Final Report

Understanding and managing avocado flesh bruising

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The Department of Agriculture and Fisheries (DAF)

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Research Provider: Department of Agriculture and Fisheries

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Summary

The avocado industry in Australia is growing in terms of production, trade and consumption. However, fruit quality on retail display is still not meeting consumers' expectations. Flesh bruising is probably one of the most serious postharvest concerns for the avocado industry. HIA Project AV12009 was commissioned as an extension of the HIA Project AV10019, with the objective of understanding flesh bruising and identifying approaches to manage the bruising.

Flesh bruising is the visible symptom of polyphenol oxidase enzyme activity in damaged flesh cells as a result of mechanical damage to those cells. The impact and compression forces responsible for flesh cell damage in avocado cv. 'Hass' fruit were studied in a series of laboratory experiments. Fruit subjected to impact or compression forces were destructively assessed for flesh bruising at the impact or compression site. Impact forces absorbed by individual avocado fruit were simulated using a swinging arm impact device. Flesh bruising increased with increasing impact energy absorbed by individual fruit, and with decreasing fruit firmness. Impact forces absorbed by avocado fruit in trays were determined using an impact recording device. Increasing tray drop height increased bruise severity. The higher tray drop angle increased bruise severity at the higher drop height of 50 cm, and decreased bruise severity at tray drop heights of 15 cm and 25 cm. Compression forces applied for firmness assessment by shoppers on fruit were simulated using a silicone thumb and strain gauge assembly. Compression forces applied by shoppers were also simulated and measured with a single zone force sensor. It was established that ~ 10 N of force was enough to cause flesh bruising in ripening avocado fruit.

In-store experiments with observations were used to determine the effects of shoppers' fruit handling practices on fruit bruising. Compression forces and pressures applied by shoppers were measured with either a single zone force sensor or a Grip^{TM} multi zone pressure sensor glove, respectively. Each squeezing event by shoppers was found to potentially increase bruise severity in firm and soft ripe avocado fruit.

Consumers' contributions to bruising were assessed by undertaking fruit sampling at the seven serial supply chain points of ripener arrival, ripener dispatch, distribution center arrival,

distribution center dispatch, retail store arrival, retail store display, and consumer's home. These fruit were subjected to destructive bruising assessment, which indicated that bruising increases as the fruit passes through each stage in the supply chain. Bruise severity at the retail store display, and from the consumers' home, was significantly higher than at all preceding sampling points. Also, consumers were given bruise free fruit at the retail store check-out point. These were later collected from the individual consumer's home. Destructive bruise assessment confirmed that the consumers' avocado fruit handling practices between the point of purchase and the point of consumption contributed to bruising in firm ripe avocado fruit.

Avocado fruit supposedly with bruised flesh in the course of normal in supply chain handling as well as with previously controlled impacts were used to determine the effect of flesh bruising on a consumer's level of satisfaction and the decision to repeat purchase. About 18% of consumers were dissatisfied with avocado fruit quality in terms of flesh bruising, and ~ 16% reported that their decisions to repeat purchase avocado fruit were negatively affected by flesh bruising.

This work has shown that the squeezing of fruit on retail display by shoppers is the most critical point for flesh bruising in the supply chain. Accordingly, adopting measures to reduce avocado fruit squeezing by shoppers would greatly help to lessen the incidence and severity of flesh bruising in avocado fruit at the time of consumption. To this end, a prototype decision aid tool was developed to assist avocado fruit shoppers in making their selection decision from the retail display. In conjunction with consumer information and education, this generation one device should be assessed by retailers and shoppers for its utility and acceptance at retail level. The knowledge acquired, and resultant learnings from this project, have and are being extended to industry through print articles in Talking Avocados, talks at conferences and meetings (e.g. Qualicado), and via electronic and social media.

Keywords

Bruise severity, diary notes, e-glove, force sensor, observations, *Persea americana* M., pressure sensor, self-explicated method, squeezing, supply chain.

1. Introduction

The consumer creates economic value in the supply chain by paying for the end product (Sampson and Spring, 2012). The other members of the chain share that value to cover their costs and to realise a profit from creating the value. If a consumer is satisfied with the purchase experience, then repeat purchases are very likely (Mowat and Collins, 2000). Retail surveys of avocado consumers however, have revealed that the consumers are not well satisfied with the quality of avocado fruit purchased from the retail shelf. For example, 40-50% of consumers have reported bad purchase experiences because of poor internal quality due to rots and bruising (Dermody, 1990). Campbell (1993) reported that consumers generally did not receive the value expected against the money they spent on avocados from the retail store. Hofman and Ledger (1999) summarised eight surveys conducted over the period 1993 to 1998 and determined that consumers were dissatisfied overall with the quality of avocado fruit marketed to them. Hofman and Ledger (2001) found that ~ 80% of avocado fruit on display had some degree of internal fruit quality defects and that ~ 25% of the sampled fruit were unusable. Further research suggested that a consumer's intent to repeat purchase avocado cv. 'Hass' fruit is negatively affected with regard to the severity and incidence of flesh defects at the time of consumption (Gamble et al., 2010; Harker et al., 2007). Flesh bruising was often the major cause of flesh discolouration in avocado fruit (Hofman, 2011). Although the extent of flesh bruising in avocado fruit varies over time, it is always a significant concern for the world avocado industry (Symonds, 2013). It was found in HIA Project AV10019 that of the avocado fruit sampled from six serial points of ripener arrival and dispatch, distribution center arrival and dispatch, retail store arrival, and the retail store display, most flesh bruising was evident in 'Hass' fruit sampled from retail store display.

Flesh bruising is the visual manifestation of polyphenol oxidase (PPO) enzyme activity on phenolics in flesh cells that experience damage due to impact and / or compression forces (Mandemaker et al., 2006). The relevant magnitudes of impact and compression forces responsible for causing flesh bruising in avocado fruit were not fully explored.

Avocado shoppers and consumers assess fruit firmness subjectively (Redgwell and Fischer, 2002) by squeezing the fruit with their hands (White et al., 1999). Resistance to squeezing by hand is a consensus technique for assessment of avocado fruit firmness. A reference firmness guide has been developed by White et al. (2009) for industry and consumers. However, squeezing of avocado fruit on retail display by shoppers to assess the degree of fruit ripeness can cause flesh bruising (Ledger, 1994), particularly in soft fruit (Gamble et al., 2010). Nevertheless, the extent of bruising due to shoppers' handling practices on fruit was not carefully explored.

Individual shoppers have different techniques for determining fruit firmness, using different parts of their hands. This variation includes different styles of fruit grip by which to apply different levels of pressure (Gurram et al., 1995). Force sensor (Anonymous, 2013) and pressure sensor (Carrozza et al., 2006) technology is becoming available. With such sensors, the level of force or pressure applied on avocado fruit can be quantified and correlated to the resultant flesh bruising at different stages of fruit firmness (unpublished data). Nonetheless, actual compression forces applied by shoppers during fruit firmness assessment at retail display and the resultant flesh bruising in avocado cv. 'Hass' fruit were not known.

Shoppers may use their thumb, their whole palm, or various combinations of thumb and fingers to assess fruit firmness. In this context, the Grip™ 'electronic glove' system (Tekscan®, 2014) can be employed to assess pressure distribution as applied by different parts of shoppers' hands during assessment of fruit firmness. Stopa et al. (2014) used Tekscan® sensors to evaluate the spread of pressure at the impact site, and the resultant elastic and plastic deformation in apples. However, this technology was not tested to discern hand pressures exerted by shoppers using different parts of their hands when assessing avocado fruit firmness. Similarly, shoppers' preferences for an in-store decision aid tool to help assess fruit firmness were not known.

Previous research conducted with avocado consumers only highlights consumers' preferences and their quality concerns (Gamble et al., 2010; Holman and Wilson, 1982), whereas consumers also constitute important players in supply chains for keeping product quality at the desired level. Consumers may contribute to product quality along with other chain members including growers and farm workers, packhouse management, transport, shipping and airways staff, local or overseas wholesalers, pre-packers, ripeners, and retailers (Gamble et al., 2008; Milne, 1998). Accordingly, they share responsibility for the ultimate product quality at the time of consumption (Campbell et al., 2009). Thus, consumer fruit handling practices between the point of purchase and the point of consumption could also contribute to the ultimate level of flesh bruising in avocado fruit at consumption. Accordingly, the contribution of consumers to causing flesh bruising in 'Hass' avocado fruit needed to be discerned.

Gamble et al. (2010) determined consumer attitudes to flesh bruising following a conjoint approach upon showing photographs of bruised flesh of avocado fruit to consumers. The conjoint method of data collection involves description of the profile of an object, for example pictures of bruising in avocado fruit, to respondents. It has advantages such as ease of use and wide application as compared to the self-explicated method (Acito and Jain, 1980). Because of the results and the range of data acquired, its preference over the self-explicated method has always remained under question (Sattler and Hensel-Börner, 2001). The self-explicated method involves presenting the actual object, for example avocado fruit with bruised flesh, to the respondents. Results produced from the conjoint method are different from self-explicated method (Leigh et al., 1984). The self-explicated method may be considered more accurate, robust, and reliable (Srinivasan and Park, 1997). However consumer attitudes in terms of the level of satisfaction and decision to repeat purchase as affected by flesh bruising, was never confirmed using the self-explicated method.

Given the profound importance to shoppers and consumers of bruising as a negative issue in ripening avocado fruit, surprisingly little has been documented about factors or events modulating bruise incidence and severity at these final points in the supply chain. The current study addressed these gaps by quantifying the contributions of shoppers and consumers to the bruising of ripening avocado cv. 'Hass' fruit. Also, the consumers' levels of satisfaction, and their decisions to repeat purchase as affected by flesh bruising, were determined by collecting consumer responses using a self-explicated approach.

2. Methodology

Relationships of flesh bruising with impact and compression forces were established through a series of laboratory experiments. Contributions of shoppers and consumers to flesh bruising were ascertained through experiments and surveys conducted in the retail stores and consumers' homes.

2.1 General approach

2.1.1 Preparation of fruit samples: Mature hard green stage avocado (*Persea americana M.*) cv. 'Hass' fruit were collected from a ripener in the Brisbane Produce Market, Rocklea, Queensland. These fruit were transported in ~ 1.5 h to a postharvest laboratory (lab) at the Gatton campus of The University of Queensland (UQG). The fruit were dipped for 10 min in a solution of 1000 $\mu L.L^{-1}$ Ethrel® ($480gl^{-1}$ 2-chloroethylphosphonic acid; May & Baker Rural Pty Ltd., Homebush Bay, NSW, Australia) and 0.01% Tween® 40 (polyoxyethylenesorbitan monopalmitate, Sigma-Aldrich Inc., St. Louis, MO, United States) for initiating the fruit ripening process. These fruit were air dried and kept in a darkened shelf life room at 20 °C and 85% RH until they reached the required stage of hand firmness (Table 2.1) (White et al., 2009). Fruit weight was recorded with a digital mass balance (Sartorius GMBH B100S, Dandenong South, Victoria, Australia). The fruit were graded into matched-samples on the basis of visual size, weight, and hand firmness for assignment to the different treatments. Each fruit was labeled using a Pental™ 100 WM white out marker.

2.1.4 Bruise severity measurement: A volume displacement method after Rashidi et al. (2007) was followed for measurement of bruise severity. The bruise-affected flesh of the fruit was excised and submerged into tap water contained in calibrated measuring cylinders of different volumes. The displacement in volume of water was recorded. The volume of any cracks resulting from impact was also taken into account by filling them from a calibrated medical syringe. Where present, the crack volume was added to that of bruised tissue to get the total bruise volume. An indicative relationship of bruise severity in terms of the volume and the percentage of bruised flesh is established. In an average fruit of ~ 250 g, ~ 2 mL of bruise volume equates ~ 1 % of bruised flesh. It depends on fruit size and size of seed in the fruit.

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.

2.1.5 Statistical analysis and graphics: The data were recorded in MS Excel (Microsoft®, North Ryde, Australia) and where applicable, analysis of variance (ANOVA) was run using Minitab® 16 (Minitab® Pty Ltd, Sydney, Australia). Where ANOVA determined significant treatment effects, LSD tests at $P = 0.05$ were applied to distinguish the significance differences amongst treatments. Graphics of the results, averages and standard error (SE) or standard deviation (SD) of lab experiments were constructed with MS Excel. The results of shopper and consumer focused study were presented as boxplots constructed with Sigmaplot® 12 (Systat Software Inc., San Jose, CA, United States). Decision tree analysis was constructed using SPSS® 22 (SPSS, New Delhi, India).

2.1.6 Ethical clearance: Approval from the Ethics Committee of the School of Agriculture and Food Sciences at The University of Queensland was obtained prior to conducting experiments involving shoppers and consumers.

2.2 Impact energy absorbed by individual fruit

Avocado cv. 'Hass' fruit were prepared as described in section 2.1.1 for the softening, firm ripe, and soft ripe stages of hand firmness (White et al., 2009). Fruit weight was recorded and firmness was quantified objectively with an AFM after Macnish et al. (1997).

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 stands for drop height, and h_r stands for rebound height. Each fruit was impacted with a swing arm device (Opara et al., 2007) against a solid metal surface (Fig. 2.1) from treatment specific heights of 25 cm (average energy absorbed ~ 0.38 J), 50 cm (average energy absorbed ~ 0.81 J), or 100 cm (average energy absorbed ~ 1.67 J).

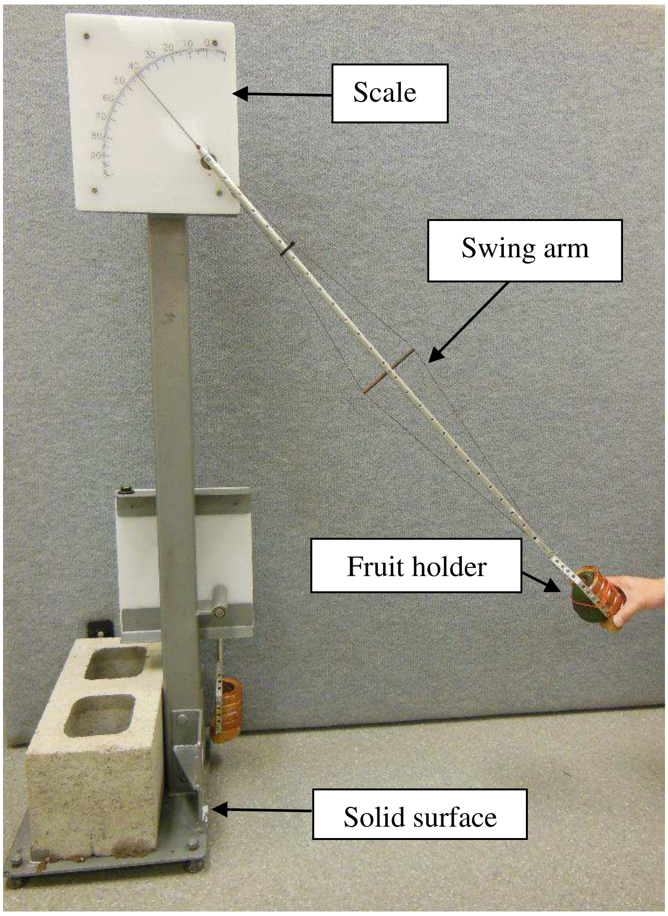

Fig. 2.1 Individual avocado fruit drop equipment. A single fruit was placed in the holder attached at the distal end of the swinging arm. The fruit was raised to the desired drop height for release and free fall onto the solid metal plate surface. The rebound height of fruit was observed against the measuring scale and recorded.

Fruit (*n* = 10) were sorted into matched samples and assigned into 27 treatments based on the fruit firmness stage, energy absorbed by the fruit, and post-impact destructive bruising assessment time. The 27 treatments were the combinations of the stage of ripeness (softening, firm ripe, soft ripe), level of energy absorbed due to drop from 25 cm, 50 cm, and 100 cm (~ 0.38 J, ~ 0.81 J, ~ 1.67 J), and post-impact time of assessment (8 h, 24 h, 48 h).

