g. mango; D. Joyce, pers. comm.). This method initially developed by B. McGlasson (pers. comm.) involves placing the sample fruit into a V-shaped metal stand. Displacement in fruit mesocarp under 500 g load is recorded after 30 s on a 'Baty' analogue displacement gauge (0.01 mm resolution, RS Components Pty Ltd).

Sinclair™ International Ltd. developed the benchtop Internal Quality Firmness Tester (SIQFT) (Howarth and Ioannides, 2002) as an efficient tool for non-destructive firmness measurement of various fruit and vegetables. It is based on a low-mass impact sensor with a sensing element in the tip of a bellows expander (Howarth et al., 2003). The sensor measures the firmness value at four different points around the equatorial circumference of the fruit and the machine calculates the average value.

White et al. (2009) described a non-destructive hand firmness guide for avocado. Fruit firmness is determined by holding the fruit in palm of the hand and gently squeezing it either with the whole hand for soft fruit, or with the fingers or thumb for hard fruit. The firmness value is ranked from 0 (hard, no 'give' in the fruit) to 7 (very overripe, flesh feels almost liquid).

Aside from the Effegi and conical probes that involve destructive firmness assessment, all of the non-destructive firmness assessment approaches described above, each possess certain advantages. The AFM has been reported as a simple and inexpensive firmness measuring device (Macnish et al., 1997). The advantages of the EF are its simplicity and ease of use coupled with its objective measurement of fruit firmness with minimal user variability (White et al., 1997). Hand squeezing is suggested for its acceptance by the industry, researchers and consumers (Harker et al., 2010), although experience and prior calibration is recommended for consistency (White et al., 1999). The SIQFT has been advocated for its relatively greater accuracy and temporal efficiency (Howarth et al., 2003; Valero et al., 2007).

In conducting initial preliminary trials on the incidence of bruising in 'Hass' avocado fruit (Mazhar et al., 2011), a correlation between the AFM and the EF was established. It was observed that the EF adversely affected internal avocado quality by inducing bruising in the flesh beneath where the fruit firmness was measured. In contrast, the AFM did not cause bruising, but was more time consuming. Being a subjective measure of fruit firmness and subject to operator variability, hand squeezing method is not technically desirable.

The need for a clearly reliable and efficient non-destructive firmness measuring instrument is evident. Accordingly, the EF, the AFM and hand squeezing were comparatively assessed against the SIQFT for utility in avocado firmness measurement. Thereby, correlations between firmness values measured by these methods and any bruising caused to the fruit by the act of measuring fruit firmness were determined for 'Hass' avocado fruit.

MATERIALS AND METHODS

'Hass' avocado fruit (*n* = 80) at the mature green stage, as harvested in Cairns and transported to a ripener, were collected on arrived at the Brisbane Markets in Rocklea. Randomly sampled fruit were transported within 2 h to a postharvest laboratory at The University of Queensland, Gatton. They were initiated to ripen by dipping for 10 min in 1000 $\mu L.L^{-1}$ Ethrel® (May & Baker Rural Pty Ltd., NSW Australia) and 0.01% Tween® 40 (Sigma-Aldrich Inc., MO USA). The dipped fruit were air dried, and kept in a shelf life room at 20° C and 85% RH until they reached the required levels of hand firmness. For data collection, fruit were labelled numbers 1 to 80.

Firmness of each individual fruit was measured with the SIQFT (Sinclair™ International Ltd, supplied by J Tech Systems, Albury Australia) the EF (Anderson Manufacturing and Toolmaking, Arataki New Zealand), and the AFM (Initially designed and assembled at CSIRO by Macnish et al. (1997)) around the largest diameter of the same fruit (Fig. 1). The SIQFT measured the fruit firmness at four random points along the diameter of the fruit and displayed the average of four values. Firmness was measured under 200 g load applied for 10 sec with the EF and under the standard 500 g load applied for 30 sec with the AFM at different locations and the tested area was marked with a white-out marker. Hand squeezing was measured after White et al. (2009), as described in Table 1. The sample fruit were held at 20° C and 85% RH for 48 h after firmness measurement allowing time for any bruise expression in response to firmness measurement.

Destructive assessment of bruising was conducted after Mazhar et al. (2011). Briefly, the whole fruit was peeled, and where applicable, the bruise-affected mesocarp underneath the marked areas was removed and immersed into water in a measuring cylinder. The change in the volume of water due to the bruised mesocarp volume was recorded as the bruise volume.

Fruit firmness data as measured by the various different techniques were statistically correlated using Minitab® 16 (Minitab Pty Ltd, Sydney, Australia). Bruise volume data for the different treatments were also statistically analysed by χ^2 analysis.

RESULTS AND DISCUSSION

Correlations between Measurements of Firmness by Different Techniques

The adjusted R^2 value for the non-linear relationship between the SIQFT and the the EF was 91.6%, for the SIQFT and the AFM was 73.7%, and for theSIQFT and hand squeezing was 77.7%. Graphs of the non-linear relationship amongst the SIQFT and the EF, the AFM, and hand squeezing are presented in Fig. 2.

White et al. (1997) suggested that the EF was effective for firmness assessment of fruit from hard to the firm ripe stage, and De Ketelaere et al. (2006) suggested that the SIQFT was more sensitive for soft fruit samples. Strong correlation of the SIQFT and the EF in this experiment indicated that the firmness values of 'Hass' avocado fruit measured with either of the instruments could be interchanged with the correlation equation. The slope of the relationship curve changed fairly consistently from hard to the softening fruit, where it stabilises to the soft ripe fruit.

R^2 value of the non-linear correlation of the SIQFT and the AFM was 73.7%, which is not as strong as for the SIQFT and the EF. This is mainly due to the difference in firmness measuring techniques and possibly can be due to the differences in fruit characteristics affecting the response of the fruit to the acoustic transmission to the SIQFT. Operator error can occur with the AFM through zeroing, longer time required for firmness assessment of each fruit, and only one point of firmness assessment (Macnish et al., 1997) compared with four points with the SIQFT.

The non-linear relationship between the SIQFT and hand squeezing was also not very strong, with only 77.7% R^2 value. The SIQFT produces a continuous measure of firmness, while hand squeezing result in a smaller set of discrete measurements. The principle of the SIQFT suggests that the estimate of firmness of relatively hard fruit is more-noise sensitive due to shorter contact times (De Ketelaere et al., 2006). Hand squeezing is believed to be more reliable when conducted by an experienced assessor (Gamble et al., 2010; Gamble et al., 2008). The relationship of the SIQFT and hand firmness suggested that the SIQFT can be used to segregate fruit firmness classes for consistent supply of uniform fruit firmness (Shmulevich et al., 2003).

Incidence of Bruising due to Firmness Measuring Instruments

The EF was associated with significantly more bruising to the fruit, compared with the SIQFT and the AFM (Table 2). Only 5% of the fruit were bruised after the SIQFT use, 6.3% following AFM, 98.8% following EF.

Flesh bruising in 'Hass' avocado fruit is the visual appearance of the cell response to impact or compression energy absorbed (Ledger and Barker, 1995). It increases at higher levels of energy absorbed and in less firm fruit (Arpaia et al., 2006). Bruising can result from firmness measurement if significant cells deformation occurs during testing, and may vary with the testing technique.

Both, the EF and the AFM assess the firmness of avocado fruit by following the same principle of measuring displacement in the fruit mesocarp due to the pressure from an applied force (García-Ramos et al., 2005). Given its lever action, the force (F) applied by the EF is 5.5 N, based on $F = mg\ (di/de)$ (EngineeringToolBox, 2009), where m = mass (0.2 kg), g= graviational force (9.8 $m.sec^{-1}$), di = length of the filcrum, and de = distance between effort force and distant end of the lever. The force applied by the AFM is 5.5 N based on $F = mg$ (Kurtus, 2012), where m = 0.5 kg and g = graviational force (9.8 $m.sec^{-1}$). The difference in bruise volume yielded due to the act of firmness measurement with these two instruments can possibly be due to the difference in pressure applied on the point of firmness measurement. In softening fruit, the pressure applied by the EF was 24221.45 $kg.m^{-1}.s^{-2}$ based on $P = F/A$ where F = force and A = area. Whereas, the pressure applied by the AFM would be a lot less depending on the contact area of the fruit and the disk (40 mm) mounting the load, which in case of softening fruit could be larger and in case of hard fruit can be smaller compared with the EF (17 mm). · These estimates may explain why the mesocarp is bruised in response to the pressure absorbed by the fruit subjected to firmness measurement by the EF as compared to the AFM.

The SIQFT works on the low-mass impact measurement principle (Shmulevich et al., 2003) using piezoelectric sensor technology (García-Ramos et al., 2005). The sensor is fixed at the tip of a rubber bellow. These are activated by compressed air and lightly touch the rotating fruit at four points around its equatorial circumference. The sensor calculates the fruit response to the impact by using the force transducer (Howarth et al., 2003) and the fruit generally does not absorb enough energy to develop flesh bruising. The SIQFT, compared with the EF and the AFM, non-destructively measures fruit firmness, and is more efficient and with less user variability coupled with relatively higher efficiency and low user variability (De Ketelaere et al., 2006).

CONCLUSION

This work has established that the fruit subjected to firmness assessment with EF develops bruising at the site of firmness measurement. Thus, the EF is not a truly non-destructive firmness measuring instrument. Between the non-destructive SIQFT and AFM devices, the SIQFT is more efficient with lesser chances of operator variability. Accordingly, among the approaches compared, the SIQFT can be recommended for use in the 'Hass' avocado supply chain QC system. It provides relatively more reliable, efficient and non-destructive measures of firmness for softening avocado fruit.

Acknowledgement
This study was conducted as part of the project entitled 'AV12009 - Understanding and managing avocado flesh bruising' which is funded by Horticulture Australia Limited with avocado industry levies and matched funds from the Australian Government and support from the Department of Agriculture, Fisheries, and Forestry (Queensland) and the University of Queensland. The research team is also thankful to J-Tech Systems Pty Ltd., Sinclair Systems International LLC., and staff of Murray Brothers for their support.

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Tables

Table 1: Levels of hand firmness for avocado fruit (White et al., 2009).

0	Hard, no 'give' in the fruit
1	Rubbery, slight 'give' in the fruit
2	Sprung, can feel the flesh deform by 2-3 mm (1/10 inches) under extreme thumb force
3	Softening, can feel the flesh deform by 2-3 mm (1/10 inches) with moderate thumb pressure
4	Firm-ripe, 2-3 mm (1/10 inches) deformation achieved with slight thumb pressure. Whole fruit deforms with extreme hand pressure
5	Soft-ripe, whole fruit deforms with moderate hand pressure
6	Overripe, whole fruit deforms with slight hand pressure
7	Very overripe, flesh feels almost liquid

Table 2: Chi^2 analyses of incidence of bruising in 'Hass' avocado fruit subjected to firmness measurement with the Sinclair Internal Quality Firmness tester, the Electronic Firmometer and the Analogue Firmness Meter.

Comparison of instruments	Chi^2	**p value**
SIQFT vs EF	140.823	0.000^{***}
SIQFT vs AFM	0.118	0.731 ns
EF vs AFM	137.243	0.000^{***}

Figures

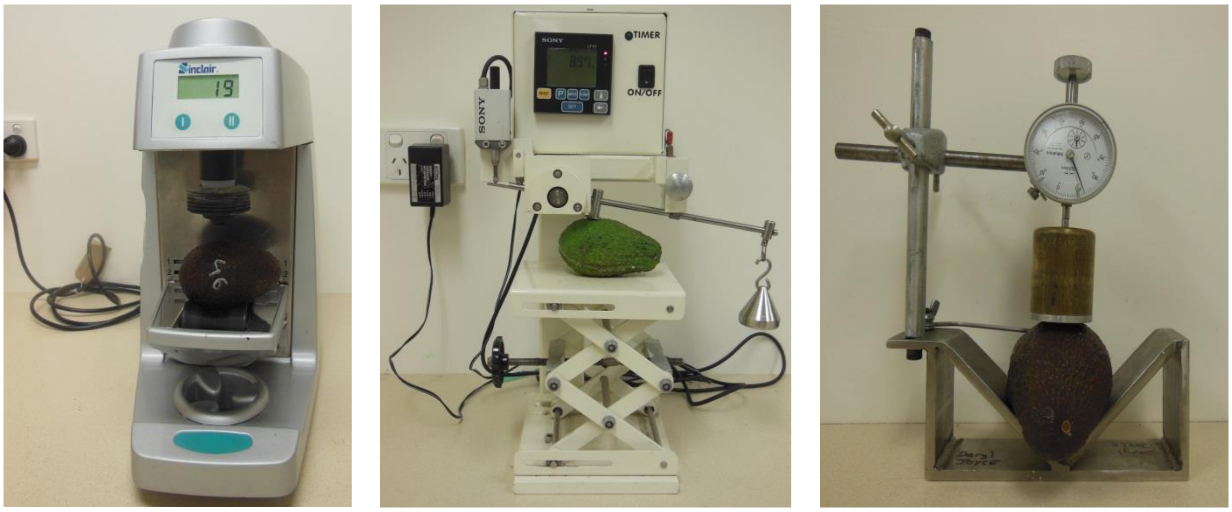

Fig. 1: Avocado cv. Hass fruit firmness measurement with the Sinclair Internal Quality Firmness tester (left), the Electronic Firmometer (centre) and the Analogue Firmness Meter (right).

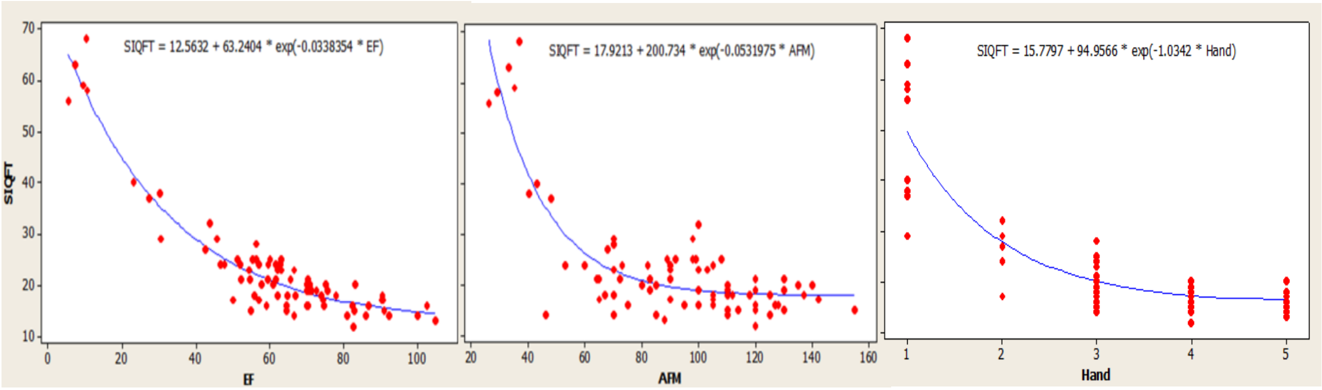

Fig. 2: Fitted line plot demonstrating the relationship between the 'Hass' avocado fruit (n = 80) firmness values measured with the Sinclair Internal Quality Firmness tester (SIQFT) and the Electronic Firmometer (EF) (left), the SIQFT and the Analogue Firmness Meter (AFM) (centre), and the SIQFT and hand squeezing (right).