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 8, 24 and 48 h. Bruise intensity parameters were recorded as described in section 2.1.3. Objective bruise severity as the volume of bruised flesh was determined as described in section 2.1.4.

This experiment was arranged, conducted and analysed as a 3 x 3 x 3 factorial randomised complete block design. The experiment data were subjected to ANOVA using Minitab® 16.

2.3 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. 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 effected with purpose built avocado tray drop equipment. Individual fruit were labeled with a white marker. Firmness of each fruit was objectively measured with an AFM (Macnish et al., 1997). The weight of individual fruit as well as the weight of the tray full of avocado fruit, 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 equipment was designed and manufactured at the School of Agriculture and Food Sciences of UQG (Fig. 2.2). The equipment has a central avocado fruit tray holder which is adjustable to hold fruit tray 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 was adjusted according to the relevant treatment. An avocado fruit tray was then locked with a springs aided clip into the holder adjusted to the required angle. The lever to unlock the springs was then released and the avocado fruit tray allowed to free fall to the ground.

Fig. 2.2 Tray drop setup used for assessment of drop heights and angles effects on bruising in ripening 'Hass' avocado fruit.

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) with PCIRD software (Techmark®, Inc., Lansing, MI, United States) installed. The PCIRD software was used to interface with the device to analyse the stored data and 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 input into the same computer. Impact data sets were acquired for each replication of each treatment.

Post-impact, the fruit trays were held in a darkened shelf life room at 20 °C for 48 h, after which destructive bruising assessment was conducted as per section 2.1.4. The distribution of fruit bruising in individual fruit in each tray was mapped.

This experiment was conducted as a completely randomised block design. Statistical analysis by ANOVA of bruise severity due to tray drop height and angle was conducted with Minitab® 16, as was the data for impacts recorded with the IRD

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.

2.4 Compression force applied to individual fruit by hand

Avocado cv. 'Hass' fruit were ripened to the firm ripe stage of hand firmness (White et al., 2009) as per section 2.1.1. These fruit were then sorted into matched samples for each treatment (n = 3) on the basis of visual size and hand firmness. Weights of individual fruit were recorded and their firmness measured non-destructively with a SIQFT (Howarth and Ioannides, 2002) before compression was applied. Fruit were compressed either manually for qualitative treatments by thumb, or mechanically for quantitative treatments using a strain gauge assembly (Mazhar et al., 2013).

The purpose built strain gauge assembly (Fig. 2.3 A-B) was comprised of a precision machined screw threaded rod to move the fruit forward or backward by manually turning a crank handle, a fruit holder to firmly support a fruit that was half set into Casting Plaster™ (Boral®, Sydney, Australia), an artificial silicone (Condensation Cure Silicone, Polymech®, Dandenong, Australia) thumb moulded around a metal T-piece together representing the flesh and bone of a human thumb, a strain gauge, and a data logger (DT80M, Pacific Data Systems®, Eight Miles Plain, Queensland, Australia) to record the force applied onto the fruit by the silicone thumb (Mazhar et al., 2013).

This experiment consisted of seven treatments: T1 = control (no compression), T2 = slight thumb compression (qualitative, manual), T3 = moderate thumb compression, T4 = firm thumb compression, T5 = 1 kg force applied with the strain gauge assembly (quantitative, mechanical), T6 = 2 kg force applied with the strain gauge assembly, and T7 = 3 kg force applied with the strain gauge assembly. Post-treatment, the fruit were held in a darkened shelf life room at 20 °C. After 48 h from compression, resultant bruise volumes were measured by the water volume displacement method (section 2.1.4).

The experiment was conducted as a completely randomised design. The bruise severity due to compression data were subjected to ANOVA using Minitab® 16.

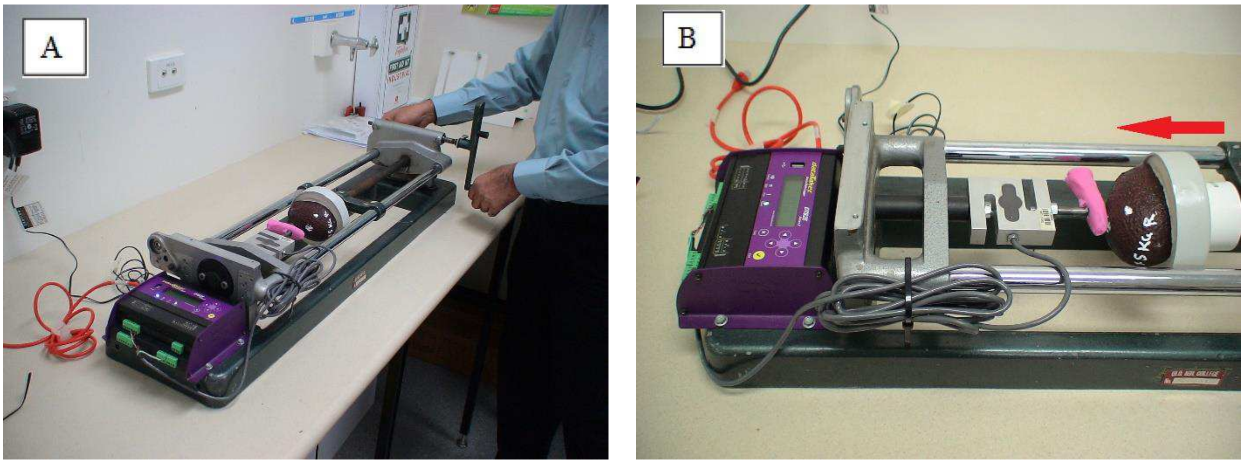

Fig. 2.3 (A) Mechanical compression test assembly comprised of a frame, a fruit holder, a moulded silicone thumb, a strain gauge and a data logger; and, (B) A close-up of the mechanical compression applied via the moulded silicone thumb onto the firm ripe avocado fruit. The red arrow indicates that the avocado fruit in the holder is moved towards the stationary silicone thumb.

2.5 Compression force applied to individual fruit measured with the force sensor

Firm ripe (White et al., 2009) fruit samples were prepared as described in section 2.1.1. The fruit were sorted for matched samples on the basis of visual size and hand firmness, and assigned to relevant treatments. Individual fruit were labeled, weighed, and objectively assessed for firmness with the AFM (Macnish et al., 1997). Fruit (n = 10) were subjected to ~ 20 N force by thumb compression. An equal number of fruit were held as controls. One person conducted all compressions so as to minimise operator variability. To effect measured force application, a single-zone force sensor (FSR 406 Interlink Electronics®, Camarillo, CA, United States) was placed between the fruit and the force applied with the thumb.

The Interlink Electronics® single-zone force sensor FSR 406 (Anonymous, 2013) was connected through a USB port to a computer with supporting software installed to operate the force sensor and record and analyse data. The software was developed at School of Rehabilitation Sciences, Griffith University (Tuttle and Jacuinde, 2011). The software was initiated to run when the force sensor was ready to record data as indicated by a continuous green light on the joint of the force sensor and the USB cable. Data of force applied on each replicate fruit were acquired and saved on the computer drive (Dell Australia Pty Limited, Frenchs Forest, NSW, Australia). The data were recovered in comma separated value (.csv) file format. The highest value of applied compression force on each replicate fruit was recorded.

Compressed and control fruit were then held in a darkened shelf life room at 20 °C for bruising assessments on days 0, 1, 2, 3, and 4. Bruise intensity was measured as described in section 2.1.3 and bruise severity as described in section 2.1.4.

The experiment was conducted in a completely randomised design. Experimental data on bruise intensity and bruise severity were subjected to ANOVA with Minitab® 16.

A repeat of this experiment was conducted with firm ripe and soft ripe (White et al., 2009) fruit, prepared as explained in section 2.1.1. The operating procedure as described for the initial experiment was followed. This repeat experiment was comprised of eight treatments: T1 = firm ripe, control (no compression), T2 = firm ripe, ~ 10 N, T3 = firm ripe, ~ 20 N, T4 = firm ripe, ~ 30 N, T5 = soft ripe, control (no compression), T6 = soft ripe, ~ 10 N, T7 = soft ripe, ~ 20 N and, T8 = soft ripe, ~ 30 N.

2.6 Compression force and resultant deformation in avocado cv. 'Hass' fruit

Avocado cv. 'Hass' fruit were ripened to the firm ripe and soft ripe firmness stages (White et al., 2009) at UQG as described in section 2.1.1. Hard green mature fruit for the experiment were collected from the Brisbane Produce Market on the experiment day. The sample fruit were transported to a lab at the School of Agriculture and Food Sciences UQ, St Lucia campus.

The fruit were sorted as matched samples on the basis of visual size and hand firmness. Fruit were assigned to compression treatments (n = 5 for T1 to T6, n = 3 for T7 to T9): T1 = hard green mature fruit, 1 mm compression, T2 = firm ripe, 1 mm, T3 = soft ripe, 1 mm, T4 = hard green mature, 1.5 mm, T5 = firm ripe, 1.5 mm, and T6 = soft ripe, 1.5 mm, T7 = hard green mature, 3 mm, T8 = firm ripe, 3 mm, and T9 = soft ripe, 3 mm. The fruit were labeled for identification.

Compression tests were performed with a CT3 texture analyser (Brookfield Engineering Labs, Inc. Middleborough, MA, United States). The CT3 texture analyser was connected to a computer (Optiplex 786, Dell® Australia Pty Limited, Frenchs Forest, NSW, Australia) with supporting software (Brookfield Engineering Labs, Inc. Middleborough, MA, United States) installed. Each individual fruit replicate was placed horizontally on the TA-BT-KIT base table fixture. A TA43 spherical probe of 25.4 mm diameter was used to complete one cycle compression test with a load cell loading of 4.5 kg, a pre-test speed of 2 mm/sec, a test speed of 0.5 mm/sec, a return speed of 0.5mm/sec, and a data acquisition rate of 10 points/sec. The probe was pre-set to compress the fruit by 1, 1.5, and / or 3 mm. Based on the literature ((viz., mango (Jha et al., 2010) and squash (Corrigan et al., 2006)), a pre-experiment run was conducted to trial these parameters for avocado cv. 'Hass' fruit. The resistance force of the fruit against the treatment specific compression and probe return was recorded and a system generated portable document format (.pdf) test report was acquired for each individual fruit replicate. The .pdf test report files were converted into Microsoft Excel® sheets for ease of data handling and analyses. The compression depth and plastic deformation data at several stages of fruit firmness was extracted for fruit in each treatment.

After compression, the sample fruit were driven back to UQG and held in a darkened shelf life room at 20 °C for 48 h before their destructive assessment for bruising was conducted (section 2.1.4).

This experiment had nine treatments and each treatment had individual fruit replications, $n = 5$ for T1 to T6, $n = 3$ for T7 to T9. Peak force data as applied by the compression and resultant bruise severity in each treatment were statistically analysed by ANOVA using Minitab® 16.

2.7 Shopper contribution to flesh bruising

2.7.1 Single fruit squeezed by a shopper

Avocado cv. 'Hass' fruit harvested from a commercial orchard in Cabarlah, Queensland were subjected to commercial ripening treatment (Hofman et al., 2001) at a ripening facility in Brisbane Produce Market. These fruit were ripened to firm ripe stage of hand firmness (White et al., 2009) and transported to two participating retail stores for each of the Coles and Woolworths supermarket chains. These retail stores were located in Gatton, Plainland, Toowong, and Mount Ommaney in Queensland. The experiment was conducted once a week for four weeks in July 2013.

Firm ripe fruit ($n = 100$), ripened and handled with extreme care beforehand in order to avoid any bruise events, were placed on display (Fig. 2.4) at each of the participating retail stores. Another set of fruit samples ($n = 10$) was held as unhandled control for each retail store. The researchers observed the display without interrupting the shoppers. As soon as a shopper tested an avocado for firmness assessment by squeezing and then placing it back on the display, the researcher discretely collected it. In this way, a total of $n = 40$ such fruit were sampled. The collected fruit were transported to the lab at UQG and held at 20 °C for 48 h to allow time for bruise expression. Objective fruit firmness was measured with the SIQFT (Howarth and Ioannides, 2002). Fruit weight was recorded with a digital mass balance. Destructive bruising assessment was conducted as explained in section 2.1.4.

Fig. 2.4 Avocado fruit display at one of the participating retail stores.

2.7.2 Random fruit squeezing by shoppers

Fruit ($n = 100$) were acquired as described in section 2.7.1 and handled extremely carefully to avoid any bruising events. They were placed on display in the retail stores of the Coles and Woolworths supermarket chains located in Gatton, Plainland, Toowong, and Mount Ommaney in Queensland. Shoppers were allowed to interact with the fruit on retail store display in a random manner, that is, by assessing the firmness of fruits for their selection for purchase. Once either the required number of remaining fruit ($n = 40$) were left on the display or a period of ~ 6 h had elapsed, the fruit were collected for assessment. In line with the random sampling approach, some of the sampled fruit would have been squeezed by more than one shopper. On the other hand, some might not have been squeezed by any shopper. The recovered fruit were transported to the lab at UQG and held for 48 h. Fruit weight was recorded with a digital mass balance, fruit firmness was measured with a SIQFT (Howarth and Ioannides, 2002), and destructive bruise assessment was conducted as per section 2.1.4. In concert, a random fruit sample ($n = 10$) was held at the lab as the control. These control fruit were subjected to destructive bruise assessment along with the fruit randomly squeezed by shoppers. This control was to benchmark the fruit quality before the fruit were subjected to random squeezing by shoppers in the supermarket retail stores. Four replicate runs of this experiment were conducted once a week in the four weeks of July 2013.

2.7.3 Multiple fruit handling by multiple shoppers

Avocado cv. 'Hass' fruit (n = 40) were ripened to the firm ripe hand firmness stage (White et al., 2009) (section 2.1.1). Fruit firmness was quantified with a SIQFT (Howarth and Ioannides, 2002). Fruit weight was recorded with a digital mass balance. The firm ripe fruit (n = 20) were handled very carefully to avoid any bruise event before display at a supermarket retail store in Gatton. As well as those fruit for presentation to shoppers (n = 20), an equal number of fruit was held as the controls. Shoppers were engaged in this study through the snowball sampling approach (Handcock and Gile, 2011) with the criteria that the participating shoppers are regular buyers of avocado fruit. All the participating shoppers interacted with each of the 20 fruit for assessment of firmness subject to their normal fruit handling practice. The 20 fruit subjected individually to squeezing by all 20 shoppers were transported to the lab at UQG for destructive bruise assessment as explained in 2.1.4. Bruise severity due to shoppers handling practices was compared with the control.

2.7.4 Fruit handling by shoppers and squeezing force recorded by a force sensor

Avocado fruit (n = 50) for this experiment were ripened to firm ripe stage of hand firmness (White et al., 2009) as described in section 2.1.1. Objective firmness of fruit was measured with a SIQFT (Howarth and Ioannides, 2002) and fruit weight was recorded with a digital mass balance. These fruit were transported to a supermarket retail store in Gatton and subjected to squeezing by avocado fruit shoppers. Four temporal replications of this experiment were conducted weekly in August 2014.

Shoppers (n = 25) engaged by the snowball sampling approach (Handcock and Gile, 2011), squeezed one fruit each with a single zone force sensor (FSR 406 Interlink Electronics®, Camarillo, CA, United States) between the fruit and the shopper's preference of thumb or fingers, as they each would normally assess the fruit firmness on the retail display. The sensor was used to measure the squeeze force applied by each shopper on the fruit in this experiment.

Sample fruit squeezed by the shoppers were replaced with an undamaged substitute fruit to compensate the store. The squeezed fruit were taken to the lab at UQG for destructive assessment after 48 h. Occurrence of bruise severity due to increasing level of squeeze force applied by shoppers, was determined by destructive assessment (section 2.1.4), and was established using a decision tree analysis (Du and Sun, 2006). Bruise severity data acquired in four repeat runs was subjected to ANOVA using Minitab® 16.

2.7.5 Assessment of an 'e-glove' for measuring the shopper's fruit squeezing pressure

The Grip™ system (Tekscan®, South Boston, MA, United states) (Tekscan®, 2014) was employed to further explore the relationship of flesh bruising in 'Hass' avocado fruit with pressure applied by shoppers assessing fruit firmness using different parts of their hands. The Grip™ system was made into an 'e-glove' by sewing the Grip™ system onto the back of a white cotton glove ('all-purpose 100% cotton gloves - One size', Ansell Cotton Gloves™, Richmond, Victoria, Australia) with cotton thread so as not to damage the sensor elements. The Grip™ system sensors were then folded around the fingers of the cotton glove and attached to the palm side of the glove using double sided tape ('1522 Medical Tape 25X 4.57M' 3M™, North Ryde, NSW, Australia) (Fig. 2.5).

2.7.5.1 Pilot study

A pilot study was conducted to determine if the Grip™ e-glove system could be employed to discern the pressures applied in squeezing avocado cv. 'Hass' fruit at different stages of firmness. It was also assessed as to whether these squeezed fruit yielded visible flesh bruising in response to squeeze based firmness testing using the e-glove.

Avocado cv. 'Hass' fruit (n = 80) at green mature hard stage of hand firmness (White et al., 2009) were collected from a ripener in Brisbane Produce Market and carefully transported in an air conditioned vehicle within ~ 1 h to a postharvest laboratory at the EcoSciences Precinct (ESP) in Dutton Park, Queensland. These fruit were ripened as explained in section 2.1.1 into softening, firm ripe, and soft ripe stages of hand firmness. Their individual weights were recorded with a digital mass balance and fruit firmness was recorded with a Turoni Hardness Tester.

Fruit (n = 20) were sorted on the basis of fruit weight and firmness. Based on matched-samples for replicates they were assigned to each of four treatments: T1 = control (mixed firmness), T2 = softening, T3 = firm ripe, and T4 = soft ripe.

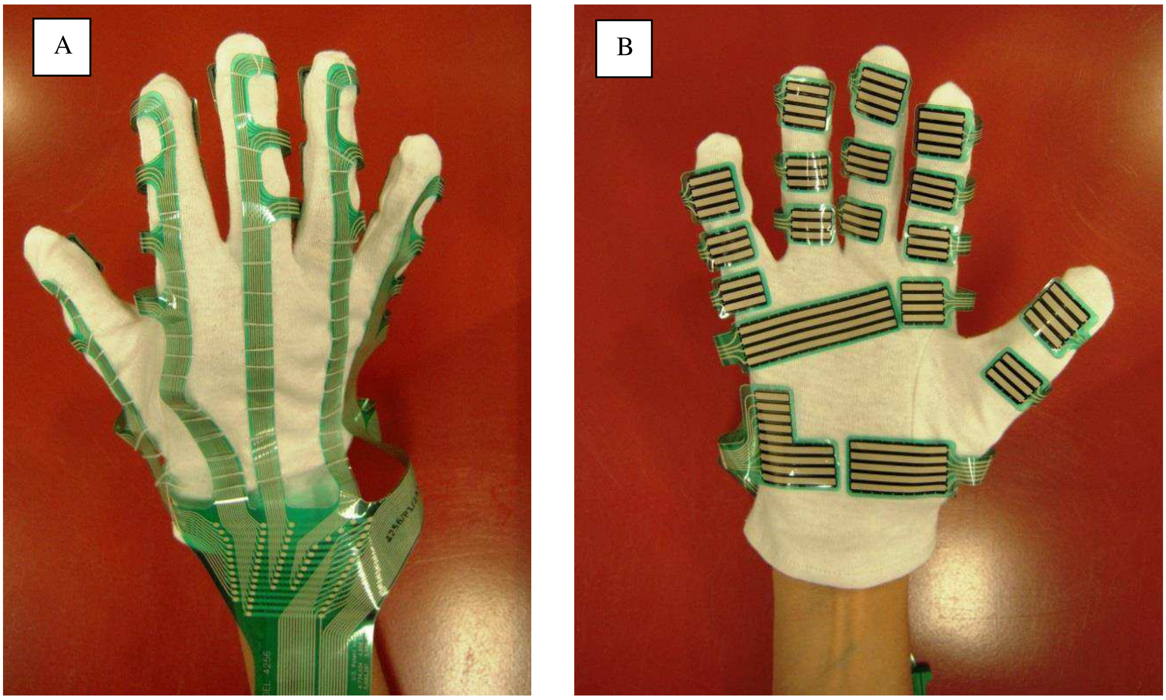

Fig. 2.5 Grip™ e-glove sensor array used to assess shoppers' contribution to flesh bruising of avocado cv. 'Hass' fruit. (A) Top view of the e-glove. Grip™ sensor array sewn onto a white cotton glove with cotton thread. (B) Bottom (palm side) view of the e-glove. After the hand shaped flexible plastic grip sensor platform was sewn to the back of the glove, the grip sensor array pads were folded around the fingers of the cotton glove and attached to the palm side using double-sided tape.

Avocado shoppers (*n* = 20) were engaged through the snowball sampling approach (Handcock and Gile, 2011) for participation in this study. The participants were given one fruit for each firmness treatment, except for an unhandled control, for squeezing by them to assess the stage of fruit ripeness. After squeezing their fruits, each participant was asked four exit survey questions (Fig. 2.6). The intent of the exit survey was to better understand the current awareness and expectations of shoppers about the on-display fruit firmness assessment.

Exit survey questions

1. Which part/s of your hand do you use to feel avocados?

2. What are you feeling for when you test an avocado? How do you tell if it's ripe?

3. Would you find printed point of sale information about choosing avocados helpful?

4. Do you think it would be useful to have a quick, simple device near the avocado display to assist you and your fellow shoppers to become better at testing avocados without damaging the fruit?

Fig. 2.6 Exit survey questionnaire used in the survey of avocado fruit shoppers on their attitude and expectations towards in-store avocado fruit firmness assessment.

The squeezed and the control fruit were held at 20 °C for 48 h to allow time for bruise symptoms to visibly express. Destructive bruise assessment was conducted as per section 2.1.4 with a view to determining the bruise severity in squeezed fruit as compared with control fruit. This pilot study informed use of the Grip™ system e-gloves in the in-store experiment described immediately below. The exit survey was to pilot the asking of survey questions as part of that same follow on experiment.

2.7.5.2 In-store experiment

An in-store experiment was conducted in a retail supermarket store at Indooroopilly Shopping Centre, Indooroopilly, Queensland. The management of the supermarket store was approached with the research proposal. Their approval was obtained to conduct the research activity in their premises. A stall, distinctly marked with the purpose of the activity, was set up in the fresh produce section (Fig. 2.7).

Fig. 2.7 Experimental set up and team members (left to right: Sohail Mazhar, Gouqin Li, Leanne Taylor, and Neil Tuttle) involved in conducting the in-store experiment on assessment of an ‘e-glove’ for measuring the shopper’s fruit squeezing pressure. (Photo by Daryl Joyce).

Avocado cv. ‘Hass’ fruit, collected from a ripener in Brisbane Produce Market at green hard stage, were ripened as described in section 2.1.1 to softening, firm ripe, and soft ripe hand firmness stages (White et al., 2009) at ESP. Fruit firmness was quantitatively measured with a Turoni Hardness Tester to reduce the fruit variability. Fruit (n = 50) free from any obvious physical defect at each of the softening, firm ripe and soft ripe firmness stages were provided on a matched sample basis for squeezing by shoppers as replicates. Matched samples were used to control variance on fruit mass and firmness across replicates, such that it did not confound treatments effects.

Shoppers (n = 50) were randomly selected at the research venue on the basic selection criteria of being a mature Australian avocado consumer (Gamble et al., 2008). The scope of study was explained to interested participants and their verbal consent was obtained. Gender and age ranges of consenting participants were recorded. Participants were then asked for their preference of left or right hand. Parameters of participants’ hands (viz. length, maximum spread of thumb to little finger, and width of the thumb) were recorded. The participants placed the Grip^{TM} system e-glove on their preferred hand and were given a tennis ball to squeeze to get a ‘feel’ for the glove. They were then asked to judge avocados by squeezing the firmness of individual fruit offered at each three levels of firmness. Pressure ($N.cm^{-2}$) applied by each shopper on each fruit was quantitatively extracted from the qualitative data comprising of images of coloured contours generated by the Tekscan® software.

The exit survey (Fig. 2.6) was employed to assess participants' attitudes to firmness measurement, and to potential in-store decision aid tools to inform the stage of fruit ripening without them physically squeezing the fruit. Participating shoppers were offered an incentive of a $10 gift voucher as compensation for their time and effort.

2.7.5.3 Confirmatory experiment

An experiment was conducted to confirm if the bruise severity in avocado fruit subjected to squeezing by shoppers wearing an e-glove is different from bruise severity in fruit squeezed by shoppers with bare hands, and in those squeezed whilst wearing a cotton glove.

Avocado cv. 'Hass' fruit, collected from a ripener in Brisbane Produce Markets at green hard stage, were ripened as described in section 2.1.1 to firm ripe hand firmness stage (White et al., 2009) at ESP. Fruit firmness was quantitatively measured with a Turoni Hardness Tester to reduce fruit variability. Fruit (n = 20) free from any obvious physical defect at firm ripe firmness stage were provided on a matched sample basis for squeezing by participantss as replicates to treatments: T1 = bare hands; T2 = cotton glove; T3 = e-glove, and; T4 = control (un-squeezed).

Participants (n = 20) were engaged following a random approach. A stall was set up at ESP foyer on the day of the experiment. Employees and visitors at ESP who had experience of consuming avocados were invited to participate in the experiment. Consenting participants were advised as to the scope of the study and their verbal consent was sought. Every participant squeezed one fruit for each treatment of fruit squeezing with bare hands, squeezing wearing the cotton glove, and squeezing wearing the e-glove. The data for the pressure applied by participants on fruit to assess for firmness by the e-glove was recorded. The squeezed fruit for all treatments, including the control, were held for 48 h before the destructive bruise assessment was conducted.

Bruise severity data of the four treatments was subjected to ANOVA using Minitab® 16.

2.7.6 In-store observations of shoppers' fruit handling practices

The contribution of shoppers to bruising the avocado fruit assessed in experiments 2.7.1 to 2.7.5 was complimented by observations recorded on fruit handling practices by random avocado shoppers (*n* = 257) during their testing for selection of fruit from retail display. Observation is an informative research tool in qualitative research (Mulhall, 2003; Wells and Lo Sciuto, 1966).

The experiment was conducted at two retail stores of each of the two supermarket retail chains which had participated in the experiment described in section 2.7.1. The observers maintained a reasonably discrete distance from the fruit display. However, they were located where the display and shoppers' practices were clearly visible without interruption to viewing. Observations were recorded on gender of the shopper (male and / or female), time spent at the display (seconds), numbers of fruit handled, numbers of fruit purchased, shoppers estimated age group (young (below 30 years), mature (30 to 50 years), or old (above 50 years), and any other avocado shopping related behaviour. The data were quantitatively analysed for the possible effect of shoppers' fruit handling practices on the resultant flesh bruising in avocado cv. 'Hass' fruit.

2.8 Consumer contribution to flesh bruising

Avocado consumers (*n* = 25) living within a radius of ~30 km from the participating supermarket retail store in Plainland, and who were willing to participate in this experiment, were engaged following the snowball sampling approach (Handcock and Gile, 2011). The contribution of consumers to bruising of avocado cv. 'Hass' fruit was assessed by the two following experiments, each with four replications conducted weekly over August 2013.

2.8.1 Fruit sampling through the supply chain

Consignments (*n* = 4) of avocado cv. 'Hass' fruit, harvested and packed into single layer 5.5 kg trays at Childers ~ 318 km north of Rocklea, and subjected to commercial supply chain handling practices, were tagged at the ripener arrival stage at Brisbane Produce Markets. Thereafter, sample fruit (*n* = 25) were randomly collected from each consignment at each of six serial sampling points: ripener arrival and dispatch (points 1 and 2), distribution center (DC) arrival and dispatch (points 3 and 4), retail store arrival (point 5), and retail store display (point 6). The intent was to quantify flesh bruising in the fruit at each of these six serial stages. Thereafter, consumers consenting to participate in the experiment were requested to pick twice the number of fruit that they typically buy from the retail display and to take these fruit to their homes according to their normal handling practices. The consumers were advised to handle all the fruit and use half the total number of fruit as per normal practice. The complementary half the number of fruit were collected back from consumers' homes (point 7) after 2 days. The fruit collected from consumers' homes were transported to the lab at UQG. After holding fruit for ~ 48 h at the lab, fruit firmness was measured with a SIQFT (Howarth and Ioannides, 2002), fruit weight was recorded with a digital mass balance, and destructive bruise assessment was conducted as per section 2.1.4.

2.8.2 Bruise free fruit subjected to consumer handling practices

Avocado cv. 'Hass' fruit ripened to firm ripe stage of hand firmness (White et al., 2009) (section 2.1.1) were provided to participating consumers at a check-out exit point in the participating retail store. The consumers were requested to take the fruit home subject to their normal handling practices. Consumers used half the number of fruit as per the preceding section 2.8.1. Also, again, the additional half number of fruit were collected back from the consumer's home after 2 d and transported to at the lab at UQG. Fruit were held for ~ 48 h. Fruit weight was recorded with a digital mass balance, objective fruit firmness was measured with a SIQFT (Howarth and Ioannides, 2002), and destructive assessment of bruising was conducted as explained in section 2.1.4.

An initial random fruit sample (n = 10) was held back at the UQG lab before giving the fruit samples to the participating consumers. This control sample set was held to benchmark initial fruit quality in terms of flesh bruising. Destructive bruise assessment of control fruit and sample fruit collected from consumers' homes was conducted at the same time.

2.9 Consumer attitude to flesh bruising

Consumer perceptions as to flesh bruising in avocado cv. 'Hass' fruit and its effect on their level of satisfaction and decision to repeat purchase were garnered using four approaches. Participating consumers were instructed by the researchers on differentiating flesh bruising symptoms from other flesh browning symptoms attributable to rots, vascular browning and chilling injury, and on writing diary notes. The latter are a useful method of data collection (Bolger et al., 2003; Patterson, 2005), such as has been applied for estimating the average food expenditure of consumers (Tsai and Tan, 2006). In this study, the diary notes were recorded in a questionnaire designed for ease of uniform data collection from all the participants.

2.9.1 Bruising in fruit used in experiment described in Section 2.8

The consumer contribution to bruising of 'Hass' avocado fruit, as quantified in experiments described in sections 2.8.1 and 2.8.2, was further elucidated with the diary notes of consumers (n = 138) in a questionnaire (Fig. 2.8). These questionnaires were given out to the consenting consumers at the retail store. They were requested to complete their responses when the sample avocado fruit were consumed. Proportional (%) bruising and additional notes on observations related to occurrence of flesh bruising were recorded by the consumers. Some also shared photos of flesh bruising that they came across at the time of fruit consumption. Consumer levels of satisfaction were recorded on a 1 to 5 scale: 1 = very satisfied, 2 = satisfied, 3 = just OK, 4 = dissatisfied, and 5 = very dissatisfied. The effect of flesh bruising on their decision to repeat purchase was recorded as 'yes' or 'no'.

2.9.2 Bruising in fruit displayed at a supermarket retail store

Consumers (n = 40) were requested to buy the fruit available on retail display in a supermarket retail store in Gatton and to take them home subject to their normal fruit handling practices. The consumers were provided with the same questionnaire (Fig. 2.8) at the time of fruit purchase from the retail store. Their response as to fruit handling and the consumption experience as per section 2.9.1 was collected from their homes once the fruit were consumed. The cost of the fruit purchased by consumers in this study was paid by the researcher to the retail store at check-out points.