Appendix H: Skin spotting situation at retail level in Australian avocados.

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Keywords: Hass, lenticel damage, quality, retail, ripening

Abstract

Skin spotting (SS) on avocado fruit is evident as blackened areas of <1 mm diameter with well-defined margins. Previous preliminary consumer research indicated that Australian consumers may be concerned by SS on avocado fruit displayed at retail level. A better understanding of SS and its likely commercial impacts was sought. Findings for cv. 'Hass' avocado from retail surveys conducted over 2 years were collated. The surveys were carried out in various retailer outlets in the capital cities of New South Wales (Sydney), Queensland (Brisbane), Victoria (Melbourne), and Western Australia (Perth). Marked differences in SS severity were recorded across the States and also across months within the one State. Differences in SS levels between types of retail outlet stores were also statistically significant. The data are discussed in terms of possible reasons for the variation observed.

INTRODUCTION

Skin spotting (SS) or nodule or lenticel damage on avocado fruit is generally associated with mechanical injury during harvest and packing (Everett et al., 2008). The symptom is typically obvious 1 - 4 d after damage in the form of small dark spots of <1 mm diameter (White et al., 2009). In cv. 'Hass', SS usually occurs on nodules, where lenticels are commonly found. It is generally believed that lenticels on avocado fruit are derived from stomata that become dysfunctional as the fruit grows (Everett et al., 2001). Lenticel damage is more severe on avocado fruit harvested during wet conditions. It is considered that the water content of the cells increases during high water availability and that loosely packed cells in and around the lenticel expand to fill the lenticel cavity. These cells are likely relatively more susceptible to mechanical damage. Mechanical forces can lead to cell membrane damage, especially in cells with higher turgor, and to enzymic reactions resulting in browning. SS is often more severe with advanced maturity and elevated holding temperatures (Milne, 1998). Additionally, fruit rubbing against one another and against packaging materials and other surfaces can contribute to the lenticel damage evident as blackened nodules (Marques et al., 2012).

SS in ‘Hass’ is effectively not visible on ripe fully coloured fruit, but is visible on partly ripened fruit (Hamacek et al., 2005). Typical levels of SS severity on partly coloured fruit can reduce the consumers’ intent to purchase (Harker and White, 2010). Excessive SS may result in loss of value from either rejection of the whole consignment or price reduction at wholesale and retail levels. However, limited through the supply chain investigation has been conducted on SS in the Australian situation.

In exploring the incidence and severity of SS on fruit in retail outlets across Australia, this paper reports on survey data collected in the course of monthly avocado fruit quality surveys coordinated by the Australian avocado industry.

MATERIALS AND METHODS

Avocado retail quality surveys were conducted monthly from September 2011 to May 2014 at 16 independent and supermarket retail stores covering Sydney, Brisbane, Melbourne and Perth. The surveys were managed by Avocados Australia Limited (AAL) and engaged trained contractors (Embry, 2009). Their training was to ensure consistent identification and rating practices between the State-based assessors. A random sample of fruit (n = 15) on display in each participating retail store was purchased. These fruit were rated for SS based on a 0 - 4 scale of 0 = no SS, 1 = 0 - 10 % SS, 2 = 11 - 25 % SS, 3 = 26 - 50 % SS and 4 = > 50 % SS. This scale was based on White et al. (2009).

Based on the views of industry stakeholders that fruit with SS ratings of 3 (26 - 50 %) and 4 (> 50 %) are not acceptable (data not shown), the survey data for these two categories were collated and statistically analysed for variance between survey variables with Minitab® 16 (Minitab® Pty Ltd, Sydney, Australia).

RESULTS AND DISCUSSION

SS severity varied significantly (P < 0.05) between the State capital cities where the avocado fruit samples were collected, the sample months during the years and the store types of supermarket versus independent retail outlets.

More SS was recorded for fruit in New South Wales (Sydney city) and in Queensland (Brisbane city) followed by in Western Australia (Perth city) and in Victoria (Melbourne city) (Fig. 1). A potential reason for this could be overall longer transport distances (Luza et al., 1989) from farms to market. A longer transit time may create the opportunity for relatively more rubbing over time of fruit against fruit and / or against their cardboard tray walls and / or plastic tray liners (Mandemaker et al., 2006).

The pattern of SS varied throughout the year (Fig. 2). This sampling month variability from September 2011 to May 2014 might also be explained by fruit traveling from different production regions and, therefore, arriving after variable transit times. Supplies onto Australian markets of 'Hass' avocado fruit throughout the calendar year typically come from North Queensland in February to June, from Central Queensland in March to August, from Central Queensland in June to September, from Western Australia and Northern territory in August to March, and from New Zealand in September to March (Symonds, 2014). Additionally, there is some production from the Tri State region spanning the intersection of the States of New South Wales, Victoria and South Australia and from central New South Wales.

The retail store effects (Fig. 3) may reflect differing sources of fruit for supermarket chains and independent retailers and also different subsequent end of supply chain (e.g. distribution centre or wholesale market) and in-store fruit handling practices. The finding that the fruit quality was differentially affected by the retail store type is consistent with that of Millichamp and Gallegos (2013). They compared the quality of fruit and vegetables across retail outlets and reported differences between supermarket and farmers market retail streams.

Other variables contributing to variation in SS on 'Hass' avocado fruit at retail level may include differences in the production (viz. genotype, environment and management factors), harvesting, packing and distribution practices of individual orchards, packhouses and transport companies (Hofman et al., 2010; Schaffer et al., 2013). Schaffer et al. (2013) suggested that fruit turgidity (plant tissue and / or cell levels), brushing, packing wet, and rough postharvest handling are potential contributors to SS on 'Hass' fruit. Hofman et al. (2010) and Blakey (2011) reported that prolonged low temperature storage can also predispose 'Hass' avocados to SS.

CONCLUSION

This study indicates that the severity of SS on cv. 'Hass' avocado fruit at retail level is problematic for industry stakeholders. The degree of the problem varies with the seasonal time and Australian State capital city where sampling is conducted. Difference in SS severity in the four State capital cities involved (Sydney, NSW; Brisbane, Qld.; Melbourne, Vic.; and Perth, WA) might be due to variably prolonged transit times and / or transport conditions. Difference in SS incidence and severity in independent and supermarket retail stores was also discerned. The findings suggest that a more complete understanding of the SS issue, including underlying causal factors and protocols to minimise the problem in Australia, needs to be developed.

ACKNOWLEDGEMENT

This study was conducted as a small part of project ‘AV10019 – Reducing flesh bruising and skin spotting in avocado supply chains’ which was funded by Horticulture Australia Limited with avocado industry levies and matched funds from the Australian Government and plus support from the Queensland Department of Agriculture, Fisheries and Forestry and The University of Queensland. The research team also thanks staff at the University of Queensland and at Balmoral Orchards for their support.

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Figures

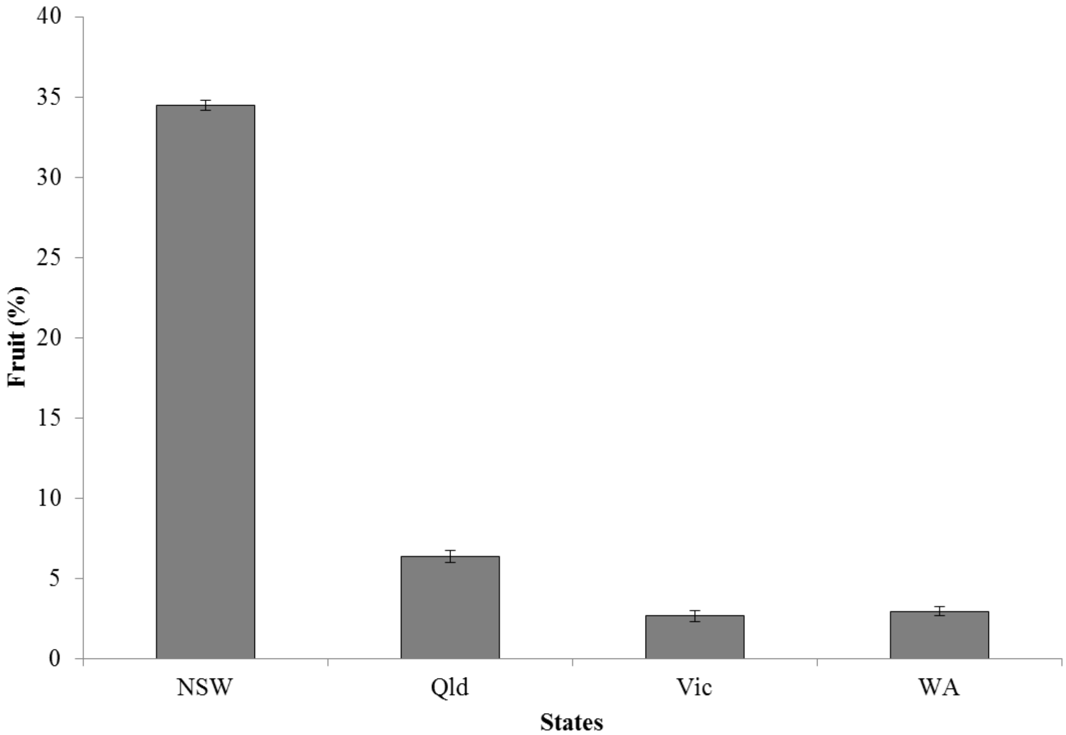


Fig. 1. The incidence of avocado fruit with unacceptable skin spotting (>26% of skin surface) found in sampling and assessment of fruit (*n* = 15) from September 2011 to May 2014 at retail store level. These main factor data were collated for stores in the States of New South Wales (Sydney, NSW), Queensland (Brisbane, Qld.), Victoria (Melbourne, Vic.), and Western Australia (Perth, WA). Vertical lines in the histogram show the standard error of mean.

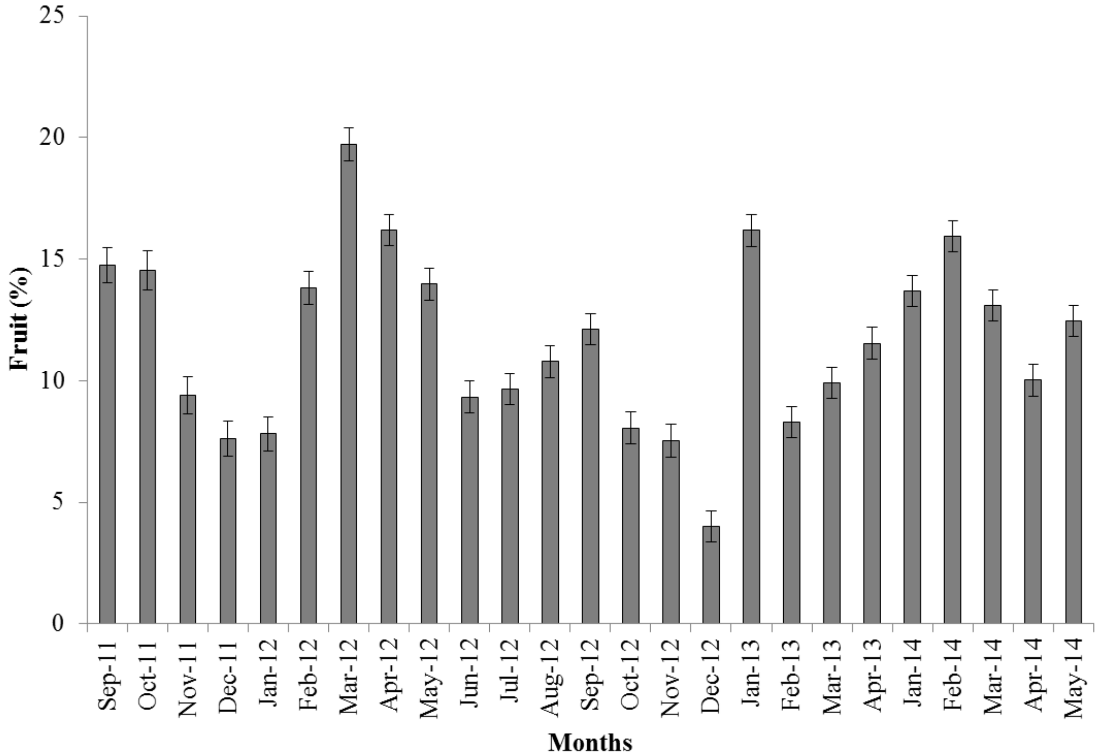


Fig. 2. The incidence of avocado fruit with unacceptable skin spotting (>26% of fruit surface) through the period from September 2011 to May 2014. These main factor data were collated for sampling and assessment of fruit (n = 15) at independent and supermarket retail level in the States of New South Wales (Sydney, NSW), Queensland (Brisbane, Qld.), Victoria (Melbourne, Vic.), and Western Australia (Perth, WA). Vertical lines in the histogram show the standard error of mean.

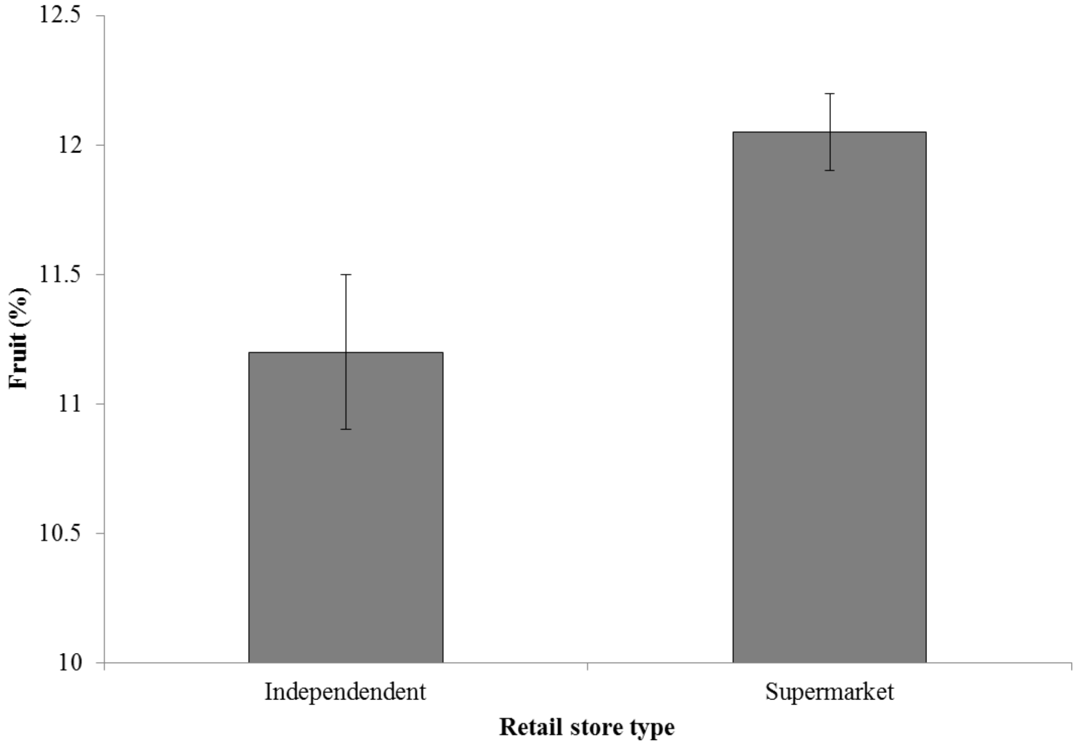
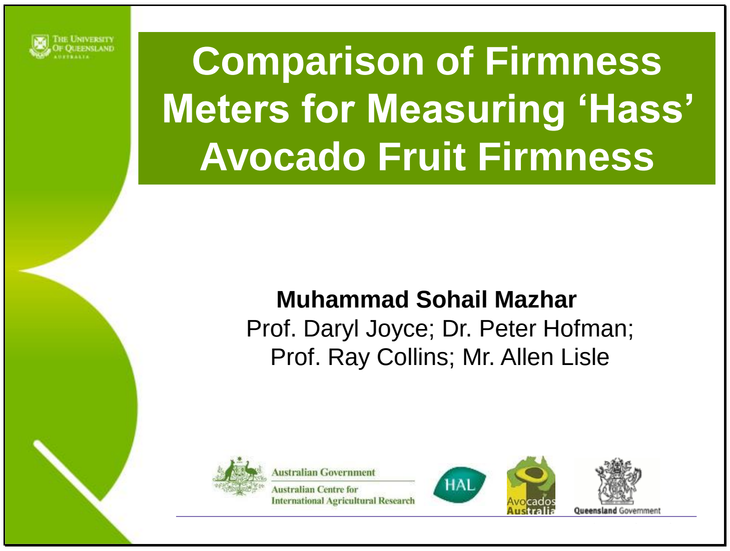


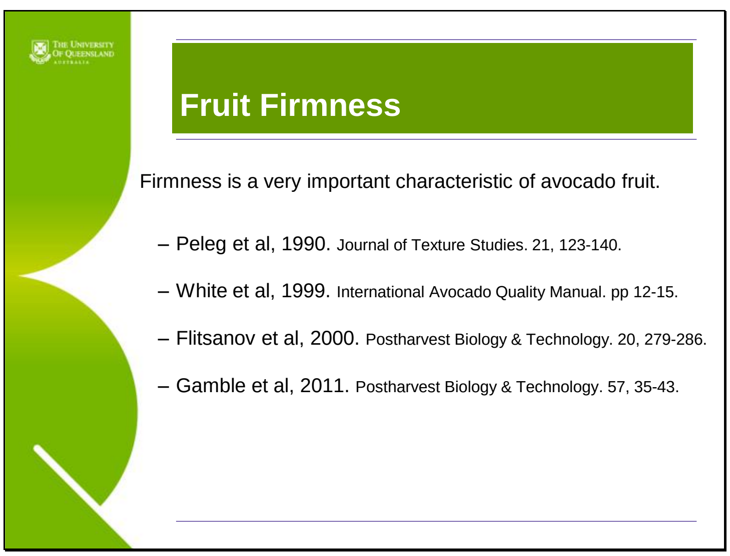
Fig. 3. The incidence of avocado fruit with unacceptable skin spotting (>26% of fruit surface) in independent and supermarket retail stores. These main factor data were collated for monthly sampling and assessment of fruit (n = 15) from September 2011 to May 2014 at retail level in the States of New South Wales (Sydney, NSW), Queensland (Brisbane, Qld.), Victoria (Melbourne, Vic.), and Western Australia (Perth, WA). Vertical lines in the histogram show the standard error of mean.

Appendix I: Comparison of firmness meters for measuring 'Hass' avocado fruit firmness.

Slide 1

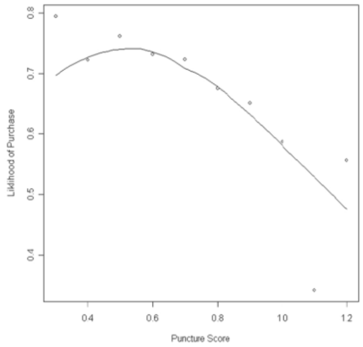


Slide 2



Slide 3

Firmness affects the intent to repeat purchase



http://industry.avocado.org.au/documents/ANZAGC09/Wed/MR2/Roger%20Harker.pdf

Slide 4

Avocado hand firmness guide

0	Hard, no 'give' in the fruit
1	Rubbery, slight 'give' in the fruit
2	Sprung, can feel the flesh deform by 2-3 mm (1/10 inches) under extreme thumb force
3	**Softening, can feel the flesh deform by 2-3 mm (1/10 inches) with moderate thumb pressure**
4	**Firm-ripe, 2-3 mm (1/10 inches) deformation achieved with slight thumb pressure. Whole fruit deforms with extreme hand pressure**
5	**Soft-ripe, whole fruit deforms with moderate hand pressure**
6	Overripe, whole fruit deforms with slight hand pressure
7	Very overripe, flesh feels almost liquid

White et al. (2009)

Slide 5

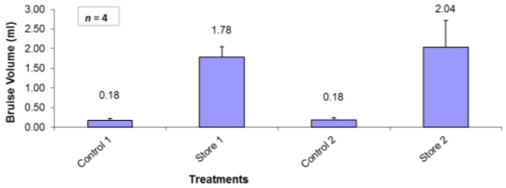
How do shoppers determine the avocado fruit firmness?

http://www.wikihow.com/Tell-if-an-Avocado-Is-Ripe, http://www.philipmarksnutrition.com/blog/, http://iyfoods.com/blog/2013/7/24/how-to-choose-a-ripe-avocado

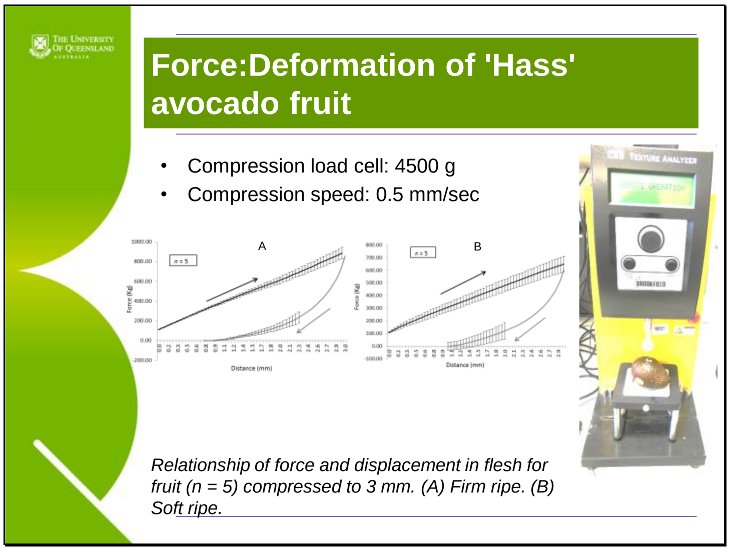
Slide 6

Shopper's contribution to flesh bruising

Contribution of fruit handling practices of shoppers to bruising in firm ripe 'Hass' avocado fruit – multiple handling over ~ 6 h



Slide 7



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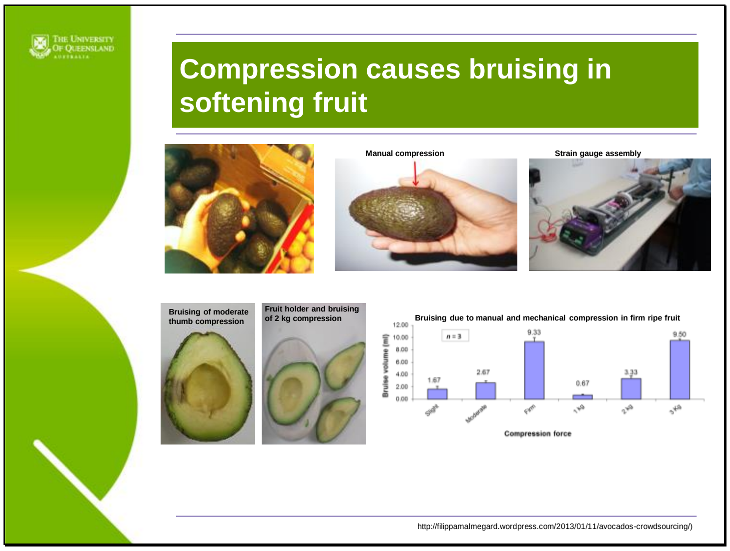
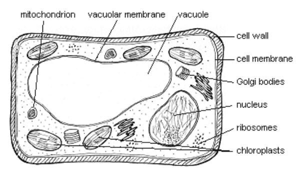


Slide 9

Bruising



Plant cell stress and strain mechanism

Mechanical injury - Impact and compression

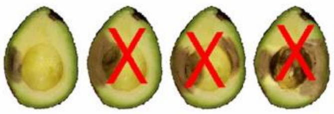
Cell physiology – increased rate of respiration and ethylene generation

Symptoms of bruising

Mishra and Gamage (2007), Golacki et al. (2009), http://assoc.garden.org/onlinecourse/PartI6.htm

Slide 10

Consumers don't like flesh bruising



Need to identify an approach (method) for firmness assessment that is really not destructive……

http://industry.avocado.org.au/QualityProgram.aspx

Slide 11

Scope of this study

This study was conducted as part of a larger HAL project '*Reducing flesh bruising and skin spotting in Hass avocado*', to …

1. establish a correlation of firmness value measured with the SIQ firmness tester with the firmness value measured with analogue firmness meter, electronic firmometer, and hand firmness.
2. assess the different firmness measuring methods for incidence of bruising due to the act of firmness measurement.

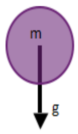
Slide 12

Firmness meters

Measurement of fruit firmness with analogue firmness meter (Left), SIQ firmness tester (Middle), and electronic firmometer (Right)

Slide 13

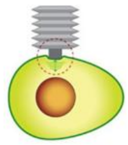
Principle of firmness meters



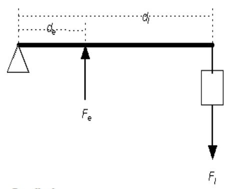
F = W = mg

F = Force
W = Weight
m = mass (Kg)
g = acceleration due to gravity

P(AFM) = 3897.727 kg.m^{-1}.s^{-2}



Surface Pressure



Fe = effort force
Fi = load fore (weight applying the force)
de = distance between effort force and distant end of lever
di = length of the fulcrum

P(EF) = 24221.45 kg.m^{-1}.s^{-2},

SIQFT works on the low-mass impact measurement principle and it employs piezoelectric sensor technology.

García-Ramos et al. 2005, Shmulevich et al. 2003, www.engineeringtoolbox.com, http://www.freshplaza.com/article/119650/Italy-Firmness-tester-for-cherries,-tomatoes-and-avocados

Slide 14

The University of Queensland Australia

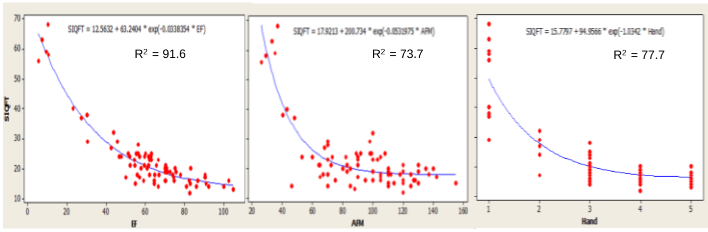
Material and methods

1. Correlation of different methods of firmness measurement.
   - Fruit (n = 80) collected at hard stage from Brisbane Markets.
   - Ripened to a range of firmness by ethephon treatment.
   - Firmness measured at different points at the same fruit with different instruments.
   - Correlation established by applying non-linear regression.

2. Assessment of different firmness measuring methods for incidence of bruising due to the act of firmness measurement.
   - Fruit from firmness assessment above were held at 20° C for 48 h.
   - Destructive bruise assessment was conducted to quantify the bruise caused by the act of firmness measurement.

Slide 15

Correlation of firmness values



Correlation of fruit firmness measured with SIQ firmness tester with electronic firmometer (Left), analogue firmness meter (Middle), and hand firmness (Right)

Slide 16

Bruising caused by the act of firmness measurement

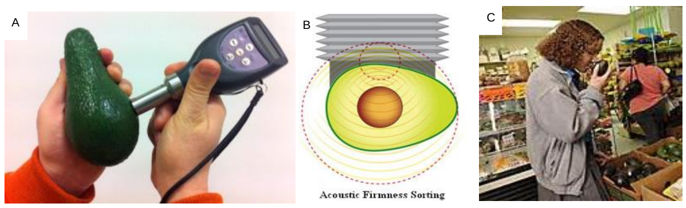
Bruise incidence with analogue firmness meter, SIQ firmness tester, and electronic firmometer.

Comparison of instruments	*Chi²*	p value
SIQFT and EF	140.823	0.000***
SIQFT and AFM	0.118	0.731 ns
EF and AFM	137.243	0.000***

Slide 17

Way forward

A



A. Hardness Tester – still destructive for softening fruit.
B. Acoustic firmness sorting – non-destructive.
C. Firmness measurement with aroma volatiles.

http://www.calavo.com/store/pro_ripe_vip.html, http://www.freshplaza.com/article/119650/Italy-Firmness-tester-for-cherries,-tomatoes-and-avocados, Obenland et al., 2012

Slide 18

The University of Queensland Australia

Expected outcomes

Reduced flesh bruising in fruit on the retail shelf because of improved practices at retail store

↓

Improved consumer satisfaction because of improved internal fruit quality

↓

Increased consumer demand and industry profitability

Slide 19

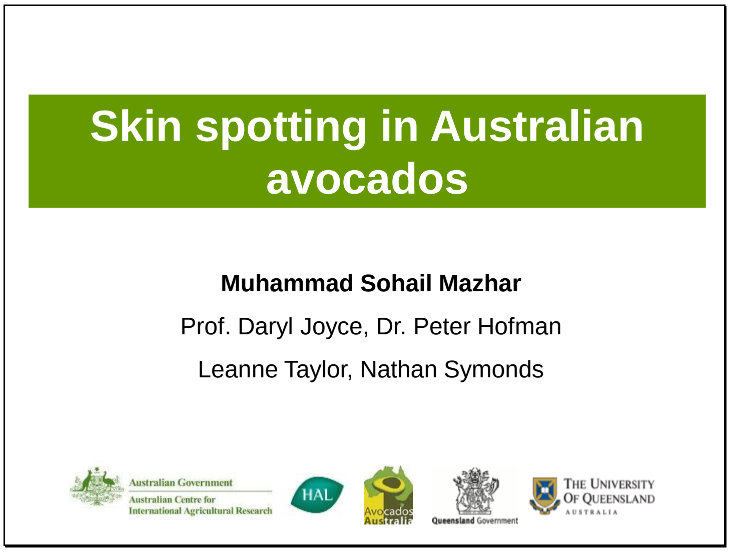
Acknowledgements

- HAL*
- Research supervisors
- J-Tech Systems Pty Ltd.,
- Ripeners (- Murray Brothers)
- Coles
- Woolworths
- UQ staff
- Co-workers (Christine, Ian, Misbah, Adeel)

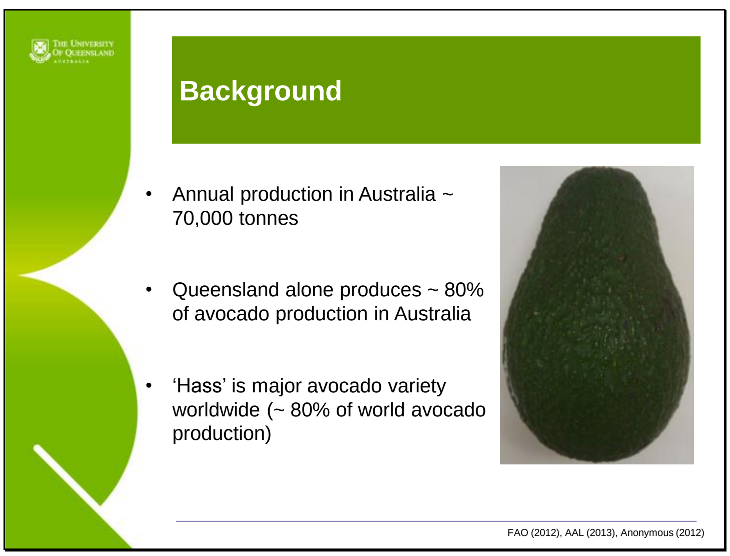
*This research has been conducted as part of the project AV10019 - Reducing Flesh Bruising and Skin Spotting in 'Hass' Avocado, which is funded by Horticulture Australia Limited (HAL) using the Avocado Industry levy and matched funds from the Australian Government.