2.9.3 Bruising in fruit subjected to controlled impact

This experiment was conducted to record consumer responses on their level of satisfaction and decision to repeat purchase as affected by known levels of bruising in fruit offered to them. Avocado cv. 'Hass' fruit (n = 60) were prepared to the firm ripe stage (White et al., 2009) as per section 2.7.1. The firm ripe stage fruit were then carefully transported in an air conditioned vehicle within ~ 1.5 h to the lab at UQG on a weekly basis over four weeks in July 2014.

1. Where did you keep your avocado fruit after they reached your home?

2. What proportion of the total number of avocados, if any, had flesh bruising at your time of consumption?

3. What percentage (%) of the avocado fruit flesh was bruised? Please note your observations.

4. What is your level of satisfaction with the quality of your avocado fruit in terms of the flesh bruising?

1. Very Satisfied   2. Satisfied   3. Just OK   4. Dissatisfied   5. Very dissatisfied

5. Has your decision to repeat purchase the avocado fruit affected with your recent experience of flesh bruising?

Note: Kindly make photographs of bruising in avocados and send me at sohail@uq.edu.au

Fig. 2.8 The questionnaire designed to record diary notes provided to the avocado consumers for their responses on avocado fruit handling, bruise assessment, and level of satisfaction and decision of repeat purchase as affected by flesh bruising in avocado cv. 'Hass' fruit at the time of consumption.

On arrival in the postharvest laboratory, fruit weight was recorded with a digital mass balance and fruit firmness was recorded with AFM (Macnish et al., 1997). Two thirds of the total number of fruit (*n* = 40) were impacted by dropping from a 50 cm height with the swing arm device against a solid metal surface. The impact site was marked with a white out marker. One third the number of fruit (*n* = 20) were not impacted and were held in a darkened room at 5 °C. For the impacted fruit, the rebound height was recorded and energy absorbed by the fruit was calculated after Schoorl and Holt (1980), as explained in section 2.2. Average energy absorbed in these fruit was ~ 0.81 J. Impacted fruit were held in a darkened shelf life room at 20 °C for 48 h to allow sufficient time for bruise expression.

Half of the total number of impacted fruit (*n* = 20) with the control bruised flesh were given to consumers (*n* = 20) engaged through the snowball sampling approach (Handcock and Gile, 2011). They were coached to record diary notes on their consumption experience. The diary note questions included severity of flesh bruising in the fruit and its effect on their level of satisfaction and decision to repeat purchase; viz., questions 3 to 5 in Fig. 2.8. The other half of the impacted fruit (n = 20) were subjected to destructive bruise assessment by a researcher as explained in section 2.1.4. This bruise severity was used as the researcher's reference point or benchmark for the consumers' responses regarding the fruit given to them. At the time of collection of the diary notes, the consumers were given a sound substitute fruit as compensation for their participation in the study.

3. Outputs

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

Reports, co-incident with reports on AV10019, were presented to and / or shared with all project participants at the end of each avocado season in 2013 and 2014. Project planning and feedback meetings included the following.

- Pre-season meeting (project scientists, AAL and HIA); 14th January 2013; Woolloongabba.
- 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 organising 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

- Milestone reports and HIA annual industry reports via HIA.

- 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).
- 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 riperners 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. 2015. Bruising and rots development in impacted hard green mature avocado cv. 'Hass' fruit. *Talking Avocados*. **25**, 30-33.
- Mazhar, M., D. Joyce, P. Hofman, R. Collins, M. Gupta. 2014. Bruising by hand in softening avocado fruit – Preliminary study. *Talking Avocados*. **24**, 29-31.

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

- 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 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.
- AV10019 – Reducing flesh bruising and skin spotting in 'Hass' avocado. Qualicado, AAL, 12th November 2013, Melbourne.

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

4.1 Bruise development in individual fruit

4.1.1 Impact energy

Flesh bruise severity in avocado cv. ‘Hass’ fruit trended to increase ($P \leq 0.05$) with increased impact energy absorbed upon drops from 25 cm, 50 cm, and 100 cm height (Fig. 4.1A).

4.1.2 Fruit firmness

Bruise severity increased ($P \leq 0.05$) with decreasing fruit firmness for softening, firm ripe, and soft ripe ‘Hass’ avocado fruit (Fig. 4.1B).

4.1.3 Time of assessment

Flesh browning was not visible at 8 h after impact. However, it manifested by the second bruising assessment conducted at 24 h after impact and further increased ($P \leq 0.05$) by the third assessment at 48 h (Fig. 4.1C).

Bruise severity in all of softening, firm ripe and soft ripe avocado fruit having absorbed each of ~ 0.38 J, ~ 0.81 J, and ~ 1.67 J energy, and assessed at 8 h, 24 h, and 48 h, increased with increased impact energy absorbed, with passage of time after the impact event, and with decreased fruit firmness (Table 4.1). Flesh damage upon bruising due to impact energy absorbed by the fruit initially appeared in the form of softened flesh tissue and cracks at and near the impact site. These damages became more obvious as the affected flesh tissue changed colour from greenish to brownish. The bruise continued to grow in terms of severity (viz. volume) and intensity (viz. browning) to the third assessment time of 48 h. The effects of each level of impact energy absorbed by the fruit (viz., ~ 0.38 J, ~ 0.81 J, and ~ 1.67 J for fruit dropped from 25 cm, 50 cm, and 100 cm respectively) and the post-impact times of bruising assessment (viz., 8 h, 24 h, and 48 h) were significantly different from one another. In terms of fruit firmness, softening stage fruit had less bruise severity compared with either of the firm ripe and soft ripe fruit. The effects on bruise development in fruit impacted at the two later stages of hand firmness were on par.

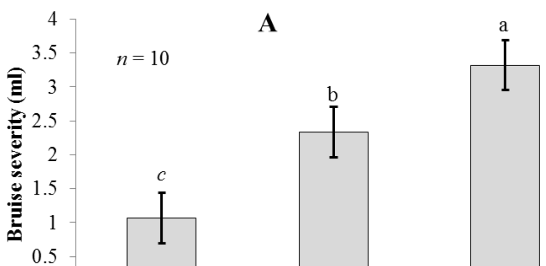

Fig. 4.1 Bruise severity in avocado cv. 'Hass' fruit (n = 10) having absorbed different levels of impact energy at the firm ripe stage of hand firmness (A), impacted from 25 cm drop height at different stages of fruit firmness (B), and firm ripe fruit impacted from 25 cm drop height subjected to destructive bruise assessment at different post-impact durations (C). Vertical lines represent standard deviation from the mean. Different letters represent level of significance between the treatments.

As a measure of colour, hue of the flesh at the impact site was significantly ($P < 0.05$) affected by all three fruit hand firmness stages, energy levels absorbed by the fruit, and post-impact times to bruise assessment (Table 4.2). Chroma of the bruised flesh gradually decreased (became less bright) for impacted fruit subjected to bruise assessment at 8, 24, and 48 h after impact (Table 4.3).

Table 4.1 Flesh bruising (ml) due to impact energy absorbed by individual avocado fruit (n = 10) at softening, firm ripe and soft ripe stages of hand firmness and assessed at 8 h, 24 h, and 48 h after impact (± SD).

	8 h			24 h			48 h		
	~0.38 J	~0.81 J	~1.61 J	~0.38 J	~0.81 J	~1.61 J	~0.38 J	~0.81 J	~1.61 J
Softening	0.0±0.0	0.0±0.0	0.0±0.0	2.4±1.0gh	3.0±1.0gh	3.4±0.9gh	2.3±0.7gh	3.5±1.2fgh	4.4±1.3efg
Firm ripe	0.0±0.0	0.0±0.0	0.0±0.0	7.7±3.3def	8.8±2.2d	10.6±2.9d	7.8±2.3de	16.1±5.7c	16.5±3.8c
Soft ripe	0.0±0.0	0.0±0.0	0.0±0.0	23.4±4.8b	28.8±2.3a	28.7±2.7a	26.8±5.9ab	29.8±2.6a	30.8±4.6a

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

Table 4.2 Effect of fruit firmness, impact energy absorbed by the fruit ($n = 10$), and post-impact fruit holding duration on hue of bruised flesh (± SE).

Firmness	Hue	Energy absorbed	Hue	Post-impact holding duration	Hue
Softening	97.1 ± 0.5 a	~0.38 J	97.2 ± 0.5 a	8 h	103.1 ± 0.5 a
Firm ripe	96.0 ± 0.5 ab	~0.81 J	94.7 ± 0.5 b	24 h	94.4 ± 0.5 b
Soft ripe	95.1 ± 0.5 b	~1.61 J	96.4 ± 0.5 a	48 h	90.7 ± 0.5 c

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

Table 4.3 Effect of post-impact fruit ($n = 10$) holding duration on chroma of bruised flesh (± SE).

Post-impact holding duration	Chroma
8 h	37.8 ± 0.3 a
24 h	31.6 ± 0.3 b
48 h	27.4 ± 0.3 c

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

4.2 Impact energy absorbed by fruit in trays

A greater tray drop height (50 cm versus 25 cm) and a tray drop angle from the horizontal (30 degrees at 50 cm versus 0 degrees at 50 cm) significantly increased ($P < 0.05$) the resultant bruise severity in firm ripe hand firmness stage avocado cv. 'Hass' fruit. However, the tray drop angle effect for 30 degrees versus horizontal (0 degrees) was not significant in fruit trays dropped from 25 cm (Fig. 4.2). This implies that the interaction effect of tray drop height and drop angle affect the bruise severity in fruit trays.

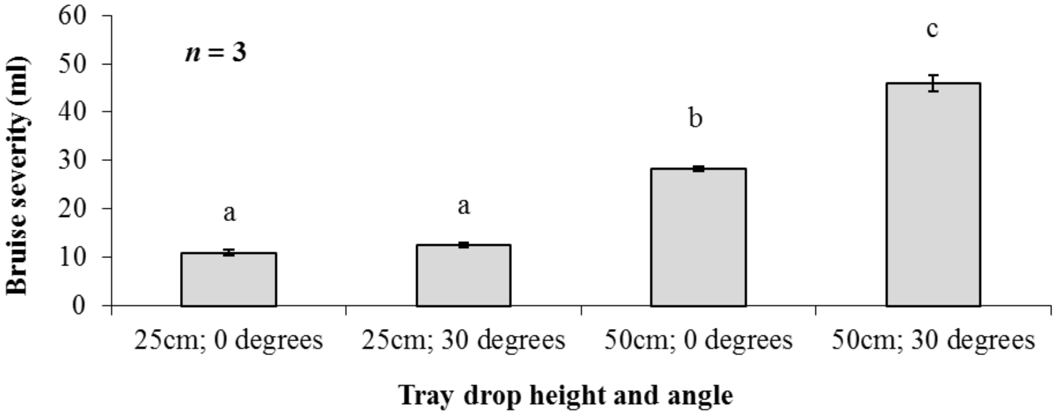

Fig. 4.2 Average flesh bruising (ml) in individual fruit held in fruit trays (*n* = 3) dropped from different heights and drop angles. Vertical lines represent standard deviation from the mean. Different letters represent level of significance between the treatments.

In another experiment conducted to evaluate the effect of other combinations of tray drop heights and drop angles, the treatments of 15 cm, 0 degrees; 15 cm, 15 degrees; 15 cm, 30 degrees; 25 cm, 0 degrees; 25 cm, 15 degrees; and 25 cm, 30 degrees all gave rise to significant bruise severity as compared with the control. Main factor treatment effects of tray drop height (Factor A) and tray drop angle (Factor B) were both significant ($P < 0.05$). The interaction effect (A * B) of tray drop height and tray drop angle was not significant ($P > 0.05$) (Table 4.4). Thus, the tray drop angle does not cause flesh bruising at lower tray drop heights. Mapping of average bruise severity in impacted fruit trays showed less bruise severity per fruit for fruit placed at position 1, which increased ($P < 0.05$) to fruit held at position 5. Bruise severity was mapped across the trays indicated (Fig. 4.3).

The effect of fruit position on bruise severity was significant ($P < 0.05$) for both drop heights of 15 and 25 cm and both drop angles of 15 and 30 degrees. However, the fruit position did not have a significant ($P > 0.05$) effect in terms of bruise severity in trays dropped from either height at 0 degrees drop angle.

An IRD device placed into the trays of fruit measured impact forces in the second experiment. Tray drop height and drop angle significantly ($P < 0.05$) affected the levels of force recorded. The IRD in trays dropped at 0 degrees (i.e. from the horizontal) experienced higher force as compared with either of the 15 and 30 degrees drop angles for both the 15 and 25 cm drop heights (Fig. 4.4).

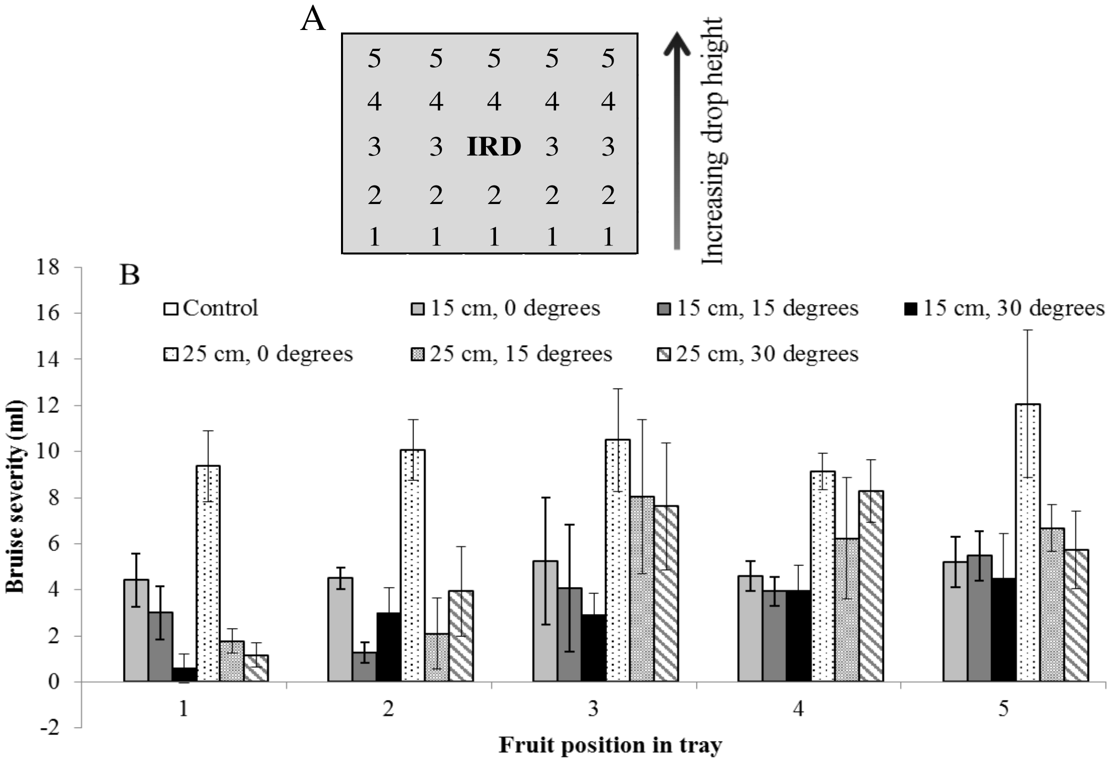

Fig. 4.3 (A) Arrangement of avocado cv. 'Hass' fruit in tray for mapping the bruise severity in response of tray drop from different heights and drop angles. Fruit number 1 always positioned closer to the ground and fruit at position 5 always positioned away from the ground when the trays were dropped 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 level of significance between the treatments.

Table 4.4 Effects of tray drop height and drop angle on bruise severity (ml) in avocado cv. 'Hass' fruit (± SD).

Factors/treatments	Number of fruit in tray	Number of trays (replications)	Bruise severity (ml)
Tray drop height (Factor A)			
15 cm	24	3	3.6 ± 1.1 a
25 cm	24	3	7.3 ± 2.8 b
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. Tukey's LSD test at $P = 0.05$.

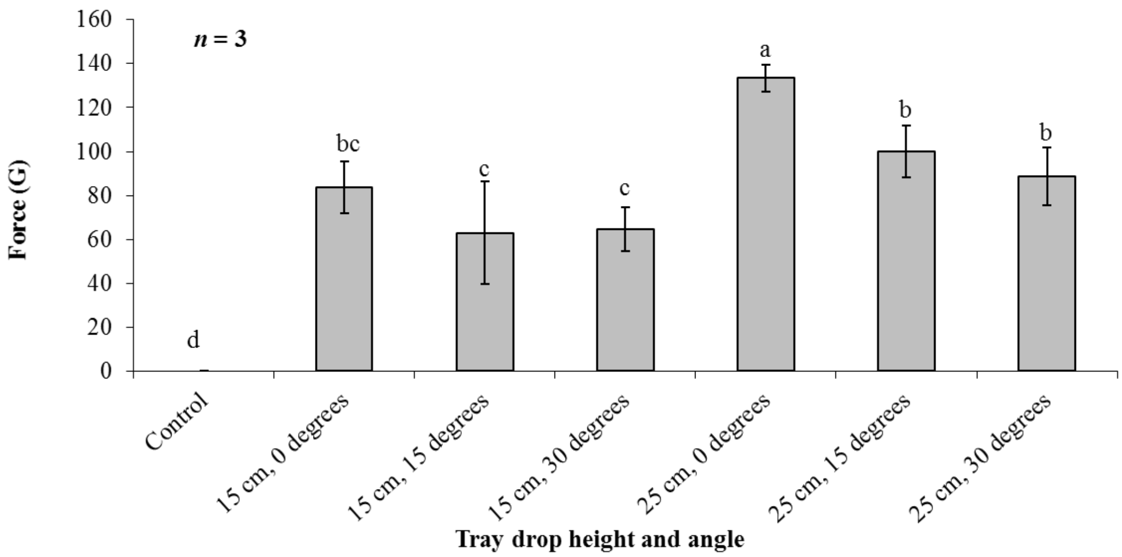

Fig. 4.4 Forces (G) recorded by an IRD in fruit trays (*n* = 3) full of avocado cv. 'Hass' fruit plus the impact recording device. Treatments were different combinations of tray drop height and drop angles. Vertical lines represent standard deviation from the mean. Different letters represent level of significance between the treatments, LSD at $P = 0.05$.

4. 3 Compression force applied to individual fruit by hand

Bruise severity in fruit compressed with all three levels of manual (qualitative) and the three levels of mechanical (quantitative) compression force treatments was significant ($P \leq 0.05$) as compared with uncompressed control fruit (Table 4.5). Both slight manual compression treatment and minimal mechanical compression treatment at 1 kg caused flesh bruising in the firm ripe avocado fruit. The severity of bruising rose significantly ($P \leq 0.05$) with increased manual compression (i.e. moderate and firm) and increased mechanical compression (i.e. 2 kg and 3 kg).

Table 4.5 Flesh bruise severity in avocado cv. 'Hass' fruit subjected to manual and mechanical compression (± SD).

Treatment		**Replications**	**Bruise severity (ml)**
Control		3	0
	Slight	3	1.7 ± 0.8 cd
Qualitative force	Moderate	3	2.7 ± 0.6 bc
	Firm	3	9.3 ± 1.2 a
	~ 1 kg	3	0.7 ± 0.3 de
Quantitative force	~ 2 kg	3	3.3 ± 0.8 b
	~ 3 kg	3	9.5 ± 0.5 a

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

4. 4 Compression force applied to individual fruit measured with the force sensor

Flesh bruising in firm ripe avocado cv. 'Hass' fruit was significant ($P < 0.05$) upon compression as compared with uncompressed control fruit. The average bruise severity was 0.4 ± 0.5 ml in fruit subjected to compression force of ~ 20 N as compared with 0.0 ± 0.01 ml in control fruit. Considering chroma, the value was 37.1 ± 6.4 for fruit compressed with ~ 20 N force as compared with the unbruised flesh chroma value of 42.1 ± 3.4 for control fruit.

Bruise intensity in terms of chroma value of bruised flesh and bruise severity was significantly ($P < 0.05$) related to the day of assessment (Table 4.6). Chroma values gradually decreased over the assessment period from day 0 to day 4. In contrast, however, there was no significant difference in hue and bruise severity after the first day of assessment.

Table 4.6 Bruise severity, hue, and chroma of the fruit ($n = 20$) subjected to ~ 20 N compression force and assessed over four days after compression treatment (± SD).

Day of assessment	**Bruise severity (ml)**	**Hue**	**Chroma**
d 0	0.0 ± 0.0 b	105.9 ± 2.4 a	43.9 ± 2.7 a
d 1	0.6 ± 0.6 a	100.0 ± 3.0 c	37.7 ± 5.3 b
d 2	0.7 ± 0.7 a	102.5 ± 4.8 bc	36.1 ± 6.0 bc
d 3	0.6 ± 0.6 a	101.0 ± 3.1 bc	35.1 ± 5.4 bc

d 4	0.4 ± 0.4 ab	103.6 ± 3.3 ab	32.9 ± 6.7 c

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

In a repeat run of the experiment, bruise severity, hue and chroma were significantly ($P < 0.05$) affected by compression forces applied as compared with control and over the increasing levels of compressive force (Table 4.7). Notably, there was no differential effect ($P > 0.05$) of fruit firmness on bruise severity for any level of compression force applied.

Table 4.7 Flesh bruise intensity and severity in avocado cv. 'Hass' fruit ($n = 20$) subjected to manual compression as measured with the single zone force sensor (± SD).

Treatment	Force applied (N)	Hue	Chroma	Bruise severity (ml)
Firm ripe, control	0	104.3 ± 2.9 a	39.1 ± 2.2 a	0
Firm ripe, ~ 10 N	10.9 ± 0.6 c	105.3 ± 3.2 a	37.1 ± 3.5 ab	0.1 ± 0.1 c
Firm ripe, ~ 20 N	20.9 ± 0.9 b	96.7 ± 8.6 b	27.8 ± 4.9 cd	0.5 ± 0.2 b
Firm ripe, ~ 30 N	30.9 ± 0.6 a	90.2 ± 10.1 c	25.3 ± 2.2d	0.7 ± 0.4 a
Soft ripe, control	0	104.3 ± 3.6 a	38.7 ± 1.7 a	0
Soft ripe, ~ 10 N	10.9 ± 0.5 c	104.9 ± 5.5 a	34.8 ± 5.5 b	0.2 ± 0.3 c
Soft ripe, ~ 20 N	21.1 ± 0.8 b	98.1 ± 9.2 b	28.3 ± 6.8 c	0.6 ± 0.4 ab
Soft ripe, ~ 30 N	30.9 ± 0.8 a	90.5 ± 20.6 c	25.9 ± 5.6 cd	0.9 ± 0.5 a

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

4.5 Compression force and resultant deformation in avocado cv. 'Hass' fruit

The resistance force of fruit against constant force applied to hard, firm ripe, and soft ripe hand firmness stage fruit decreased significantly ($P < 0.05$) with decreasing fruit firmness under compressions by 1 mm, 1.5 mm and 3 mm (Fig. 4.5 A-C). Notably, the resistance force of hard fruit exceeded the applied force such that the texture analyser failed to compress the hard fruit to > 1.5 mm depth.

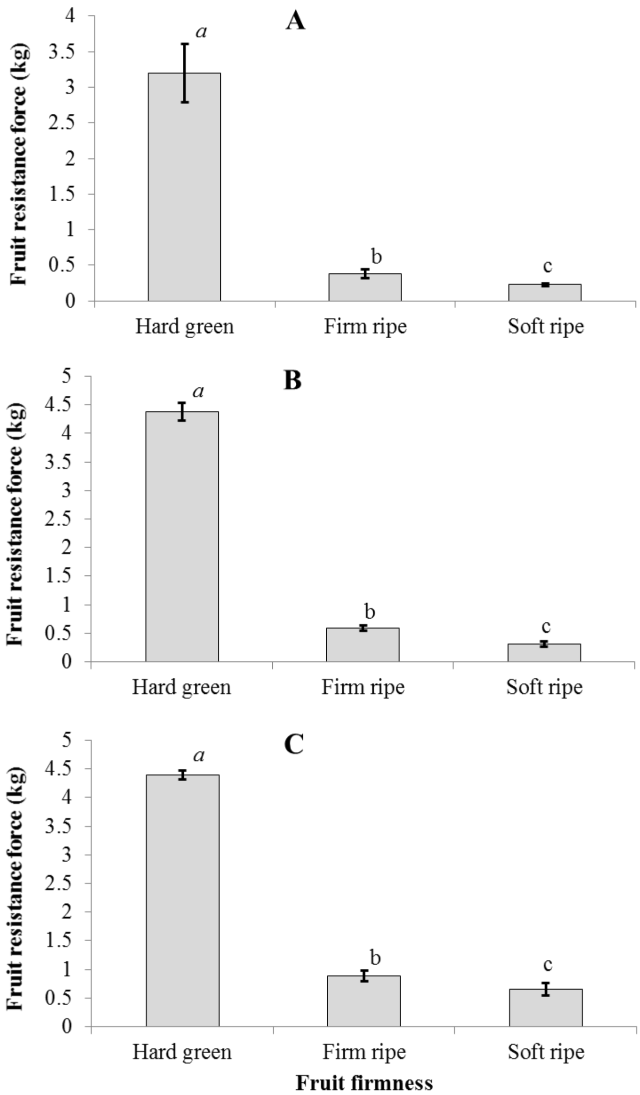

Fig. 4.5 Resistance force of hard, firm ripe, and soft ripe avocado cv. 'Hass' fruit (n = 5) compressed to 1 mm (A) and 1.5 mm (B), and fruit (n = 3) compressed to 3 mm (C) with a CT3 texture analyser under a compression load of 4.5 kg applied at a speed of 0.5 mm per second. Vertical lines represent standard deviation from the mean. Different letters represent level of significance between the treatments, LSD at P = 0.05.

Flesh deformation in response to constant compression force application was not significant (P > 0.05) for hard green mature, firm ripe, or soft ripe avocado cv. 'Hass' fruit compressed to 1 mm depth (Fig. 4.6). In contrast, flesh deformation in firm ripe and soft ripe avocado fruit compressed to 1.5 mm depth was significant ($P \leq 0.05$) (Fig. 4.6). As stated above, the hard green mature fruit initially compressed to 3 mm depth expressed maximum resistance force when these were actually compressed to just ~ 1.5 mm. Accordingly, the prescribed compression depth of 3 mm was not attained. This was because the fruit resistance force was greater than the capability of the texture analyser used under the specified operating parameters to compress the fruit such that flesh deformation was not recorded. On the other hand, flesh deformation in firm ripe and soft ripe fruit compressed to 3 mm depth was significantly higher ($P \leq 0.05$) than for any other treatment (Fig. 4.6). The force and deformation curves also show the permanent deformation due to compression to the three levels of depth in firm ripe and soft ripe fruit (Fig. 4.7).

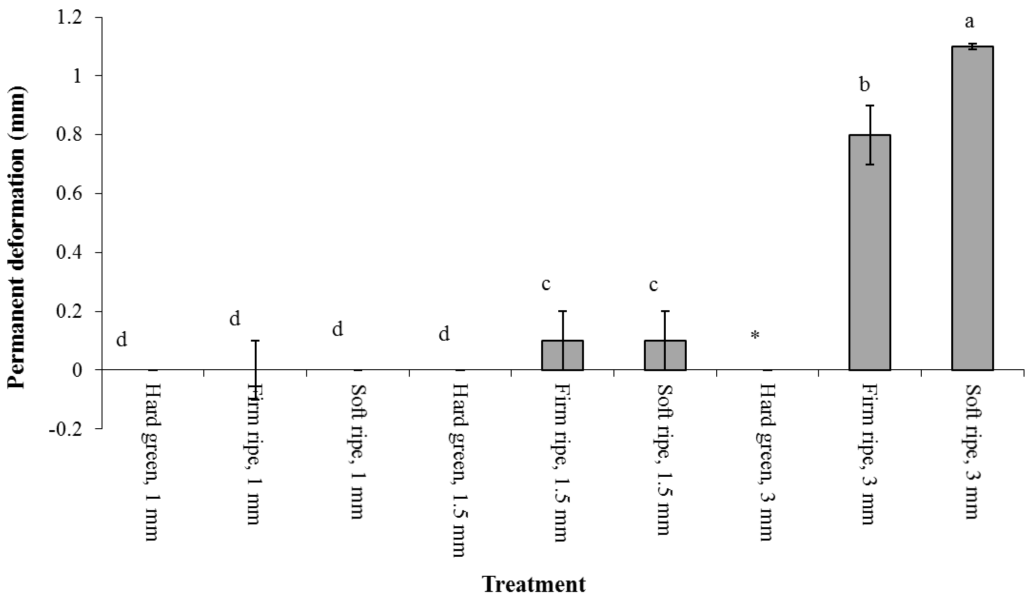

Fig. 4.6 Permanent deformation of avocado cv. 'Hass' fruit (n = 5) compressed to 1 mm and 1.5 mm and fruit (n = 3) compressed to 3 mm under an applied compression force of 4.5 kg as initially applied and then removed at the speed of 0.5 mm per second with a CT3^{TM} texture profile analyser. Vertical lines represent standard deviation from the mean. Different letters represent level of significance between the treatments. * The fruit resistance force of hard green fruit compressed to 3 mm compression depth was greater than the maximum compression ability of the CT3^{TM} texture profile analyser used in this experiment. The permanent deformation in hard green fruit compressed to 3 mm was not realised.

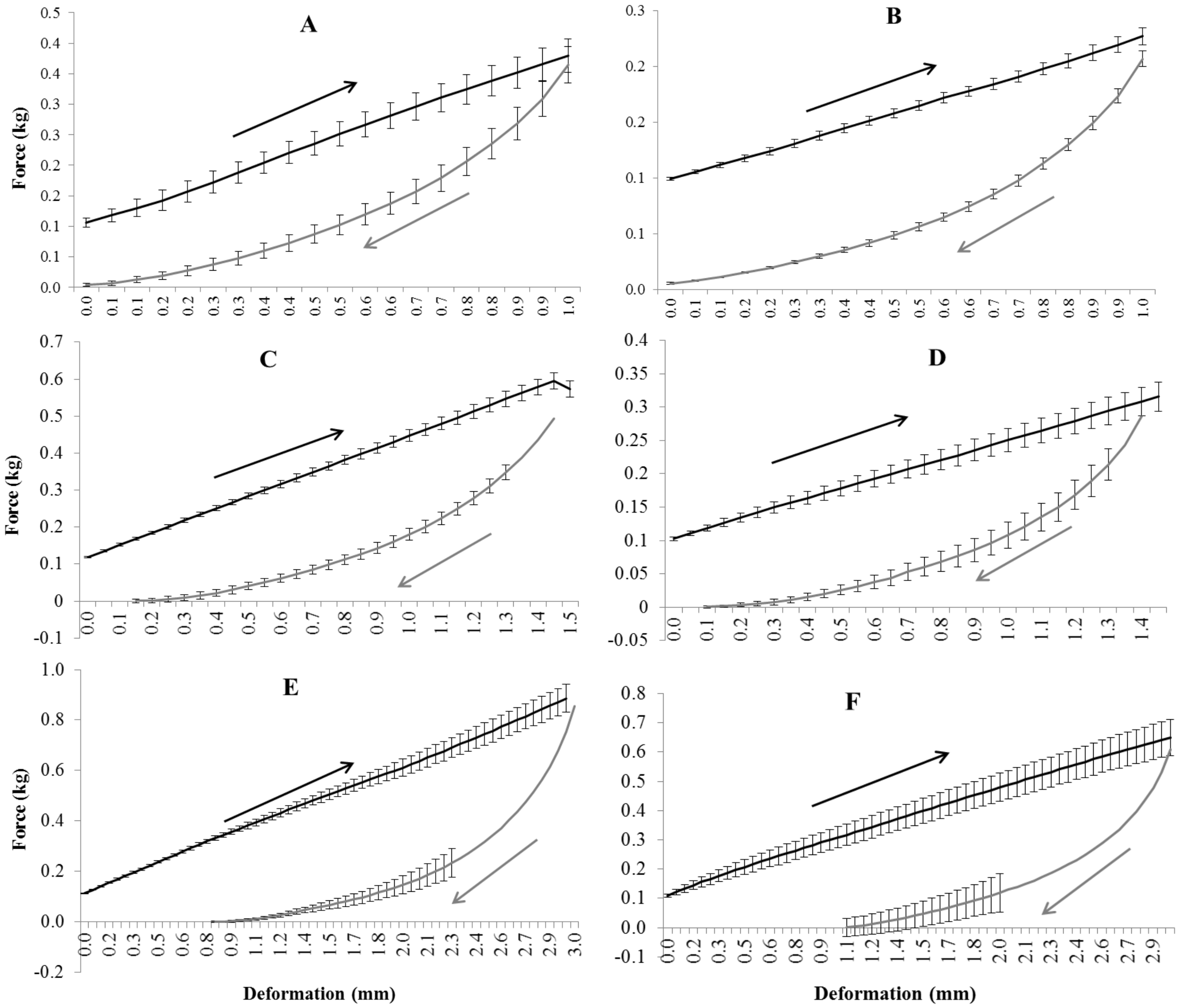

Fig. 4.7 Force and deformation relationship in avocado cv. 'Hass' fruit (*n* = 5) compressed to 1 mm and 1.5 mm and fruit (*n* = 3) compressed to 3 mm in response of an applied compression load of 4.5 g initially applied and then removed at speeds of 0.5 mm per second. (A) Firm ripe fruit compressed to 1 mm. (B) Soft ripe fruit compressed to 1 mm. (C) Firm ripe fruit compressed to 1.5 mm. (D) Soft ripe fruit compressed to 1.5 mm. (E) Firm ripe fruit compressed to 3 mm. (F) Soft ripe fruit compressed to 3 mm.