Appendix J: Skin spotting situation at retail level in Australian avocados.

Slide 1



Slide 2



Slide 3

Background

- Avocado is predominantly produced for fresh consumption, as ….
  - Salads
  - Sandwich filling
  - Guacamole
  - Accompaniment to meals
- Australian avocado consumption is 3.1 kg per person per year - doubled only over the last decade

Dorantes et al. (2004), Villanueva and Vert (2007), AAL (2012), http://industry.avocado.org.au/NewsItem.aspx?NewsId=82

Slide 4

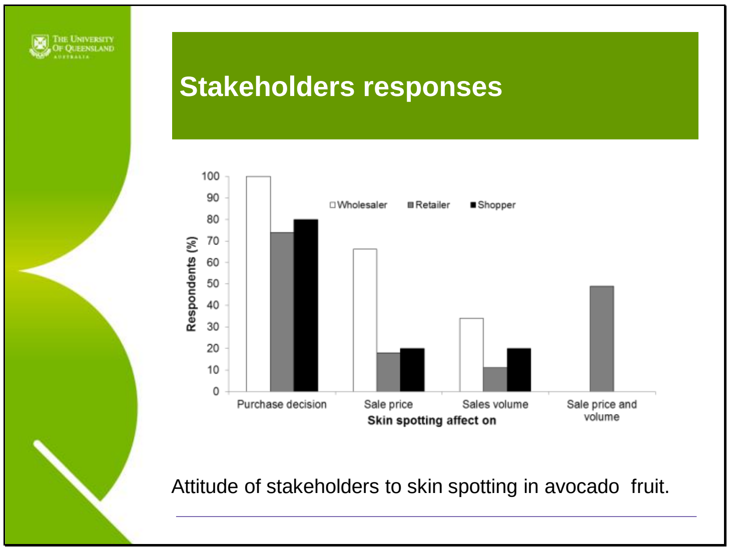
Background

- Retail surveys confirm that consumer's intent to purchase can be significantly affected due to the skin spotting.

- Rejections and discounting by agents, distribution centres, and importers occur due to skin spotting.
- Not only the prices, but also the sales quantities are affected due to the skin spotting.

Harker et al. (2010)

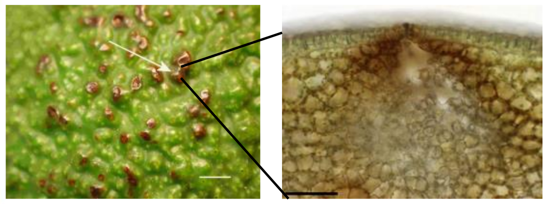
Slide 5



Slide 6

Slide 7

Skin spotting

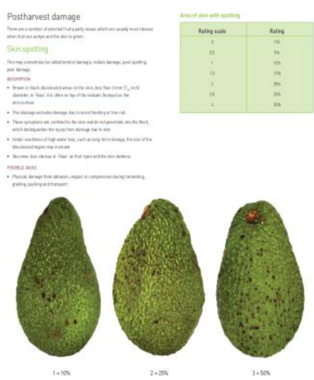


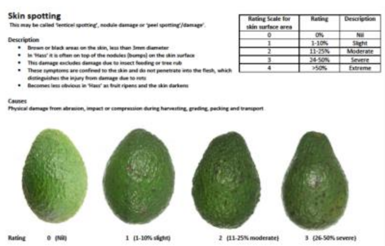
Symptoms of skin spotting on unripe ‘Hass’ avocado fruit after 24 h at 5.5 °C. Arrow shows area of diffuse browning characteristic of lenticel damage

Everett et al., 2008

Slide 8

Skin spotting rating scale





Skin spotting

This may be called 'lenticel spotting', nodule damage or 'peel spotting'/damage'.

Description

- Brown or black areas on the skin, less than 3mm diameter
- In 'Hass' it is often on top of the nodules (bumps) on the skin surface
- This damage excludes damage due to insect feeding or tree rub
- These symptoms are confined to the skin and do not penetrate into the flesh, which distinguishes the injury from damage due to rots
- Becomes less obvious in 'Hass' as fruit ripens and the skin darkens

Rating Scale for skin surface area	Rating	Description
0	0%	Nil
1	1-10%	Slight
2	11-25%	Moderate
3	24-50%	Severe
4	>50%	Extreme

Causes

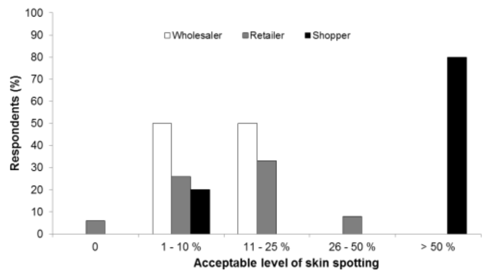
Physical damage from abrasion, impact or compression during harvesting, grading, packing and transport

Rating 0 (Nil) 1 (1-10% slight) 2 (11-25% moderate) 3 (26-50% severe)

White et al., 1999

Slide 9

Stakeholders responses



Acceptance of different levels of skin spotting.

Slide 10

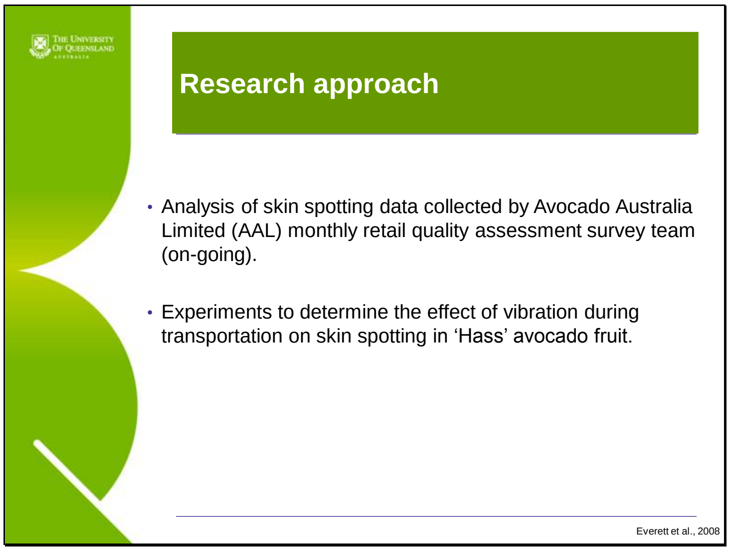
Research problem

The issues …

- Extent of skin spotting in 'Hass' avocado fruit across the Australian markets is not fully explored / reported.
- Factors contributing to skin spotting on 'Hass' avocado fruit are not fully explored.

Everett et al., 2008

Slide 11



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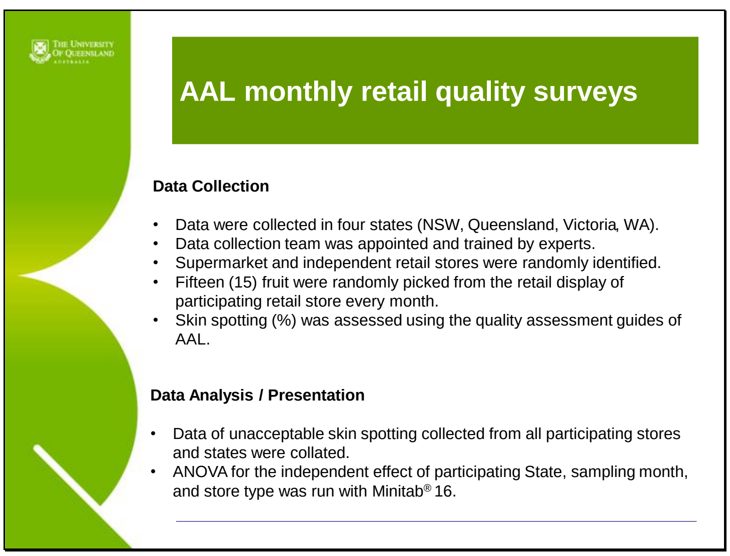
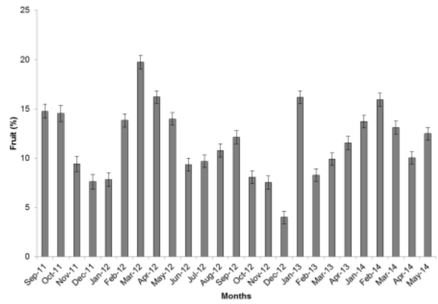


Slide 13

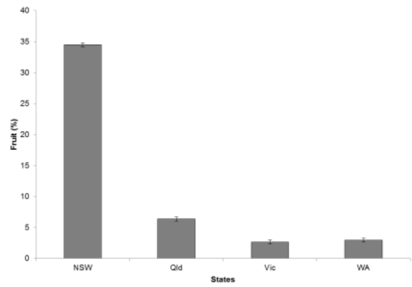
Distribution of skin spotting



Distribution of fruit with skin spotting >25 %
through the months of a calendar year.

Slide 14

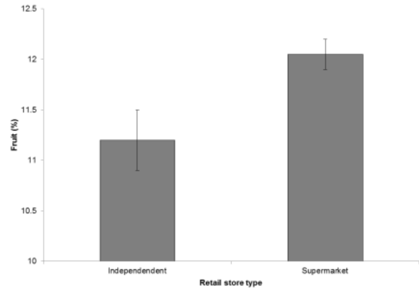
Distribution of skin spotting



Distribution of fruit with skin spotting >25 %
in Australian States - New South Wales, Queensland,
Victoria, and Western Australia.

Slide 15

Distribution of skin spotting



Distribution of fruit with skin spotting >25 %
in independent and supermarket retail stores.

Slide 16

Effect of vibration on skin spotting

Experiment 1:
T1: ~6 Hz, 330 rpm for 4 h
T2: ~6 Hz, 330 rpm for 15 h
T3: Control

Experiment 2:
T1: ~12 Hz, 330 rpm for 4 h
T2: ~12 Hz, 330 rpm for 15 h
T3: Control

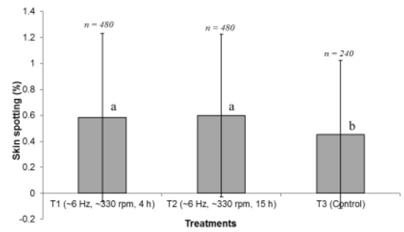
Fruit trays *n* = 4 (T1 & T2) and 2 (T3)

Vibration table

Post treatment fruit held at 20° C.
Skin spotting assessment following the AAL assessment guide was conducted on alternate days until fruit was ripe.

Slide 17

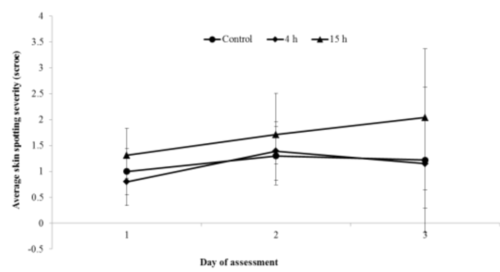
Effect of vibration on skin spotting



Vibration of fruit affects the incidence of skin spotting in 'Hass' avocado fruit (*n* = 480 in T1 and T2 and *n* = 240 in T3) given vibration treatments and the control.

Slide 18

Effect of vibration on skin spotting



Average skin spotting severity rating over the assessment period of 4 days. D 1 = day 0, D 2 = day 2, D 3 = day 4.

Slide 19

Key findings

- Stakeholders have mixed responses due to its non uniform prevalence. However, it is largely unaccepted at levels > 25 % of fruit surface.
- Skin spotting does not have a uniform pattern. Its extent and severity changes with time of the year, sampling location and store type.
- Vibration of fruit during transportation can be a potential reason of skin spotting at the wholesale point onwards.
- Further experiments are suggested to fully understand the problem, its causes and management.

Slide 20

Acknowledgements

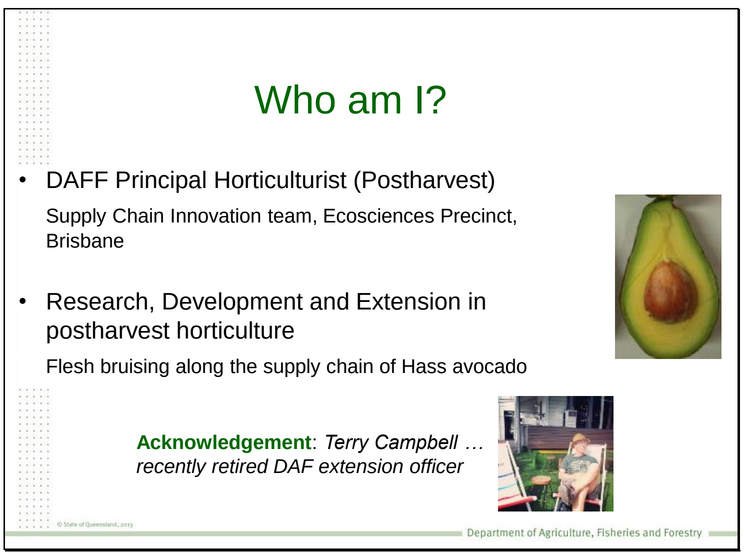
- **Research supervisors**
- **Horticulture Australia Limited***
- **Avocados Australia Limited**
- **Grower (Balmoral Orchard)**
- **Ripener (Murray Brothers)**
- **Retailers (Coles, Woolworths)**
- **UQ & QDAFF staff**
- **Co-workers** (Hunter, Lauren)

*This research has been conducted as part of the project AV10019 - Reducing Flesh Bruising and Skin Spotting in 'Hass' Avocado, which is funded by Horticulture Australia Limited (HAL) using the Avocado Industry levy and matched funds from the Australian Government.

Appendix K: Minimising risks to avocado quality by handling and temperature control

Slide 1

Slide 2



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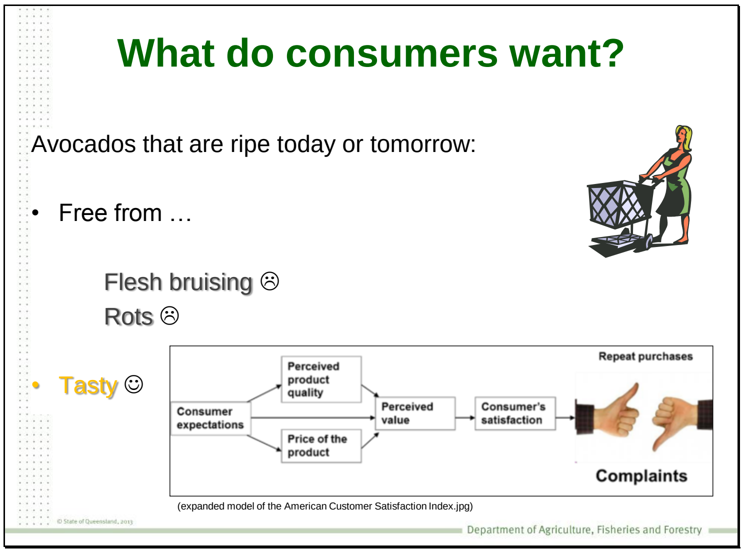

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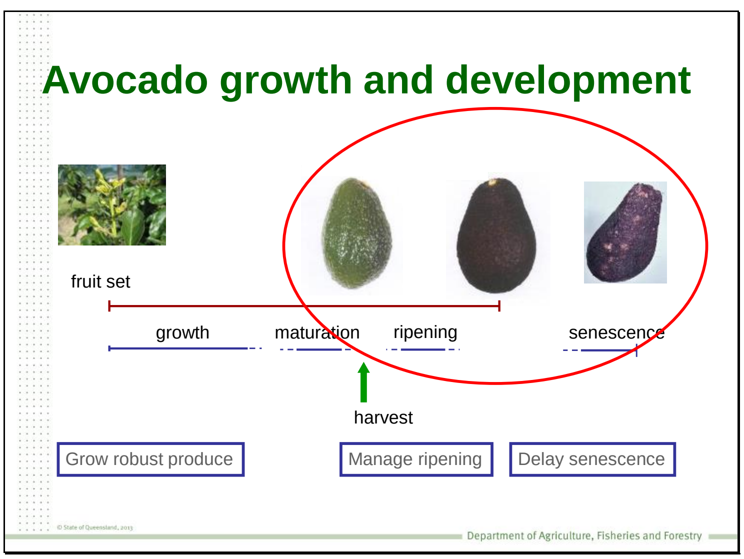

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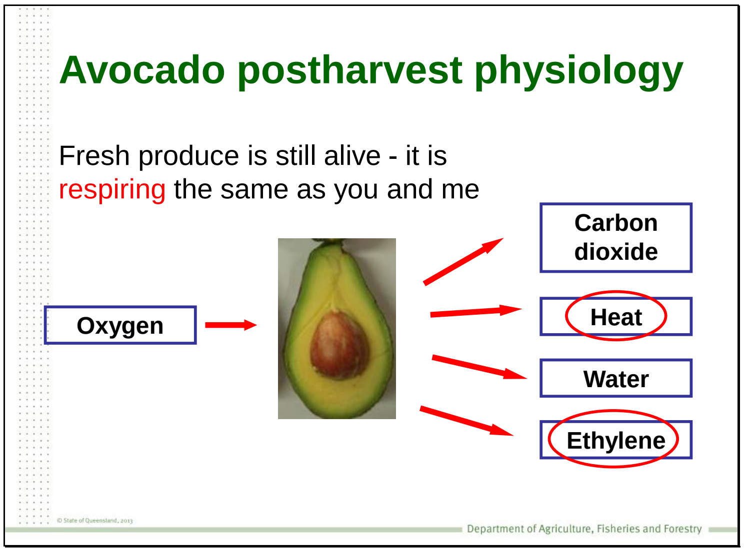

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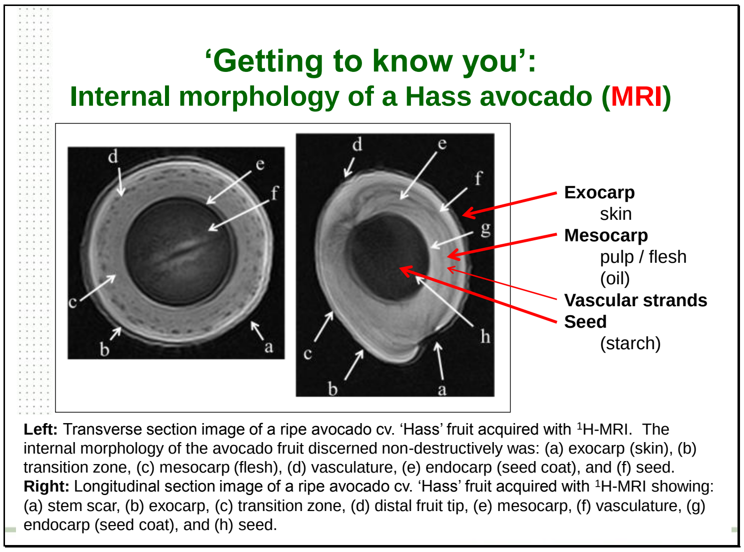

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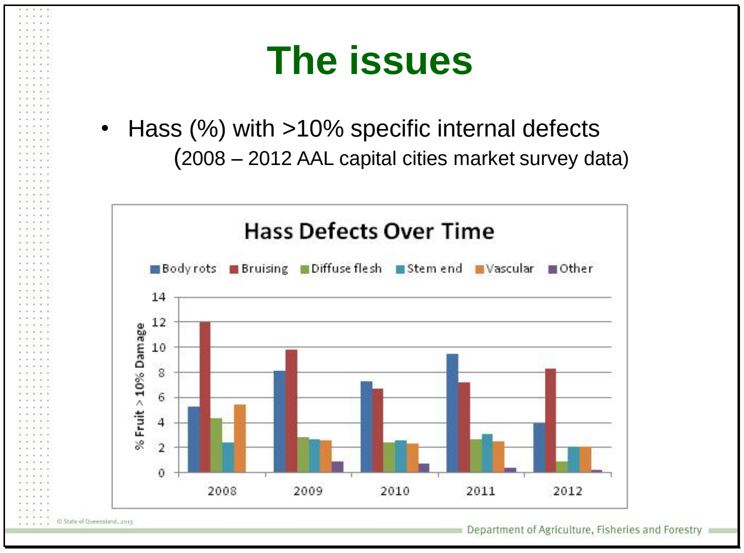

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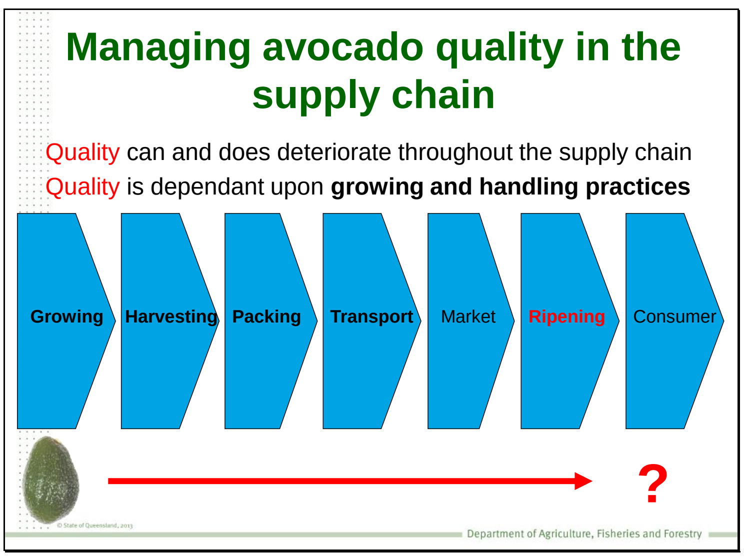

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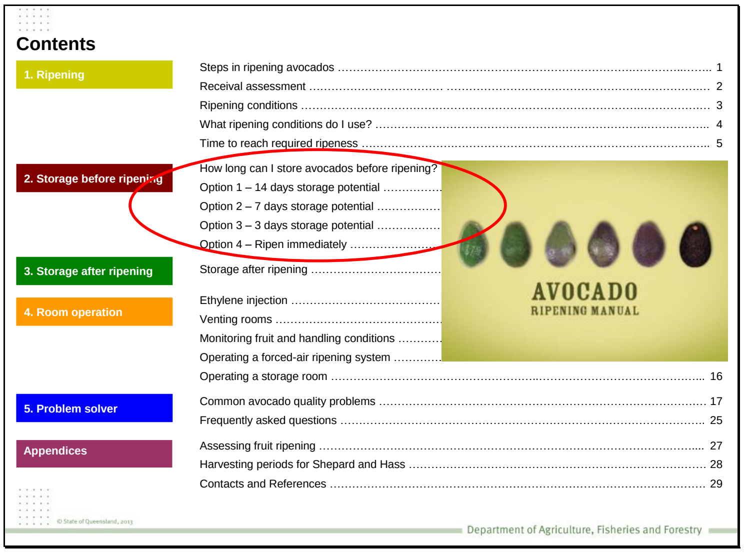

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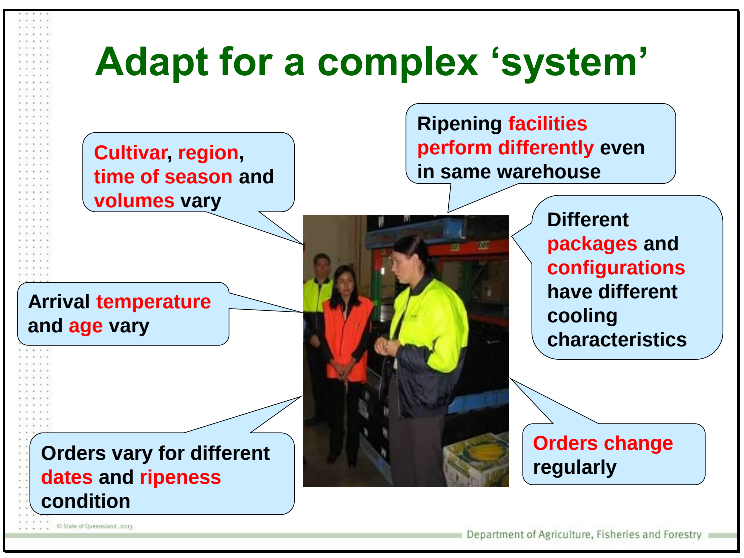


Slide 11

Problems are compounded throughout the chain and co-operation of all members is needed to solve them

Monitoring tools available and used for managing fruit quality

Information and training is needed continuously to maintain and improve chain performance

Slide 12

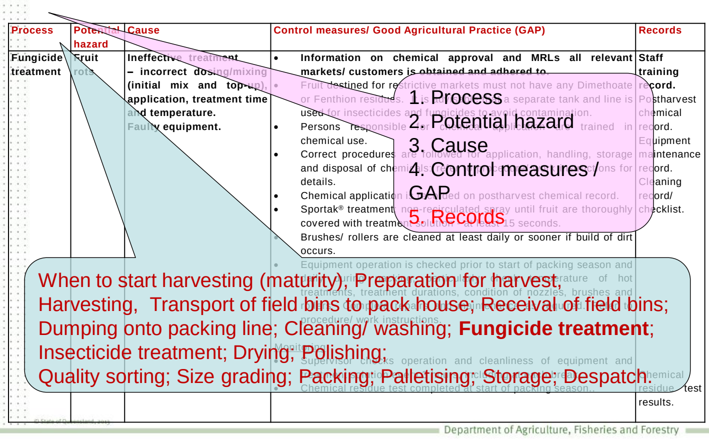
Spreading the word

- National extension program
- Improved information products
- Regional workshops, one-on-one system health checks, self-assessments

Qualicado

Slide 13

Avocado hazard analysis



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Slide 14

Controls (GAP) in the packing house

Small Operations	Medium Operations	Large Operations
Dry matter testing of fruit at receival	Dry matter testing throughout the first 6 weeks of packing	Detailed feedback on ripening performance of each block using retention samples
Postharvest fungicide, pH adjusted	Machine improvements/design to remove impacts equivalent to greater than 100 mm drop	Staff training using AAL on-line packages
Fruit probed at dispatch, transport temperature achieved within 48 hours of receival	Pre-cooling processes driven by temperature data for each cool room, pallet position, and room load	Pre-cooling and transport processes driven by temperature logging data
	Improved communication in the chain	

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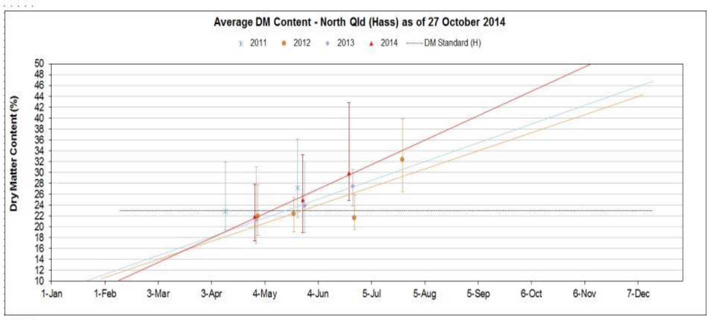
Foci in this particular presentation

Small Operations	Medium Operations	Large Operations
Dry matter testing of fruit at receival (1)	Dry matter testing throughout first 6 weeks of packing	Detailed feedback on ripening performance of each block using retention samples
Postharvest fungicide, pH adjusted (2)	Machine improvements/design to remove impacts equivalent to greater than 100 mm drop (4)	Staff training using AAL on-line packages (5)
Fruit probed at dispatch, transport temperature achieved within 48 hours of receival	Pre-cooling processes driven by temperature data for each cool room, pallet position, and room load (3)	Pre-cooling and transport processes driven by temperature logging data
	Improved communication in the chain	

Slide 16

1. Dry matter testing at receival



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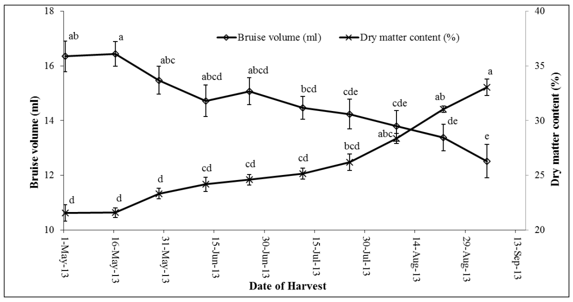
Dry matter content:
Effect of on bruise severity



- Bruise severity decreased as the dry matter content increased through the harvest period season.

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2. Post harvest fungicide, pH adjusted

Disease Control with Sportak®

'Improving yield and quality in avocado through disease management'

Dr Elizabeth Dann, DAF, Project Number: AV07000

Department of Agriculture, Fisheries and Forestry

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According to AV07000 …

… using prochloraz as a postharvest dip increased the ‘marketability’ of fruit by …

- **2.0-fold** for Shepard with high disease pressure (*31.0% marketable*)
- **1.4-fold** for Hass with low disease pressure (*55.5% marketable*)
- **2.2-fold** for Hass with high disease pressure (*25.5 % marketable*)

… as compared with untreated (water only) controls

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Moreover, according to Diczbalis et al.

- In far north Queensland (2011), prochloraz dip and spray concentrations were examined for postharvest treatments
- Packing shed use of Sportak® varied with recycled and stored solutions showing a depletion of the active ingredient
- Prochloraz concentration in solution was highly pH-dependent, with nominal solution values only being measured when the pH was < 3.0

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Diczbalis et al.