Flesh bruising did not develop ($P > 0.05$) in hard green mature, firm ripe and soft ripe fruit compressed to 1 and 1.5 mm depths. However, a significant ($P \leq 0.05$) level of flesh bruising was recorded in firm ripe and soft ripe avocado cv. 'Hass' fruit compressed by 3 mm (Table 4.8).

Table 4.8 Flesh bruise severity in avocado cv. 'Hass' fruit at hard green mature, firm ripe and soft ripe hand firmness stages as compressed with a CT3 texture analyser to 1 mm, 1.5 mm and 3 mm (± SD).

Treatment		Replications	Bruise severity (ml)
	Hard	5	0
1 mm	Firm ripe	5	0.1 ± 0.2 a
	Soft ripe	5	0.1 ± 0.2 a
	Hard	5	0
1.5 mm	Firm ripe	5	0.4 ± 0.6 a
	Soft ripe	5	0.6 ± 1.1 a
	Hard	3	0
3 mm	Firm ripe	3	6.2 ± 1.2 b
	Soft ripe	3	10.2 ± 0.6 c

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

4.6 Shopper's contribution to flesh bruising

4.6.1 Single fruit squeezed by a shopper

Bruise severity due to single fruit handling events for fruit firmness assessment by shoppers (1.0 ± 0.4 ml) was significantly higher ($P \leq 0.05$) than that in unhandled control fruit (0.1 ± 0.1 ml). Bruise severity in a fruit handled by a single shopper ranged from ~ 0.6 ml to up to 2 ml per fruit (Fig. 4.8).

Bruise severity levels recorded in two retail stores of each the two major supermarket chains in Australia significantly ($P \geq 0.05$) differed from each other (Table 4.9).

Table 4.9 Mean bruise severity in fruit ($n = 40$) squeezed by a shopper in two retail stores of the two supermarket retail store supply chains (± SE).

Supply chain	Bruise severity (ml)
1	0.9 ± 0.1 b
2	1.1 ± 0.1 a

Bruise severity values not sharing the same letter are significantly different at 95% confidence interval.

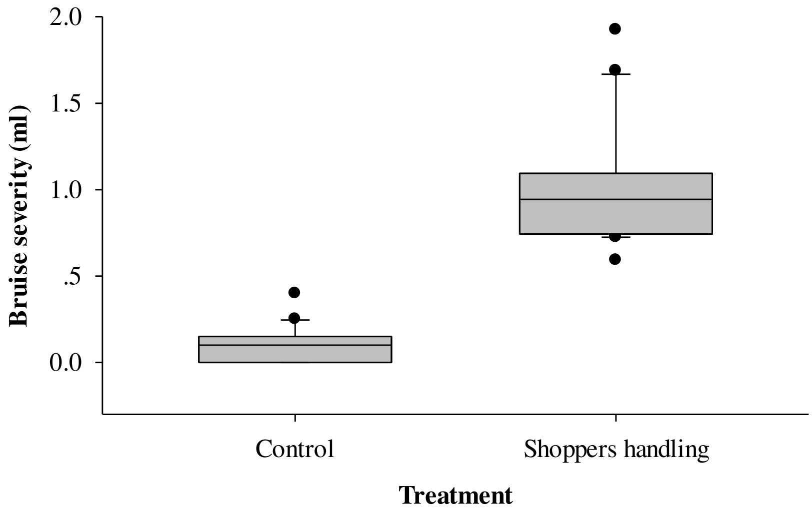

Fig. 4.8 Comparison of bruise severity in avocado cv. 'Hass' fruit subjected to a single shopper's handling event at two retail stores of two supermarket retail chains and control, destructively assessed for bruising. Horizontal lines of the bars in each treatment from bottom to top represent the first quartile, the median, and the third quartile of the data. Top terminal points of the perpendicular lines represent the maximum value. Horizontal line below the line representing first quartile in shoppers' handling treatment represent the minimum value. Black dots represent the outlier values.

4.6.2 Random fruit squeezing by shoppers

Avocado fruit subjected to squeezing at random by shoppers over a period of ~ 6 h developed flesh bruising ranging between ~ 0.5 ml per fruit and up to 7 ml per fruit (Fig. 4.9). Average bruise severity in avocado fruit randomly handled by shoppers over time was 1.9 ± 1.4 ml, this being significantly higher ($P \leq 0.05$) than the average bruise severity in control fruit (0.2 ± 0.1 ml). Average flesh bruise severity in the fruit subjected to random squeezing by shoppers at the retail display of the two supermarket supply chains was not statistically different ($P \geq 0.05$).

4.6.3 Multiple fruit handling by multiple shoppers

Multiple squeezing events (n = 20) by multiple shoppers significantly increased ($P \leq 0.05$) bruise severity in avocado cv. 'Hass' fruit as compared with unhandled control fruit. Average flesh bruising in avocado fruit handled for firmness assessment by 20 shoppers was 12.6 ± 3.8 ml (Fig. 4.10). There was no bruising in unhandled control fruit (was 0.0 ± 0.0 ml).

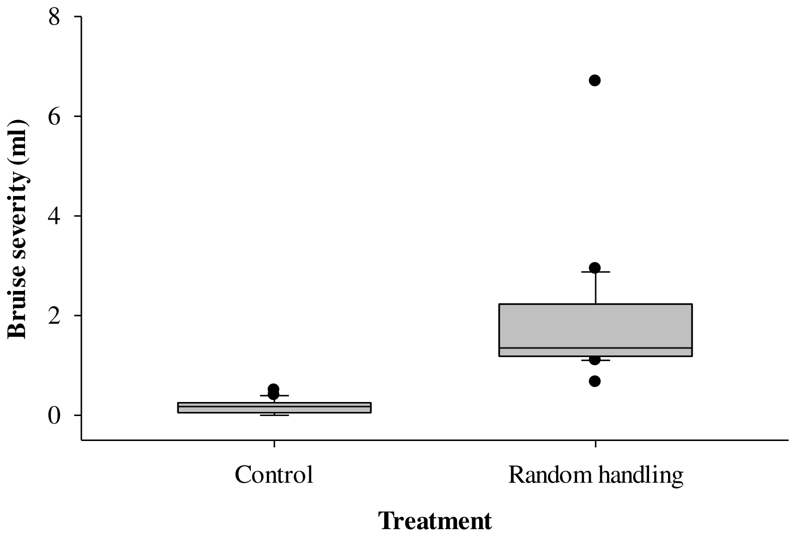

Fig. 4.9 Flesh bruising in avocado cv. 'Hass' fruit subjected to shoppers' random handling events at two retail stores of two supermarket retail chains and in control fruit. Fruit were destructively assessed for bruising. Horizontal lines of the bars in each treatment from bottom to top represent the first quartile, the median, and the third quartile of the data. Horizontal lines below the lines representing first quartile represent the minimum value. Top terminal points of the perpendicular lines represent the maximum value. Black dots represent the outlier values.

4.6.4 Fruit handling by shoppers and squeezing force recorded by a force sensor

Compression forces applied by shoppers on avocado fruit in the course of firmness assessment, as recorded with a FSR 406 force sensor, ranged from 2.9 N to 28.6 N. Mean flesh bruising in avocado fruit subjected to squeezing by shoppers ranged from 0.0 ml to 3.5 ml. Based on these data, flesh bruising in firm ripe avocado cv. 'Hass' fruit could be predicted by regression analysis: flesh bruising = -0.537 + 0.0765 (applied force), where $n_{x, y} = 95$ and $P \leq 0.05$. Goodness of fit (R^2) for the applied force and resultant flesh bruising regression was 69%. Decision tree analysis (Fig. 4.11) of force applied by shoppers on fruit for firmness assessment showed that up to the applied compression force of 7.7 N, only ~ 3.2% of fruit were bruised ($P \leq 0.05$). When the compression force was in the range 7.7 N to 12.7 N, the incidence of flesh bruising increased to ~ 18% ($P \leq 0.05$). Above 12.7 N as applied by shoppers, the incidence of flesh bruising rose to ~ 87% ($P \leq 0.05$).

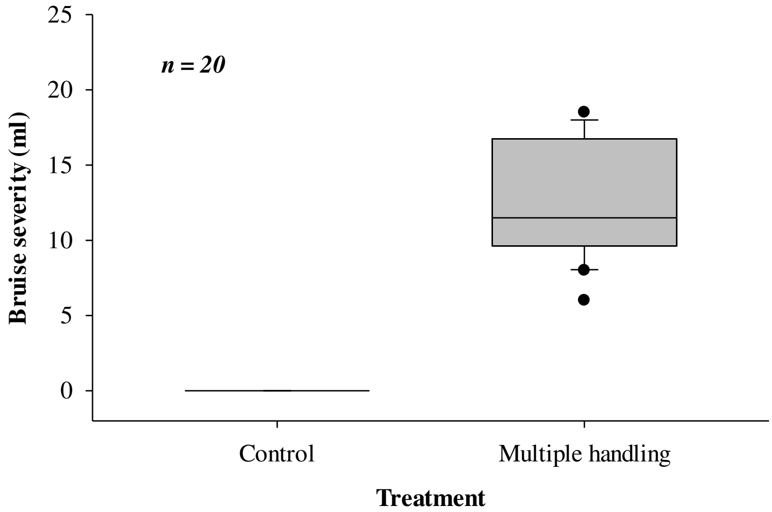

Fig. 4.10 Boxplot of bruise severity in avocado cv. 'Hass' fruit (*n* = 20) subjected to multiple squeezing events by shoppers (*n* = 20) and a control. Fruit were subjected to destructive bruising assessment after 48 h of collection. There was no bruising in control fruit. The bottom boundary of the bar representing bruise severity data of the fruit handled by shoppers shows the first quartile of the data set. The second line above shows the median, and the top boundary of the bar shows the third quartile of the data. The top terminal point of the line on the bar represents the maximum value, and the bottom terminal point of the vertical line below the bar shows the minimum value. Black dot symbols represent the outlier values.

Flesh bruising in repeat runs of the experiment differed in four runs of the experiment (Table 4.10).

Table 4.10 Mean bruise severity in fruit squeezed by shoppers (*n* = 25 on week 1-3; *n* = 20 on week 4) in four replications of the experiment (± SD).

Replication (week)	Bruise severity (ml)
1	0.1 ± 0.2 c
2	0.1 ± 0.2 c
3	0.4 ± 0.6 b
4	0.9 ± 1.1 a

Bruise severity values not sharing the same letter are significantly different at 95% confidence interval.

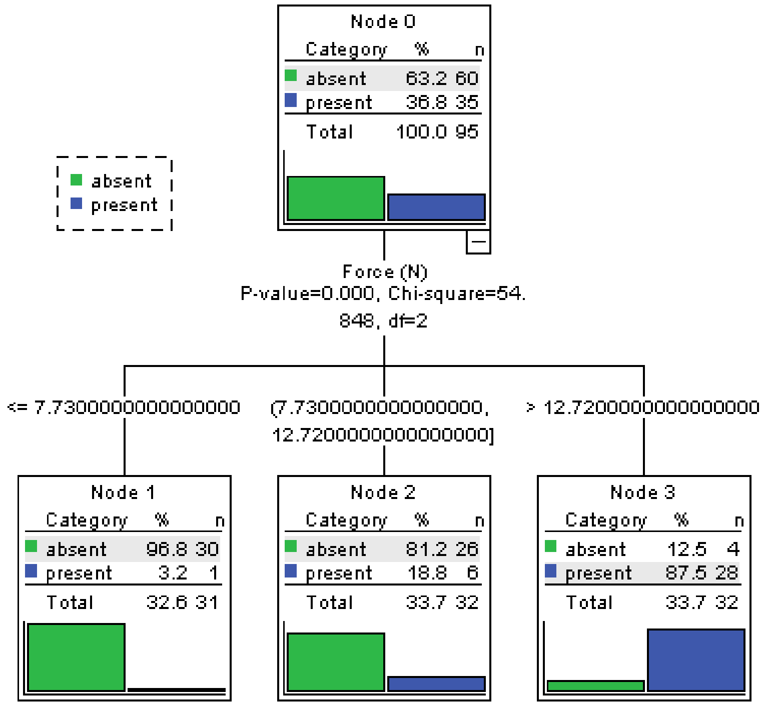

Fig. 4.11 Decision tree of the relationships for compression forces applied by shoppers for fruit firmness assessment and resultant flesh bruising in firm ripe avocado cv. 'Hass' fruit. The left bar within each box shows the proportional (%) absence of bruising. The right bar in each box shows the proportional presence of flesh bruising. The top box shows the overall proportional incidence of bruising. The three lower parallel boxes show the incidence of flesh bruising at different ranges of compression force.

4.6.5 Assessment of an e-glove for measuring the shopper's fruit squeezing pressure

The pilot evaluation of the Grip™ sensor e-glove study showed that the fruit squeezed by shoppers developed significantly ($P \leq 0.05$) more flesh bruising as compared with unhandled control fruit. Average bruise severity in the control fruit was 0.6 ± 0.9 ml. In contrast, it was 1.1 ± 1.7 ml, 3.0 ± 2.8 ml, and 5.8 ± 5.1 ml in fruit squeezed at softening, firm ripe, and soft ripe hand firmness stages, respectively.

The results of the in-store experiment show that as the fruit firmness measured with Turoni Hardness Tester for softening, firm ripe, and soft ripe fruit decreased, the mean flesh bruising due to squeezing with the Grip™ sensor e-glove increased (Table 4.11). Shoppers squeeze hard on softening fruit and that pressure applied for firmness assessment reduces with decreasing fruit firmness to the firm ripe and soft ripe stages of hand firmness (Table 4.11, Fig. 4.12).