Sportak® treatments (ml/100L)	Nominal prochloraz concentration (mg/L)	Prochloraz concentration (mg/L)	pH
20	90.0	34.7	6.63
40	180.0	41.7	6.46
55	247.5	33.3	6.33
55 + HCl	**247.5**	**269.3**	**1.53**
70	315.0	51.3	5.3

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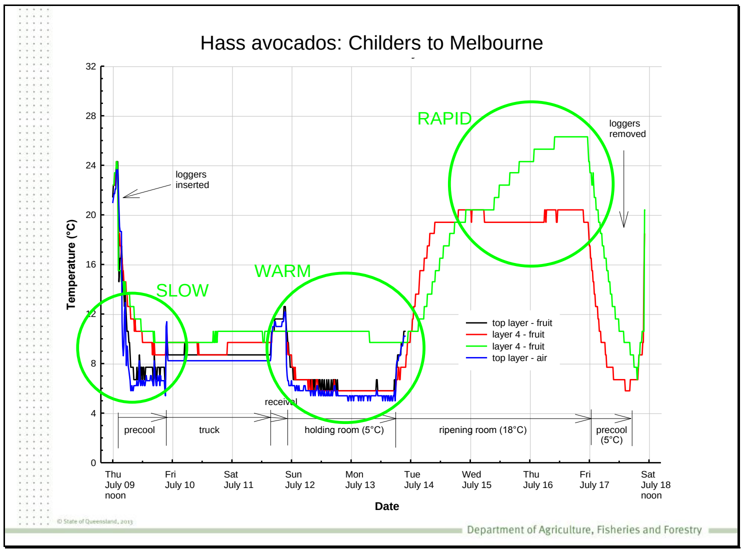
3. Pre-cooling

Pre-cooling process operations are best driven by knowledge of temperatures for each of the …

- **specific cool room**
- **pallet position in the room**
- **room fruit load**

Slide 23



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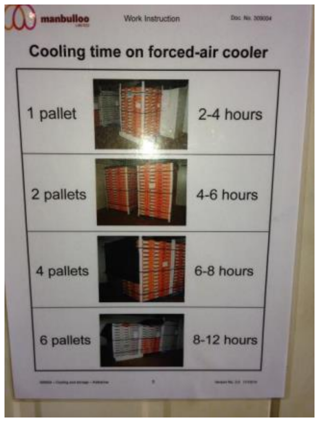
Slide 25

Room load affects pre-cooling time



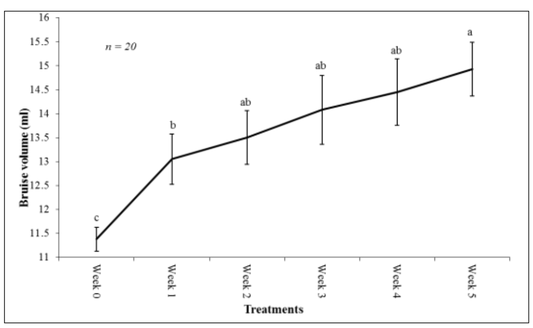
1.7 times longer

2.3 times longer

3.2 times longer

Slide 26

Pre-ripening holding duration:
Effect on bruise volumes



- Bruise severity increased with longer storage duration

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4. Machine improvements / design

Types of mechanical (physcial) injury …

- Abrasion … e.g. scuffing, vibration
- Impact … e.g. drop, collision
- Compression … e.g. squashing, squeezing

Effects …

- Skin spotting
- Flesh bruising, including cracking

General aim in packhouse re bruising

- **Remove impacts** equivalent to >100 mm (10 cm) drops

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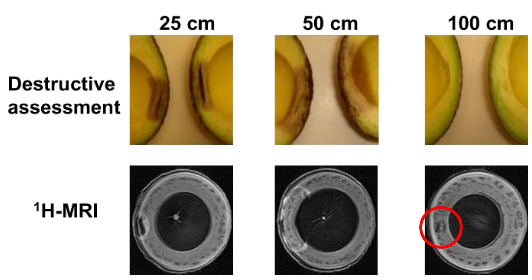
Bruising in 'Hass' avocado fruit



- Firm ripe fruit dropped from 25 cm (LHS) and 50 cm (centre)
- **Hard green mature fruit (*n*=1) dropped from 100 cm (RHS)**
- Bruising assessed at 48 h

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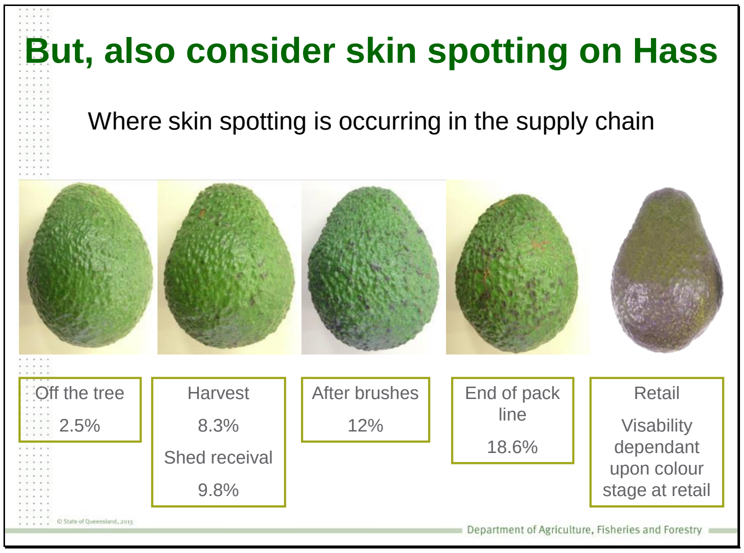
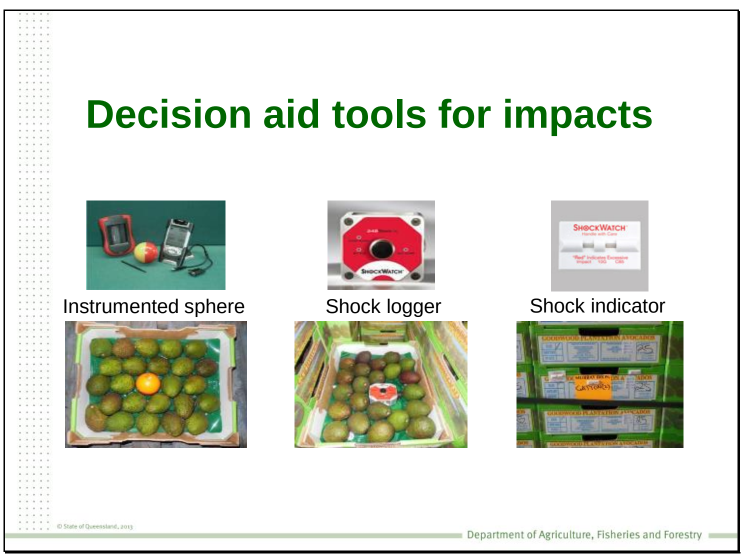
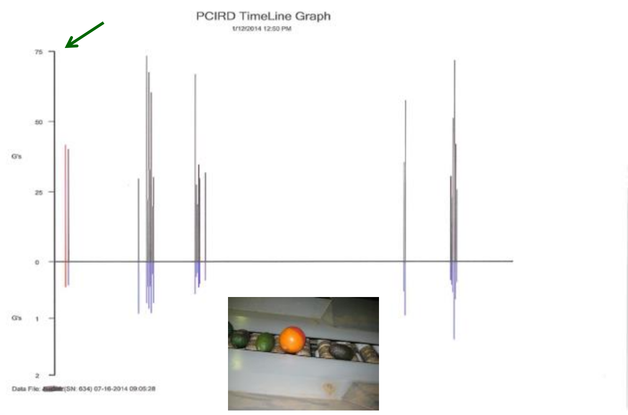


Slide 30



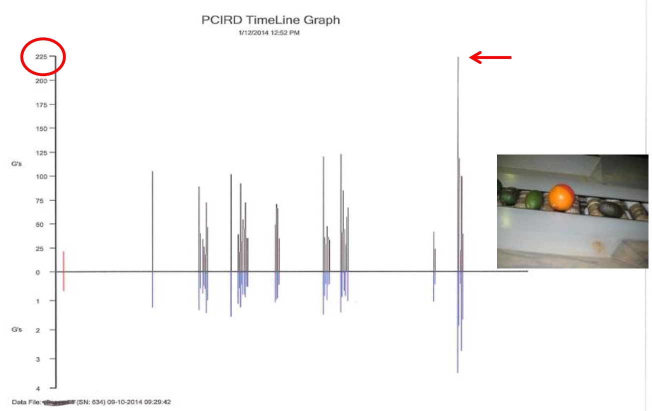
Slide 31

Instrumented sphere packing line data



Slide 32

Problematic rough points?



Slide 33

Problematic drop point?

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Slide 34

Dealing with ‘rough’ points

- Cushion ‘bare’ surfaces
  - Use padding, chutes, flaps, etc.
- Replace worn cushioning
  - Regular maintenance
- Minimise elevation changes
  - Across belts, rollers, brushes, etc.
- Unify fruit flow rates
  - Avoid packing line width changes

http://www.shockinglydelicious.com/california-avocados-packing-and-ready-for-retail/

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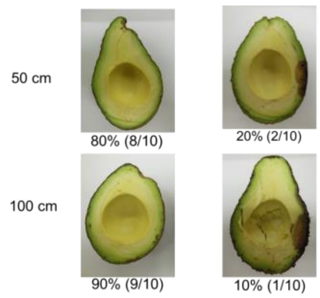
Slide 35

Is decay a consequence of impact of hard green mature fruit?

Assessment on day 10 from impacting hard green mature fruit at 50 and 100 cm drop heights



- No evidence of visible bruising
- However, pathogen infection initiated on some fruit from day 7

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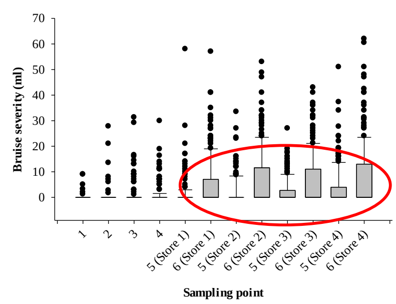
Slide 36

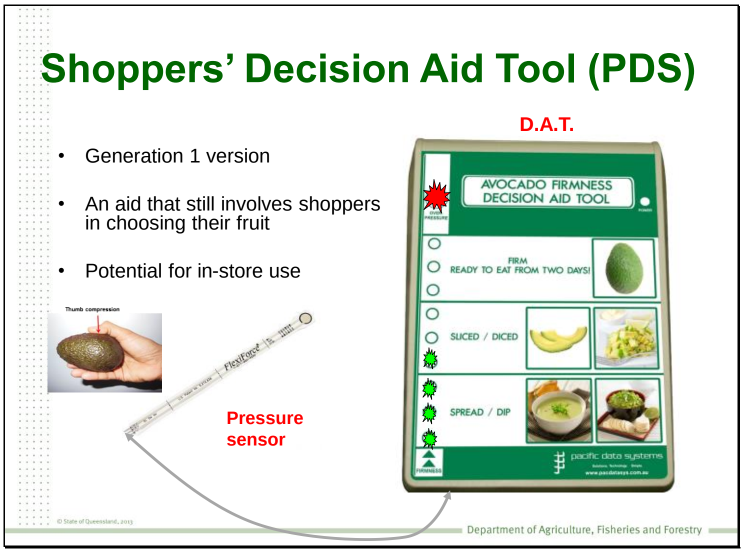
Thru. the supply chain bruise severity



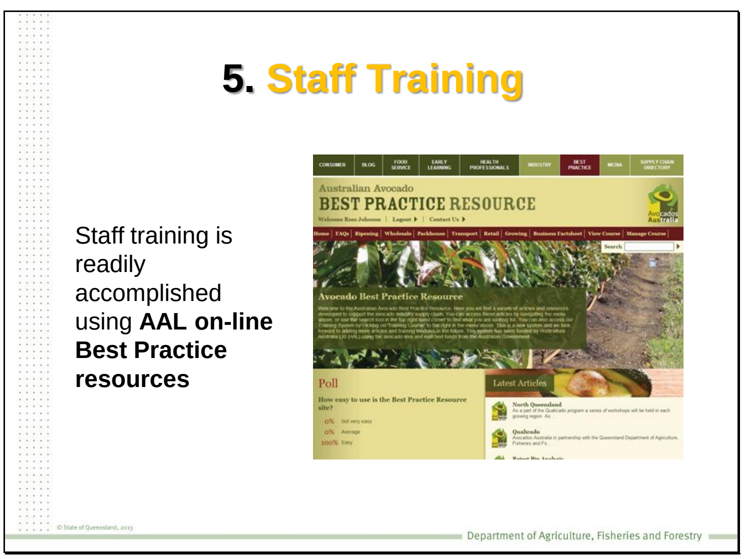
Boxplots of bruising severity in avocado fruit sampled from 6 serial sampling points of 2 supermarket chains and subjected to destructive bruise assessment.

1 = ripener arrival, 2 = ripener dispatch, 3 = distribution center arrival, 4 = distribution center dispatch, 5 = retail store arrival, 6 = retail store dispatch.

Slide 37



Slide 38



Slide 39

Train, train, train … *ad infinitum*

Pickers guide …

- Listen
- Check
- Empty
- Check
- Protect
- Collect
- Drive

Don't drop!

Slide 40

Packhouse guide …

Maturity, Pre-cooling, Storage, Ripening … and, be gentle

Slide 41

Transport guide …

Fruit pre-cooled?

Trays stacked properly?

Pallets secured properly?

Truck checks …

- Refrigeration working?
- Clean and hygenic?
- Load stablisation needs?
- Compatible produce?

Consignment note?

Slide 42

Key 'take home' messages …

1. Dry matter testing of fruit at receival	Dry matter testing throughout first 6 weeks of packing	Detailed feedback on ripening performance of each block using retention samples
2. Postharvest fungicide, pH adjusted	4. Machine improvements, design to remove impacts equivalent to greater than [illegible] mm drop	5. Staff training using AAL on-line packages
Fruit probed at dispatch, transport termperature within 48 hours of receival	3. Pre cooling processes driven by temperature data for each cool room and pallet position and room load	Pre cooling and transport processes driven by temperature logging data
	Improved communication in the chain	

CONTINUAL IMPROVEMENT MINDSET

Slide 43

Thank you …

and, please 'ask' and 'suggest'

Daryl Joyce
E-mail: daryl.joyce@daff.qld.gov.au
Mob: 0428 867 804

http://www.weeklytimesnow.com.au/business/focus/peninsula-avocados-at-red-hill-south-go-from-strength-to-strength/story-fnker6cy-1226877089098

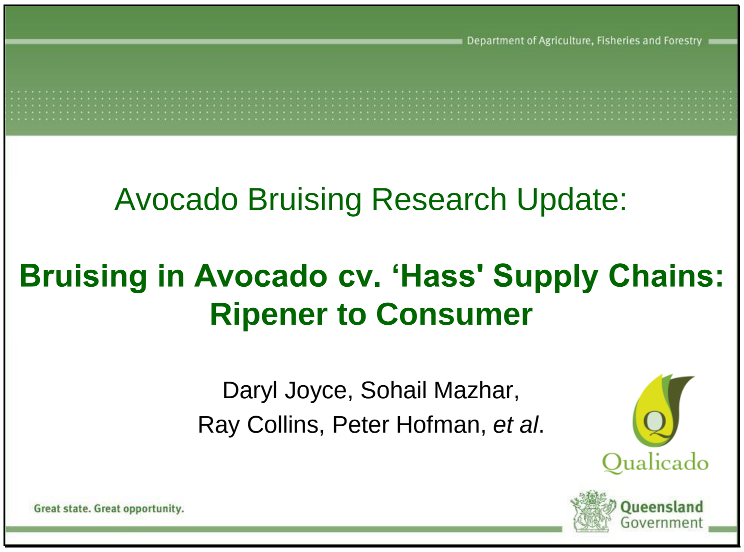
Slide 44

AVOCADOS AUSTRALIA's **Tamborine/Northern Rivers Growers' QUALICADO WORKSHOP**
When & Where: 9.00am start (arrive 8.30am) to 3.30pm, **Thursday 26 March 2015** Host: **Tom & Veronica Silver**
Address: Laurel Park, Wardell Rd, Alstonville NSW
PROGRAM 08.30am Complimentary coffee and tea on arrival
09.00am Welcome by Nathan Symonds, Avocados Australia
09.10am **Supply Chain Program Overview** – John Tyas, Avocados Australia
09.30am **Best Practice Resource Overview** – Nathan Symonds, Avocados Australia
09.45am **Grower Self Assessments** – Nathan Symonds, Avocados Australia
10.20am Morning Tea (25mins)
10.45am **Nutrition for Healthy Avocados** – Simon Newett, QDAF
11.30am **Maximising Profit in Avocados** – Howard Hall, CDI Pinnacle Management
12.15pm Lunch (45mins)
01.00pm **Implementation of ICA-30 Protocol** – Kathy Goulding, NSW DPI
01.20am **Handling and Temperature Control** – Daryl Joyce, QDAF
02.05pm **Understanding Infocado** – John Tyas, Avocados Australia
02.30pm **Orchard Walk** – with Tom Silver
- Nutrition & Irrigation In-Field – Simon Newett, QDAF
03.00pm Wrap Up & Evaluations – Nathan Symonds, Avocados Australia
03.10pm Finish
Note: This program may be subject to change. **Growers:** Please wear clean shoes when visiting the orchard to help us meet recommended orchard biosecurity measures. Don't forget a hat and please also advise us if you have any special dietary requirements. **Contact:** For more information or to RSVP contact **Nathan Symonds**, Supply Chain Program Manager, Avocados Australia on mobile 0458 004 198 or call 07 3846 6566, supplychain@avocado.org.au.
Location Map & Directions:
Venue: Packing shed at Laurel Park, Wardell Rd, Alstonville NSW
Directions from Brisbane:
- Follow Pacific Motorway to Bruxner Hwy/B60 in West Ballina. Exit from Pacific Hwy - 1 h 52 min (182 km)
- Continue on Bruxner Hwy/B60. Drive to Wardell Rd in Alstonville - 10 min (10.2 km)

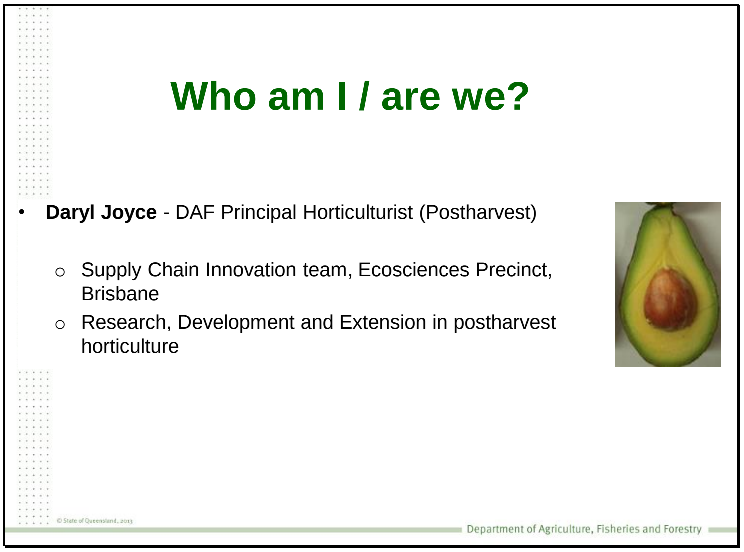
Acknowledgements: This project has been funded by Horticulture Innovation Australia Limited using the Avocado Industry levy and funds from the Australian Government. Avocados Australia would also like to acknowledge the financial support from the following Qualicado Program sponsor:
For more information about Barmac see their website: www.barmac.com.au

Appendix L: Bruising in avocado cv. 'Hass' supply chains: Ripener to consumer

Slide 1



Slide 2

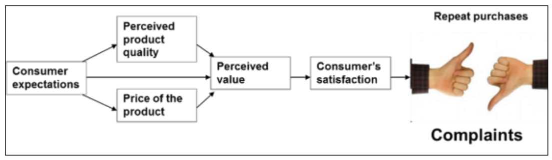


Slide 3

What do consumers want?

Avocados that are *ripe today or tomorrow*:

- Free from …
  - Flesh bruising
  - Rots
- Tasty

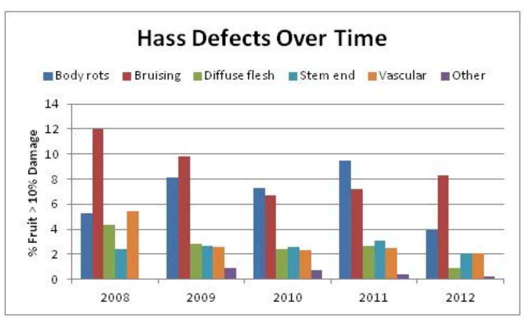


(expanded model of the American Customer Satisfaction Index.jpg)

Slide 4

The issues

- Hass (%) with >10% specific internal defects
  (2008 – 2012 AAL capital cities market survey data)



Slide 5

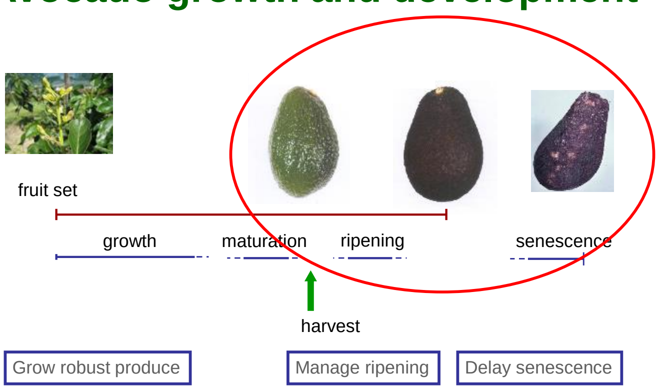
The research problem

The issue … "*Up to 80% of 'Hass' avocados on the retail shelf have defects in the flesh which affect the consumers' intent to repeat purchase*"

… '*Incidence of bruising at' and 'contribution of' each stage in the supply chain is unknown*

Slide 6

Avocado growth and development



Slide 7

Avocado hand firmness guide

(White et al. 2009)

0	**Hard, no 'give' in the fruit**
1	Rubbery, slight 'give' in the fruit
2	Sprung, can feel the flesh deform by 2-3 mm (1/10 inches) under extreme thumb force
3	**Softening, can feel the flesh deform by 2-3 mm (1/10 inches) with moderate thumb pressure**
4	**Firm-ripe, 2-3 mm (1/10 inches) deformation achieved with slight thumb pressure. Whole fruit deforms with extreme hand pressure**
5	**Soft-ripe, whole fruit deforms with moderate hand pressure**
6	Overripe, whole fruit deforms with slight hand pressure
7	Very overripe, flesh feels almost liquid

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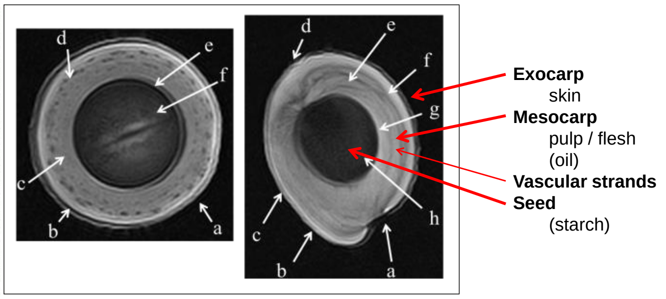
Slide 8

'Getting to know you': Internal morphology of a Hass avocado (MRI)



Left: Transverse section image of a ripe avocado cv. 'Hass' fruit acquired with ^{1}H-MRI. The internal morphology of the avocado fruit discerned non-destructively was: (a) exocarp (skin), (b) transition zone, (c) mesocarp (flesh), (d) vasculature, (e) endocarp (seed coat), and (f) seed. **Right:** Longitudinal section image of a ripe avocado cv. 'Hass' fruit acquired with ^{1}H-MRI showing: (a) stem scar, (b) exocarp, (c) transition zone, (d) distal fruit tip, (e) mesocarp, (f) vasculature, (g) endocarp (seed coat), and (h) seed.

Slide 9

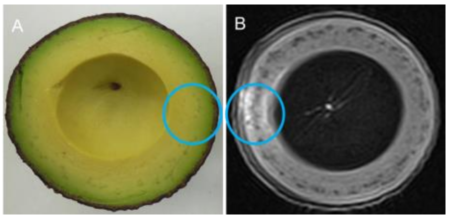
Bruising mechanism

1. Impact and compression forces
2. Stress and strain of cells and tissues
3. Resultant mechanical injury of cells and tissues
4. Altered cellular physiology
   - Mixing of enzymes (e.g. PPO) and substrates (e.g. phenolics)
5. Expression as browning of bruised regions

Mishra and Gamage (2007), Golacki et al. (2009), http://assoc.garden.org/onlinecourse/PartI6.htm

Slide 10

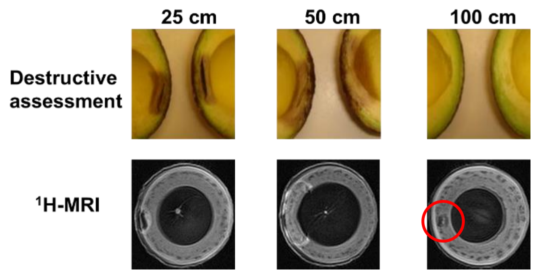
Impact energy dissipation



A: Image of a transverse destructive cross section through a firm ripe avocado cv. 'Hass' fruit impacted from 50 cm drop height (0.81 J energy absorbed). The impacted fruit mesocarp marked with a circle was not visually distinguishable from the non-impacted flesh immediately after impact. **B:** T_2 weighted ^{1}H-MRI image of a firm ripe avocado cv. 'Hass' fruit impacted from 50 cm drop height (0.81 J energy absorbed). The impact site, marked with a circle, was non-destructively visualised immediately after impact and the impacted mesocarp appeared hyperintense as compared with the surrounding mesocarp.

Slide 11

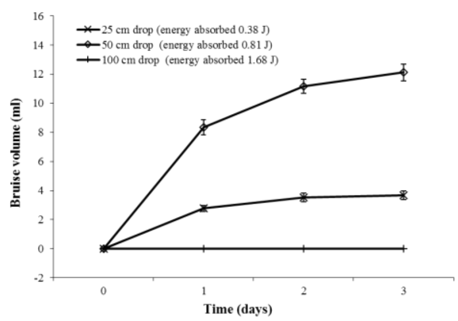
Bruise development in avocado fruit



- Firm ripe fruit dropped from 25 cm (LHS) and 50 cm (centre)
- **Hard green mature fruit (*n*=1) dropped from 100 cm (RHS)**
- Bruising assessed at 48 h

Slide 12

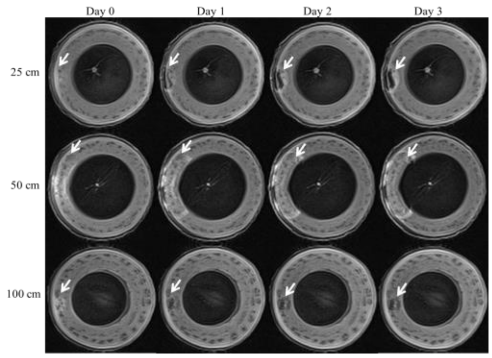
Destructive assessment:
Bruising severity over time



Firm ripe fruit (*n*=2) dropped from 25 cm and 50 cm; hard fruit (*n*=1) dropped from 100 cm.

Slide 13

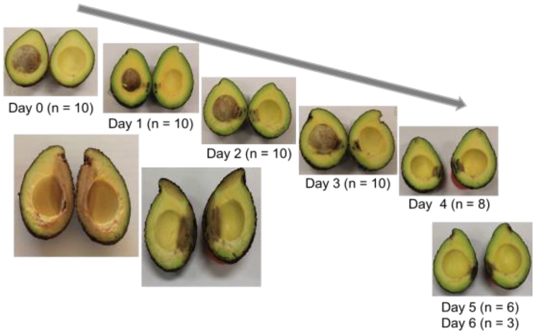
Bruising increase over time



Firm ripe fruit (n = 2) dropped from 25 cm and 50 cm; hard fruit (n = 1) dropped from 100 cm.

Slide 14

Bruise expression in fruit



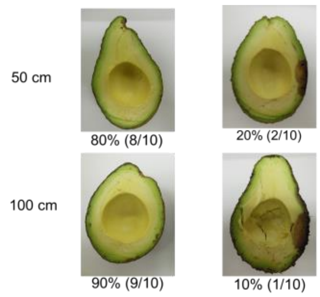
Bruise volume increased over time at room temperature (20ºC) in fruit (n = 10) having absorbed 0.85 J energy at the firm ripe stage.

Pathogen infection appeared on the fruit from day 4.

Slide 15

Is decay a consequence of impact of hard green mature fruit?

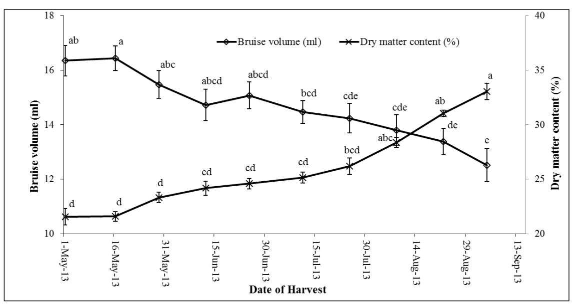
Assessment on day 10 from impacting hard green mature fruit at 50 and 100 cm drop heights



- No evidence of visible bruising
- However, pathogen infection initiated on some fruit from day 7

Slide 16

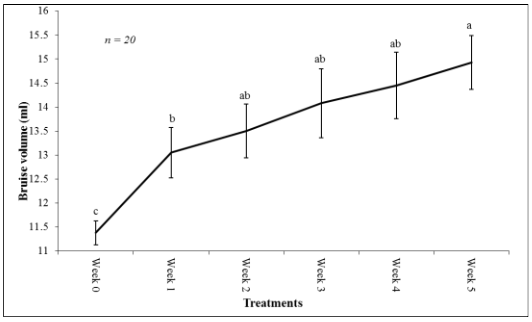
Dry matter content:
Effect on bruise severity



Bruise severity decreased as the dry matter content increased through the harvest period season.