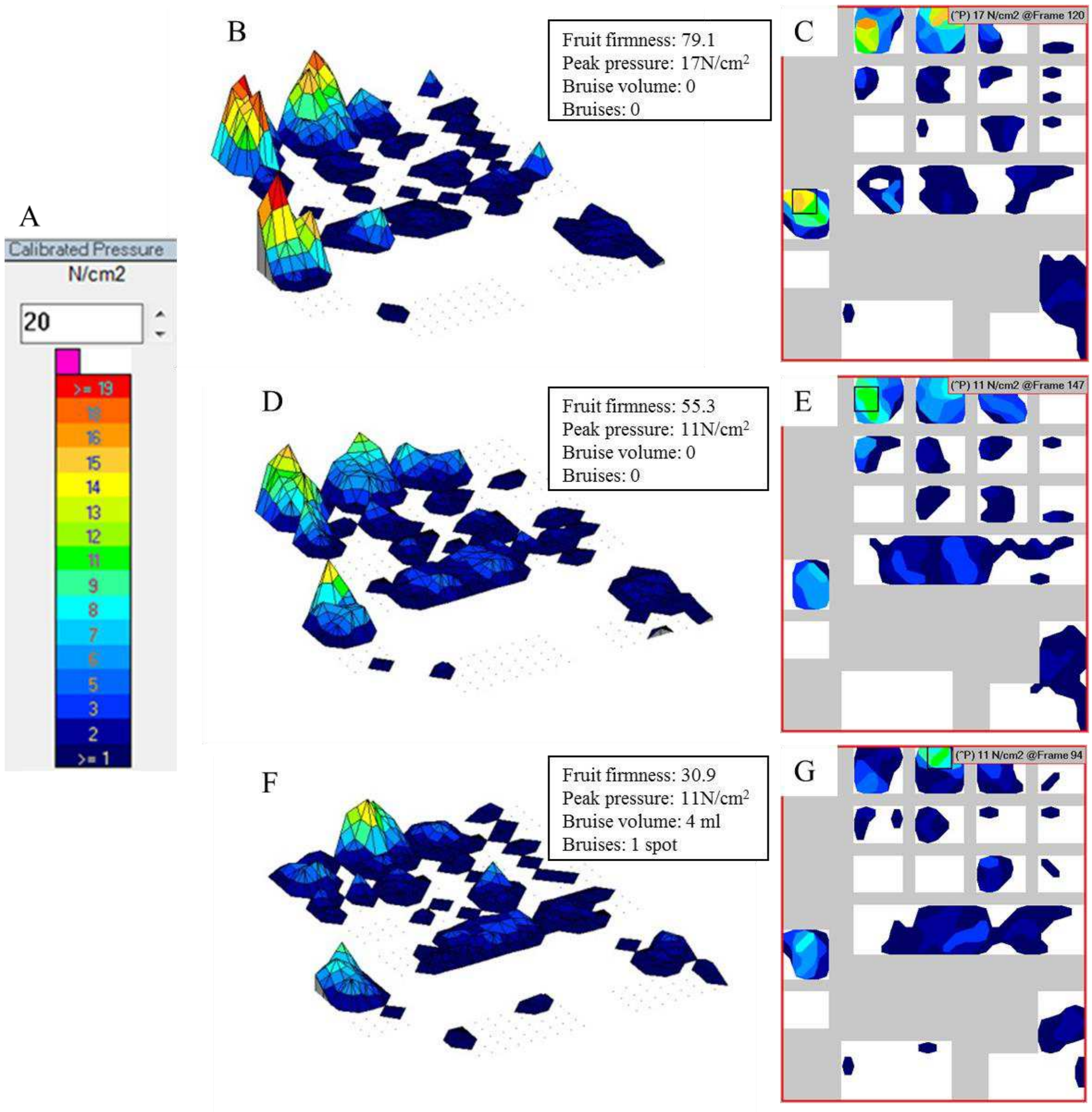

Fig. 4.12 (A) False colour calibration bar for pressure as applied by with the Grip™ sensor in N.cm^{-2} pressure. (B, D, F) 3D view of pressures applied by different parts of a shopper's right hand to softening, firm ripe, and soft ripe fruit, respectively. The corresponding text boxes present fruit firmness values as measured with a Turoni Hardness Tester, peak pressures as applied with the Grip™ sensor e-glove, resultant bruise volumes in the fruit, and bruise number in the fruit flesh. (C, E, G) 2D plan view of the pressure readings of the pressure sensor pads of Grip™ sensor e-glove for softening, firm ripe, and soft ripe stage fruit, respectively. The small square boxes outlined in black on the pressure sensor pads show the part of hand where the shopper applied peak force on the fruit in the course of firmness assessment.

Table 4.11 Mean values of peak pressure applied by shoppers and measured with Grip™ sensor e-glove, fruit firmness measured with Turoni Hardness Tester (THT), and bruise severity in softening, firm ripe, and soft ripe avocado cv. 'Hass' fruit (n = 50) (± SD).

Hand firmness	Firmness (THT)	Peak pressure ($N.cm^{-2}$)	Bruise severity (ml)
Softening	67.8 ± 7.7 a	11.2 ± 0.8 a	1.6 ± 2.7 c
Firm ripe	50.5 ± 2.9 b	9.02 ± 0.8 b	3.9 ± 3.2 b
Soft ripe	29.0 ± 2.4 c	8.29 ± 0.8 b	6.3 ± 4.1 a

Mean values sharing the same letter do not differ significantly from each other by Tukey's LSD test at P = 0.05. ± values represent the mean standard error for the peak pressure and standard deviation for firmness and bruise severity.

The average age range of the respondents was from 36 to 45 years. On the prospect for choice of either in-store printed point of sale material or a decision aid tool, 33% preferred the former and 44% preferred the latter. Regarding the parts of their hand used for firmness assessment, the survey responses suggested that 18% use only their thumb, 20% use their thumb and index finger, 8% use their thumb and middle finger, 8% use their thumb and forefinger, 8% use all fingers, and 6% use their whole hand.

Furthermore, 90% of the shoppers reported that they feel for firmness / softness of fruit when they assess the fruit at the retail display. Only 8% shoppers reported that they considered skin colour an indicator of fruit ripening. The remaining 2% reported that they feel for other fruit features, like if the stone has separated from the flesh by shaking the fruit and if the button at the stem end has separated from the fruit. The shoppers who participated in the in-store experiment were 32% female and 68% male.

The confirmatory experiment confirmed that bruise severity in avocado fruit squeezed by shoppers with bare hands, wearing cotton gloves, and wearing the e-glove compared with the unhandled control fruit is on par ($P > 0.05$) (Table 4.12).

Table 4.12 Mean bruise severity in fruit squeezed by shoppers (n = 20) with bare hands, wearing cotton gloves, wearing e-glove and un-squeezed control (± SD).

Replication (week)	Bruise severity (ml)
Bare hands	1.0 ± 2.1 a
Cotton gloves	0.05 ± 0.2 a
E-glove	0.5 ± 2.0 a

Control	0.0 ± 0.0 a

Bruise severity values not sharing the same letter are significantly different at 95% confidence interval.

4.6.6 In-store observations of shoppers' fruit handling practices

In this experiment on observations of shoppers' fruit handling practices of fruit on retail display, ~ 74% of the shoppers were female and ~ 26% were male. In terms of age groups, ~ 45% shoppers were 'young', ~ 32% 'mature', and ~ 23% 'old'. Sub-grouping revealed that the shoppers were comprised of 31.5% young females, 13.2% young males, 24.9% mature females, 7% mature males, 17.5% old females, and 5.8% old males. The average time spent at the retail display by female shoppers was 6.4 sec and that spent by male shoppers was 5.5 sec. Female shoppers handled an average of 3.4 fruit and purchased on an average of 1.3 fruit. Male shoppers handled 2.3 fruit and purchased 1.0 fruit. Young female shoppers spent 6.4 sec at the display, handled 3.2 fruit, and purchased 1.3 fruit. Young male shoppers spent 4.7 sec at the display, handled 2.1 fruit, and purchased 1.1 fruit. Mature female shoppers spent 6 sec on display to handle 3.5 fruit and purchase 1.4 fruit. Mature male shoppers handled 2.6 fruit in 7.6 sec and purchased only 0.9 fruit. Old female shoppers spent 6.8 sec on display, handled 3.4 fruit, and purchased 1.4 fruit. Old male shoppers purchased 1 fruit after handling 2.5 fruit on the retail display in 4.7 sec (Table 4.13).

Table 4.13 Fruit handling observations for in-store shoppers (n = 257). Age group and gender of the shoppers are presented against mean values of time (sec) spent by shoppers on retail display, number of fruit handled by shoppers, and number of fruit purchased by shoppers.

Group of shoppers	Number of shoppers (n)	Mean Time spent on display (sec)	Mean number of fruit handled	Mean number of fruit purchased
Young	115	5.87	2.89	1.23
Females	81	6.37	3.22	1.27
Males	34	4.68	2.09	1.12
Mature	82	6.37	3.27	1.28
Females	64	6.03	3.47	1.38
Males	18	7.56	2.56	0.94
Old	60	6.27	3.18	1.30
Females	45	6.80	3.42	1.40

Males	15	4.67	2.47	1.00

Maximum and minimum times spent at the retail display by shoppers were 41 sec and 1 sec respectively. Two shoppers squeezed up to 15 fruit in a single visit. On the other hand, some shoppers did not touch even a single fruit during their visit of the avocado retail display. Numbers of fruit purchased by shopper visiting the avocado display ranged from zero to six. Peak hours of the day in terms of number of shoppers visiting the avocado retail display were 11 am and 3 pm.

4.7 Consumers' contribution to flesh bruising

4.7.1 Fruit sampling through the supply chain

Mean bruise severities (± SD) in avocado cv. 'Hass' fruit (n = 20) randomly sampled at seven serial points of the supply chain were 0.2 ± 0.1 ml, 0.2 ± 0.1 ml, 0.3 ± 0.1 ml, 0.3 ± 0.1 ml, 1.6 ± 0.5 ml, 5.4 ± 0.2 ml and 9.6 ± 2.2 ml respectively. The average bruise severity in fruit collected from sampling points 1 to 5 was statistically on par and significantly ($P \leq 0.05$) lower than bruise severity in fruit collected from multiple sampling points 6. The bruise severity in fruit sampled from the multiple sampling points 7 was significantly higher ($P \leq 0.05$) again (Fig. 4.13). In ~ 20% of fruit sampled at sampling points 7, average bruise severity was > 20 ml in single fruit.

4.7.2 Bruise free fruit subjected to consumer handling practices

Clean fruit handed to consumers at the check-out point of a supermarket retail store developed an on average flesh bruise volume of 0.8 ± 0.2 ml as compared to control fruit at 0.0 ± 0.0 ml. The range of bruise severity due to consumer handling practices was from 0 to 7 ml per fruit (Fig. 4.14). Bruise severity in the four replicate runs of the experiment was statistically on par (Table 4.14).

Table 4.14 Mean bruise severity in fruit (n = 25) subjected to consumers' handling practices from the point of purchase to the point of consumption in four replications of the experiment (± SD).

Replication (week)	Bruise severity (ml)
1	0.9 ± 1.7 a

2	0.9 ± 1.8 a
3	0.8 ± 1.4 a
4	0.7 ± 1.4 a

Bruise severity values not sharing the same letter are significantly different at 95% confidence interval.

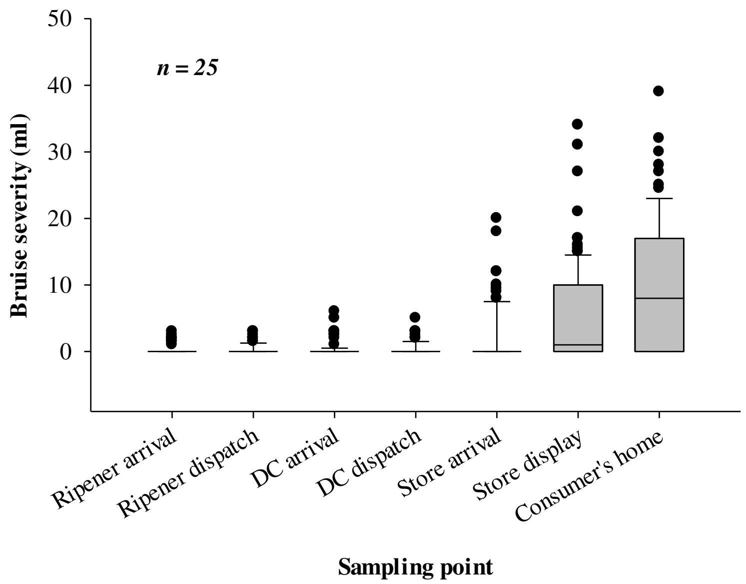

Fig. 4.13 Boxplot of bruise severity in avocado cv. 'Hass' fruit (n = 20) sampled from seven serial sampling points of a supermarket retail store chain and subjected to destructive bruising assessment. Fruit sampling points were: ripener arrival, ripener dispatch, distribution center arrival, distribution center dispatch, retail store arrival, retail store display, and the consumer's home. Bottom boundaries of the bars represent the first quartile, and the lines within the bar show 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.

4.8 Consumer's attitude to flesh bruising

Avocado cv. 'Hass' consumers experienced a wide range of flesh bruising. Fruit sampled through the supply chain and destructively assessed for bruise severity had an average of 9.6 ± 2.2 ml of flesh affected by bruising in those fruit sampled at the final point of the consumer's home (Section 4.7.1). The range in bruising varied from 0 to ~ 40 ml per fruit. Clean fruit presented to consumers at retail check-out and collected from their homes had 0.8 ± 0.2 ml bruising (Section 4.7.2). The bruise severity in collected fruit varied from 0 to ~ 7 ml per fruit.

Average bruise severity in fruit picked by consumers from the retail display of a supermarket retail store, evaluated in another study (presented in the final report of HIA Project AV10019), was 1.0 ± 1.5 ml. The range of flesh bruising in the fruit of retail display was also from 0 to ~ 40 ml per fruit. Flesh bruising in fruit subjected to controlled impact from 50 cm drop height was, on an average, 8.8 ± 4.3 ml (Section 2.9.3) (Table 4.15). Range of the bruise severity was from 0 to 22 ml per fruit.

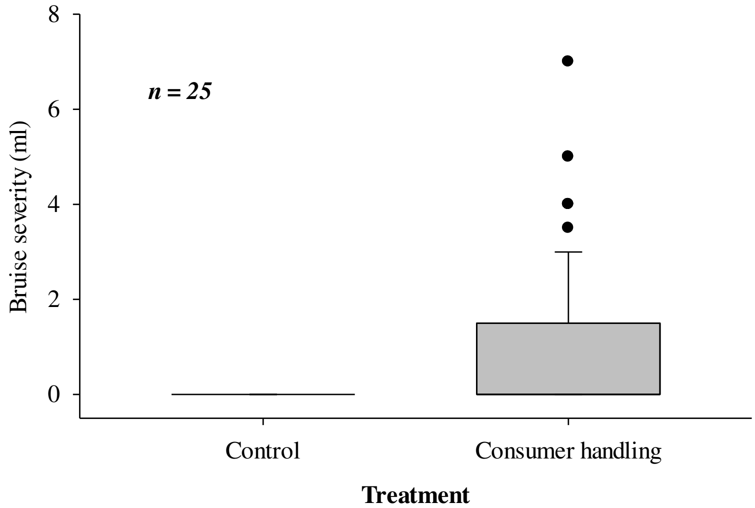

Fig. 4.14 Bruise severity (ml) in avocado cv. 'Hass' fruit subjected to consumers' fruit handling practices at firm ripe stage of firmness and destructively assessed for bruising after collection from consumers' homes. Control fruit did not show any bruising. Bottom boundary of the bar in this figure represents the first quartile and the median of the data. Upper boundary of the bar represents the third quartile. Top terminal point of the perpendicular line on the bar represents the maximum range of the data. Black dots show the outlier values.

The 178 consumer responses showed that 49% of the consumers held their fruit on a table in their kitchen, 25% held them in a fridge, 24% held them in a fruit bowl (24%) and 2% kept them in a cupboard. The incidence of flesh bruise incidence was reported as 50% by 50% of consumer respondents, as 0% by 33%, 25% by 12%, 100% by 4%, and 75% by 1% of them.