Slide 17

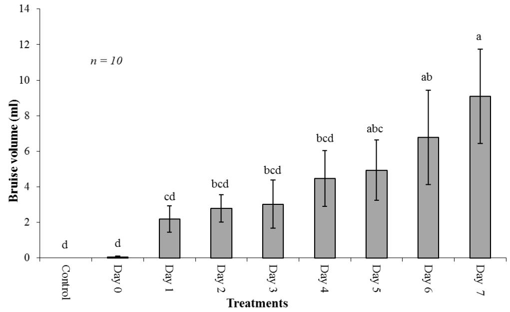
Pre-ripening holding duration:
Effect on bruise severity



Bruise severity increased with longer storage duration.

Slide 18

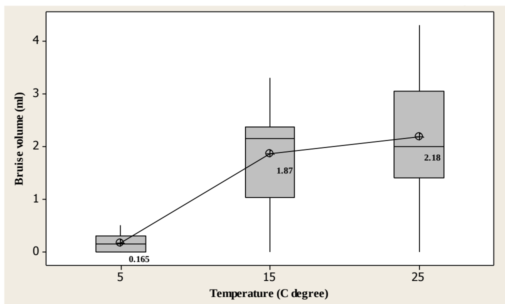
Post-impact holding duration:
Effect on bruise severity



Firm ripe fruit impacted from 50 cm drop height, held at 20ºC, and subjected to destructive bruise assessment daily until day 7 after impact, as compared with a non-impacted control.

Slide 19

Fruit holding temperature:
Effect on bruise severity



Increasing post-impact fruit holding temperature increased bruise severity in impacted avocado fruit

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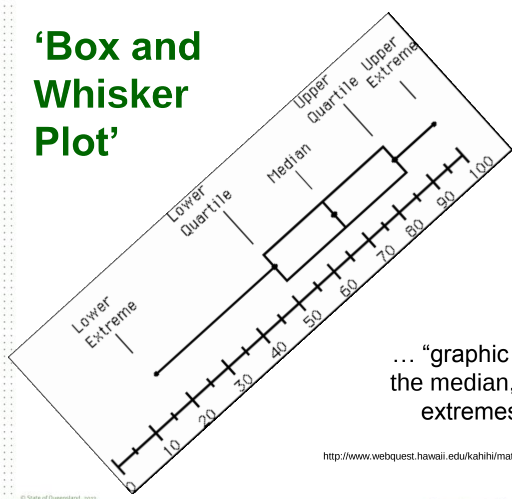
Slide 20

‘Box and Whisker Plot’



… “graphic way to display the median, quartiles, and extremes of a data set”

http://www.webquest.hawaii.edu/kahihi/mathdictionary/B/boxwhiskerplot.php

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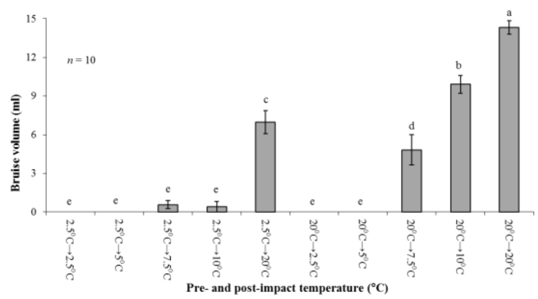
Slide 21

Pre- & post-impact holding temps.:
Effects on bruise severity



Lower fruit holding temperatures, less bruise severity.

Slide 22

Tools for identifying impacts

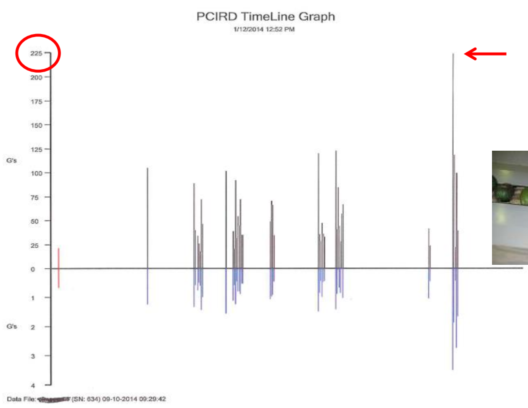
Instrumented sphere

Shock logger

Shock indicator

Slide 23

‘Rough’ points in a packing line



Slide 24

Dealing with ‘rough’ points

- Cushion ‘bare’ surfaces
  - Use padding, chutes, flaps, etc.
- Replace worn cushioning
  - Regular maintenance
- Minimise elevation changes
  - Across belts, rollers, brushes, etc.
- Unify fruit flow rates
  - Avoid packing line width changes

http://www.shockinglydelicious.com/california-avocados-packing-and-ready-for-retail/

Slide 25

Impact of avocado fruit in trays:
Effect on bruise severity

Impact recording device and shock loggers were used in these experiments for their calibration for further use in the supply chain studies.

Fruit trays (n = 3) impacted from different heights and drop angles (2 experiments conducted).

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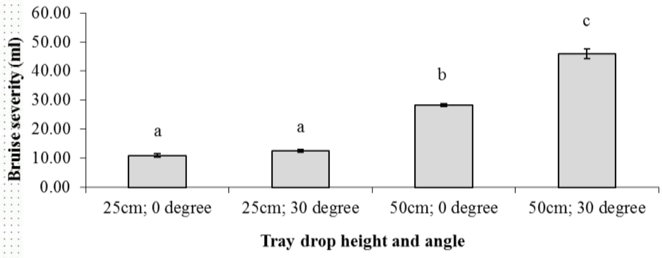
Slide 26

Interaction:
Drop height & angle



At the higher drop height of 50 vs. 25 cm, bruise severity was greater and was a **function of drop angle as well as of drop height.**

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Slide 27

‘Through the supply chain’:
Sampling and assessments

Ripener arrival → Ripener dispatch → DC arrival → DC dispatch → Store arrival → Store display → Store check out

Supply chain sampling and bruise assessment - 2011 and 2012

Store staff study 2013

- Ripener - 1
- Distribution centre (DC) - 2 (major supermarkets)
- Retail stores - 8 (4 for each supermarket)
  - *Store staff*
- **Shoppers**
  - *Consumers*

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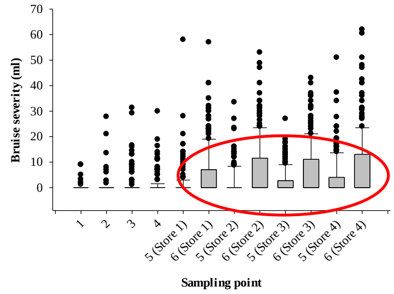
Slide 28

Thru the supply chain bruise severity

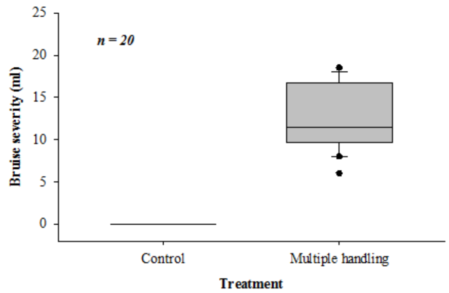


Boxplots of bruising severity in avocado fruit sampled from 6 serial sampling points of 2 supermarket chains and subjected to destructive bruise assessment.

1 = ripener arrival, 2 = ripener dispatch, 3 = distribution center arrival, 4 = distribution center dispatch, 5 = retail store arrival, 6 = retail store dispatch.

Slide 29

Shopper's contributions to bruising:
Handling fruit multiple times



Flesh bruising (ml) in avocado cv. 'Hass' fruit (*n* = 20) each squeezed by shoppers (*n* = 20) compared with control.

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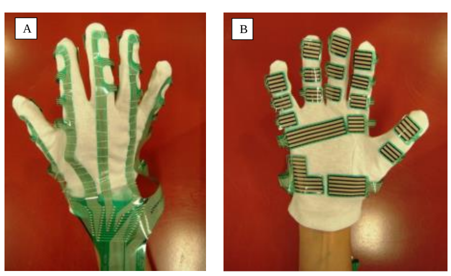
Slide 30

Shopper's selecting fruit



A Grip™ sensor glove was used to measure pressures applied by shoppers to assess avocado fruit firmness. Resultant flesh bruising was quantified.

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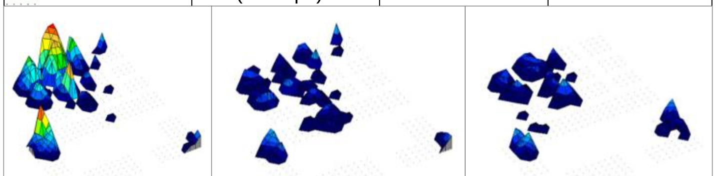
Slide 31

Indicative Tekscan glove data

Participant no.	Individual fruit no.	Bruise volume (ml)	Firmness units (larger value = firmer)
6	10 (Softening)	0	72.7
	57 (Firm ripe)	9	55.3
	149 (Soft ripe)	4	29.9



Softening | Firm ripe | Soft ripe

Slide 32

Shoppers' Decision Aid Tool (PDS)

- Generation 1 version
- An aid that still involves shoppers in choosing their fruit
- Potential for in-store use

Slide 33

'Take home' messages

1. Consumers don't like flesh bruising
2. *Flesh bruising is still a problem in the avocado industry*
3. Green mature fruit are seemingly relatively insensitive to impact bruising
4. *Greater drop heights (impact energy) cause greater bruising*
5. Bruise volumes increase over time after bruising events
6. *Low dry matter fruit are relatively more damaged by bruising*
7. Longer time in the system, both pre-ripening and post-ripening, leads to relatively more damage from bruising events
8. *Lower fruit holding temperatures before and / or after bruising events give relatively less damage*
9. Bruising of green mature and ripening fruit may predispose them to decay
10. *Fruit in dropped trays may be relatively more damaged by fruit-to-fruit collisions*
11. Most fruit bruising (compression energy) occurs at retail store and home levels in the supply chain post-ripener
12. *Decision aid tools are potentially available for store staff and consumers to lessen bruising*

(NB: black font, relatively well established; grey font, more work required)

Slide 34

Thank you

and

please 'ask' and 'suggest'

http://904fitness.com/the-fat-fruit/

http://industry.avocado.org.au/QualityProgram.aspx

Daryl Joyce
E-mail: daryl.joyce@daff.qld.gov.au
Mob: 0428 867 804

Slide 35

Acknowledgements

- Research associates
  - Growers, ripeners, supermarket chains, independent retailers, and consumers
- Co-workers
  - DAF, UQ and PDS staff and students
- Technical advisors
  - Dr. Neil Tuttle, Dr. Ian Brereton, and Dr. Gary Cowin

Horticulture Innovation Australia

Avocados Australia

The University of Queensland Australia

Queensland Government

Australian Government Australian Centre for International Agricultural Research

Slide 36

PROGRAM When: 8.30am (for a 9.00am start) to 11.45am, Thursday 12 March 2015 Where: Sydney Markets Conference Centre, Level 1, 250-318 Parramatta Rd, Sydney Markets **RSVP:** Contact Nathan Symonds on 07 3846 6566 or supplychain@avocado.org.au by Monday 9 March 2014

All avocado wholesalers, ripeners and transporters in the area are invited to attend. The program includes information on ripening practices, avocado bruising and an opportunity to learn more about the Qualicado program.

Purpose of Qualicado:

Through Qualicado, support and monitoring systems are being developed to empower industry members to implement changes and track their progress in improving quality. Qualicado represents a program of continuous improvement for avocado industry members. Growers, packers, wholesalers, ripeners and transporters are encouraged to participate in this system with the overarching goal being to improve quality for the end consumer. For more information about the Qualicado program visit the Avocados Australia website (http://industry.avocado.org.au) and view the Grower Notice.

Proposed Agenda:

08.30am Complimentary coffee and tea on arrival
09.00am Welcome by Nathan Symonds, AAL Program Manager
09.05am **Avocado Supply Chain Program Overview** - John Tyas, CEO AAL (30mins)
09.35am **Best Practice Resource** – Nathan Symonds, AAL Program Manager (20mins)
10.00am **Improving Avocado Ripening Practices** – Daryl Joyce, QDAFF (30mins)
10.30am Break (15mins)
10.45am **Avocado Bruising Research Update** – Daryl Joyce, QDAFF (30mins)
11.15am **Infocado Improvements –** John Tyas CEO AAL (20min)
11.35am Evaluations - Nathan Symonds, AAL Program Manager
11.45am Wrap Up & Finish

Appendix M: Skin spotting survey questionnaires.

A: ‘Hass’ avocado skin spotting survey - <u>Wholesaler</u>

(Note - Please tick the most appropriate answer of each question)

Q. 1. Does skin spotting adversely affect your purchasing of ‘Hass’ avocado fruit from your growers?

Yes No Sometimes (please comment)

Comment:____

Q. 2. How do you feel that skin spotting on ‘Hass’ avocado fruit is likely to affect purchasing by your retail customers?

No effect Reduced quantity

Reduced price Reduced quantity and price

Comment:____

Q. 3. Looking at the ‘Hass’ avocado fruit skin spotting scale provided, what is the minimum acceptable level of skin spotting that you would accept?

0 1 2

3 4

Comment: ____

(Skin spotting scale provided at the end of the retailers’ and shoppers’ questionnaires).

B: 'Hass' avocado skin spotting survey - <u>Retailer</u>

(Note - Please tick the most appropriate answer of each question)

Postcode: ________

Q. 1. If you could directly select your own stock would skin spotting adversely affect your purchasing of 'Hass' avocado fruit?

Yes	No	Sometimes (please comment)

Comment:____

Q. 2. How do you feel that skin spotting on 'Hass' avocado fruit is likely to affect purchasing by your shoppers?

No effect	Reduced quantity
Reduced price	Reduced quantity and price

Comment:____

Q. 3. Looking at the 'Hass' avocado fruit skin spotting scale provided, what is the minimum acceptable level of skin spotting that you would accept?

0	1	2	3

Comment:____

Q. 4. Type or retail store?	Coles	Woolworths	Aldi
	IGA	Independent green grocer	Other

(Skin spotting scale provided at the end of the shoppers' questionnaire below).

C: 'Hass' avocado skin spotting survey - Shopper

(Note - Please tick the most appropriate answer of each question)

Q. 1. Does skin spotting adversely affect your purchasing of 'Hass' avocado fruit from your retail supplier?

Yes No Sometimes (please comment)

Comment:____

Q. 2. How is skin spotting on 'Hass' avocado fruit is likely to affect your purchasing?

No effect Reduced quantity

Reduced price Reduced quantity and price

Comment:____

Q. 3. Looking at the 'Hass' avocado fruit skin spotting scale provided, what is the minimum acceptable level of skin spotting that you would accept?

0 1 2 3 4

Comment:____

Q. 4. What do you think causes skin spotting on 'Hass' avocado fruit?

Suggestion…

____

(Skin spotting scale provided below).

Skin spotting

This may be called 'lenticel spotting', nodule damage or 'peel spotting'/damage'.

Rating Scale for skin surface area	Rating	Description
0	0%	Nil
1	1-10%	Slight
2	11-25%	Moderate
3	24-50%	Severe
4	>50%	Extreme

Description

- Brown or black areas on the skin, less than 3mm diameter
- In 'Hass' it is often on top of the nodules (bumps) on the skin surface
- This damage excludes damage due to insect feeding or tree rub
- These symptoms are confined to the skin and do not penetrate into the flesh, which distinguishes the injury from damage due to rots
- Becomes less obvious in 'Hass' as fruit ripens and the skin darkens

Causes

Physical damage from abrasion, impact or compression during harvesting, grading, packing and transport

Rating **0 (Nil)** **1 (1-10% slight)** **2 (11-25% moderate)** **3 (26-50% severe)**