Table 4.15 Mean bruise severity in pre-bruised avocado cv. 'Hass' fruit (n = 20) given to consumers for their responses on level of satisfaction and intention to repeat purchase as affected by the bruise severity in four replications of the experiment (± SD).

Replication (week)	Bruise severity (ml)
1	9.2 ± 2.6 ab

2	8.0 ± 2.3 bc
3	11.6 ± 3.8 a
4	6.4 ± 6.0 c

Bruise severity values not sharing the same letter are significantly different at 95% confidence interval.

Out of 244 consumer responses, 32% reported no bruise severity in the fruit at the time of consumption, 36.5% reported 0-10% flesh affected by bruising, 18.5% reported 11-25% of fruit flesh affected by flesh bruising, 9% reported 26-50% flesh bruise severity, and 4% reported more than 50% fruit flesh affected by bruising.

According to the diary notes, 47% reported that they were very satisfied with the avocado fruit quality and their consumption experience, 22% were satisfied, 13% were just OK, 11.5% were dissatisfied, and 6.5% consumers were very dissatisfied with the fruit consumption experience in terms of flesh bruising.

The avocado consumption experience did not affect the decision to repeat purchase with ~ 84% of the consumers, whereas the decision to repeat purchase of avocado cv. 'Hass' fruit of 16% was negatively affected.

Dissatisfied consumers included 5% of the consumers who experienced up to 10% flesh bruising, 24% of the consumers who experienced 11-25% flesh bruising, and 56% of the consumers who experienced 26-50% flesh affected by flesh bruising. The group of very dissatisfied consumers was comprised of 12% of the consumers who experienced 11-25% flesh bruising, 22% of the consumers who experienced 26-50% flesh bruising, and 83% of the consumers who experienced more than 50% of flesh affected by flesh bruising.

Consumers who reported that their decision to repeat purchase avocado cv. 'Hass' fruit was affected by their recent consumption had experienced bruise severity of more than 50% of the fruit flesh (15%), 26-50% (41%), 11-25% (41%), and 1-10% (3%). From the similar group of consumers, 5% consumers reported that they were still satisfied with the product quality, 8% consumers said that they were just OK, 46% consumers said that they were dissatisfied and 41% consumers advised that they were very dissatisfied with the extent of flesh bruising in avocado fruit at the time of consumption.

4.9 Decision aid tool

The prototype decision aid tool or DAT was developed with the support of the Queensland based electronics engineering firm, Pacific Data Systems. The Gen I device is comprised of a force sensor connected to a console with six green (bottom and lower middle), three amber (upper middle) and one red LED (top) lights (Fig. 4.15). The green LEDs light up initially with increasing compression. The red LED lights up as a warning of imminent over compression. Three different use or fitness for purpose categories for avocado fruit at serially increasing stages of hand firmness are printed adjacent to corresponding LED lights as prints on the console: six green LEDs span 'spread / dip' and then 'sliced / diced'; three amber LEDs span 'firm, ready to eat from two days'. Accordingly, the shopper should ideally stop squeezing when the LEDs light bar illuminates up to reach the firmness desired for the consumptive utilisation purpose. In addition, for quantitative information to developers, actual force sensor readings in N units can be viewed on a screen concealed from the shopper on the back of the console.

Thus, when a shopper assesses avocado fruit firmness with the force sensor of the DAT, lighting up of the green to amber LEDs will guide him or her as to the stage of fruit firmness. The harder the fruit, the more compression force will need to be applied by shoppers. At a preset specific and relatively high level of force, the red LED light will illuminate to warn the shopper not to compress any further. The shopper may then chose to try another fruit to test for the consumption purpose.

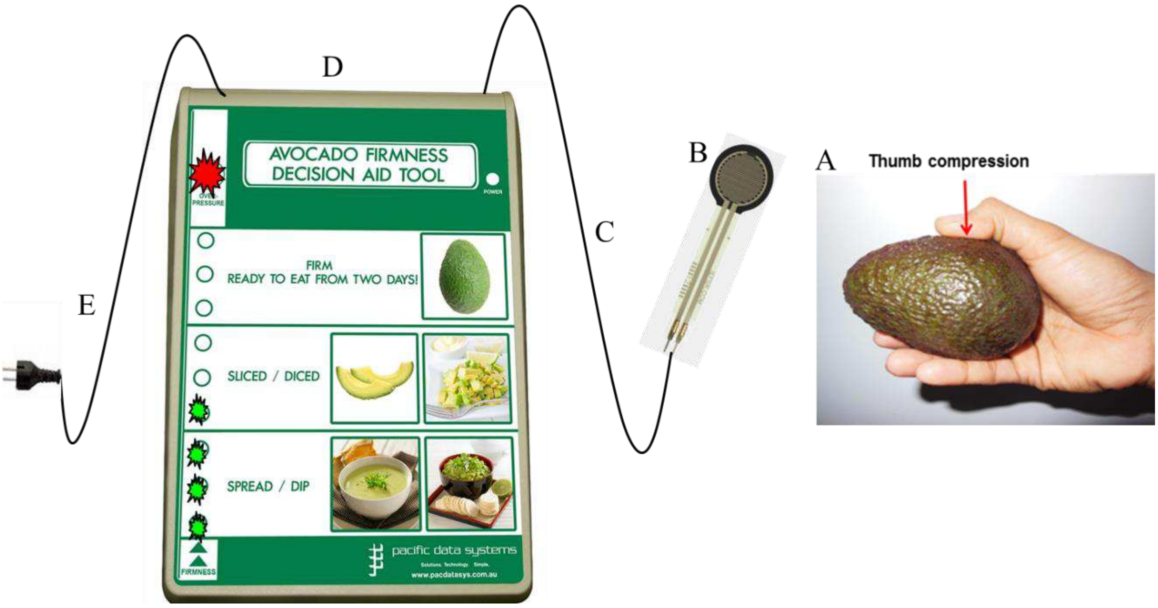

Fig. 4.15 Set up and operational procedure of the decision aid tool (DAT). A: Shopper assessing the fruit firmness. B: Force sensing resistor. C: Cable for connection between the force sensor and the DAT console box. D: DAT console box with the front view visible to the shoppers. E: Power connection. The lighting up of green LED lights from bottom towards the top reflects the level of force applied by the shopper and the corresponding avocado use prints informs the shopper as to the individual fruit's fitness for consumption use purpose. As a fail-safe measure, a red LED would illuminate to warn the shopper when the compression force would reach a pre-set maximum threshold compression force level.

5. Evaluation and Discussion

Project activities were prioritised in consultation with industry and other stakeholders. Stakeholders included Avocados Australia Limited (AAL), avocado growers, ripeners, wholesalers, retailers and service providers. Pre-season consultation meetings were conducted at the beginning of each Queensland 'Hass' avocado fruiting season to share activity plans and adjust them according to inputs from stakeholders. Similarly, post-season meetings were conducted at the end of each avocado season to share the findings of each year with the same stakeholders. Laboratory experiments were conducted in collaboration with avocado growers, wholesalers and ripeners, and external agencies and institutes including Pacific Data Systems and Griffith University. In-store experiments were conducted in collaboration with the two major supermarket retail chains of Australia. Project findings were available in real time for participating industry stakeholders to incorporate in their everyday avocado fruit handling practices if and as appropriate.

This project has greatly enhanced the understanding of flesh bruising responses over time in individual avocado cv. 'Hass' fruit at different hand firmness stages as subjected to various impact and compression force levels. Moreover, for fruit unitised in trays, influences of drop height and drop angle on fruit bruising and deformation in fruit flesh were investigated for the first time. The insight gained on bruise expression relative to causal events provides for more informed bruise assessment and consequently informs bruise monitoring and reduction practices in commercial avocado supply chains. In order to develop a more complete cause and effect profile and to lean threshold tray drop heights and angles with respect to flesh bruising, this initial research should ideally be expanded in the future.

Clearly, based on the results of several experiments, shoppers' squeezing of fruit for firmness assessment is a major cause of flesh bruising in avocado fruit. Moreover, the damage in terms of bruise severity increases over the course of consumers' fruit handling between the point of purchase and consumption. The key findings of this project, as complemented by the findings of the allied HIA Project AV10019, have been illustrated in draft pictorial guides (Appendix A) as a potential step towards shopper and consumer education. Retail store staff also contribute to ultimate flesh bruising experienced by the consumers. The first-cut draft guides cover: avoid fruit squeezing on retail display; minimise fruit holding duration; keep fruit at low temperatures through the supply chain into consumers' homes. Nonetheless, the principles extolled warrant validation in further research in the supply chain context as do education materials in a utility to the target audience context.

Knowledge of relationships among fruit firmness, applied compression forces and pressures, resultant flesh bruising, consumers' tolerance levels for flesh bruising, and their notional acceptance of an in-store decision aid tool (DAT) for assisting in the avocado fruit purchase decision, informed the development of a 'first generation' (Gen I) prototype DAT. Future research into helping shoppers with fruit selection in-store, while simultaneously avoiding overpressures that lead to flesh bruising, is proposed.

The DAT was demonstrated to industry stakeholders in 2014 post-season meetings. They were positive as to the prospects for its further development and refinement for in-store use. Future generation devices may continue to be decision aid based, in allowing the shopper to determine the end point of squeezing; i.e. decision aid tools. Alternatively, they may be strictly decision based in terms of reporting the mechanical firmness of individual fruit without manually involving the shopper in the process of fruit choice, i.e. decision tools. For future development of the best bet tool, a combination of consumer survey and device testing would be adopted to inform the development and refinement process.

The project findings have proven to industry that reducing or eliminating fruit squeezing by shoppers at the retail display point is the single most critical control point to reduce flesh bruising in the avocado fruit supply chains. A DAT approach is recommended as is its complementation with point of sale guides. Other information approaches, such as radio, TV and social media are also recommended to spread the work that minimising fruit squeezing at retail level is central to improving avocado fruit quality and repeat purchases by consumers. That is, development and refinement of practices (e.g. tools and education) to reduce flesh bruising caused in fruit at the retail display level, and also subsequently in the home, would undoubtedly lead to greater consumer satisfaction and more repeat purchases.

6. Recommendations

These recommendations should be considered in conjunction with those presented in the final report on complimentary HIA project AV10019. Herein, they are presented in three parts. Section 6.1 presents general recommendations based on the Project AV12009s' overall findings. Section 6.2 presents strategic recommendations that integrate key learning's from this Project. More specific recommendations are presented in Sub-sections 6.2.1 and 6.2.2. The context of these sub-sections is that much of the experimental work reported above researched issues and opportunities in the avocado supply chain that have not previously been properly explored either in Australia or, indeed, oversea; e.g. those at retail store level and into consumers' home. Accordingly, significant scope does remain for acquiring better (e.g. more complete) understanding in a good number of the areas probed in this project (e.g. retail home supply chain stages; novel technologies for fruit selection by consumers; education materials for store staff, shoppers, and consumers) with a view to further increasing demand, including through greater repeat purchase frequency, for cv. 'Hass' avocados by Australian consumers.

6.1 General recommendations based on the research findings

- Training of avocado fruit handling operations staff throughout the supply chain to reduce flesh bruising in avocado cv. Hass fruit.
- Education of and information for store staff, shoppers and consumers on fruit handling at retail level and from retail store into the home to reduce the risk of fruit bruising.
- Development, refinement and implementation of mechanical and / or electronic decision aid tool or decision tool type technologies for use by store staff and / or shoppers at the point of retail sale.
- Complementary development and use of information and education guides to inform store staff and shoppers about how fruit bruising arises and how they can be assisted to select their fruit at the desired stage of firmness without causing flesh bruising.
- A general education strategy through marketing media (e.g. social media, advertisements) that compliments and extends the informing of staff, shoppers and consumers as to how they at retail and / or home levels can help to avoid or minimise fruit bruising.

- Empowerment of all of the abovementioned recommendations through strategic technical (e.g. DAT refinement and / or alternatives) and social (survey of practices and perceptions) research into avocado fruit handing by staff, shoppers and consumers, all with a view to improve consumer satisfaction and increase repeat purchases.

6.2 Strategic recommendations based on the research findings

- Fruit should be handled carefully, both individually and in trays. The higher the impact or compression energy absorbed by the fruit at a given stage of ripening, the greater will be the resultant bruise severity.
- Shoppers and consumers should be informed to understand their role in fruit bruising and educated to assess by less damaging ways the firmness of avocados on retail display. In this context, draft information posters (Appendix A) and the prototype DAT (Fig. 4.15) should be assessed for utility by shoppers.

6.2.1 Specific recommendations concerning extension of the current research

- Firm ripe and soft ripe fruit were bruised due to ~ 10 N compression force applied with the thumb. Threshold hand compression forces that lead to bruise development in avocados at several stages of firmness are still not fully elucidated. Detailed spatial and force information on precise pressure and bruising response levels would inform more objective fruit firmness assessments at retail displays.
- Real world mechanisms of impact or compression in terms of the energies absorbed and their dissipation in avocados at different stages of ripening or softening are not fully characterised. Their characterization in qualitative and quantitative terms would inform new and improved strategies to reduce bruising.
- A sub-group of consumers was found to accept bruise severity of $\leq 25\%$ when it was scattered around beneath the exocarp (skin) in small section sizes (volumes). This 'class' of consumers ideally needs to be categorised in relatively large scale survey research. Moreover, there are likely to be demographic differences across locations and with different fruit handling practices at retail display as well as with different threshold levels of consumer acceptance of bruise severity. The results of such work could inform prioritization of future research investments.

- What decision aid tools (i.e. those notionally involving the shopper in testing to determine fruit firmness in the context of fitness for purpose) or decision tools (i.e. those 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 selections decisions with little or no risk of contributing to bruising in avocados. Development, refinement and adoption of novel technology in retail stores could potentially markedly reduce mesocarp bruising in avocados as experienced at the time of fruit consumption. Satisfied consumers would guarantee future sustained growth of the industry.

6.2.2 Adjunct empowering research opportunities

- The present study has shown that most bruising experienced by consumers happens due to compression force applied by shoppers on the retail stores display. Towards lessening this, the relative effect on levels of mesocarp bruising of marketing individual avocados wrapped in plastic as compared with unwrapped fruit should be explored in qualitative and quantitative measures. In this regard, the perceptions of shoppers and consumers as to their willingness to buy unitised fruit as compared with present bulk retail marketing of 'ripe and ready' single fruit should be ascertained. Unitising the fruit in plastic wraps should reduce individual fruit handling by shoppers and resultant mesocarp bruise severity could be reduced. On the other hand, as consumptive convenience aside, consumer resistance to increased packaging (e.g. pre-packs) is on the rise worldwide.
- Shoppers and consumers are unwittingly bruising avocados in course of firmness assessment during fruit selection. Bruise severity experienced at the time of consumption can very probably be reduced by educating shoppers and consumers as to their role in mesocarp bruising.
- As alluded to above, a 'class' of consumers was discerned to consume avocado mesocarp when it slightly bruised in volumetric and spatial terms. Understanding aesthetic perceptions associated with consumption of mesocarp with some bruising may inform future research and development priorities and marketing strategies, perhaps in the context of food waste reduction.

- From the social science perspective, gender, age, income, education, family composition, etc. for avocado supply chain stakeholders (viz. staff of ripeners, distribution centres, shoppers, consumers) as well as purchase day and time, etc. information are likely reflect on bruise severity profiles in avocado fruit at later stages and points in the supply chain. If relationships among such factors can be established, the research, development, education and even marketing strategies might well be refined to more effectively address (i.e., reduce) mesocarp bruising in 'Hass' avocado fruit in Australian supply chains.

7. Scientific Refereed Publications

N.A.

8. IP/Commercialisation

N.A.

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10. Acknowledgements

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11. Appendices

A: Through the supply chain and point of sale guides.

B: Definitions of terminology.

C: Magazine article 1: Mazhar, M., D. Joyce, P. Hofman. 2015. Bruising and rots development in impacted hard green mature avocado cv. 'Hass' fruit. Talking Avocados. 25, 30-33.

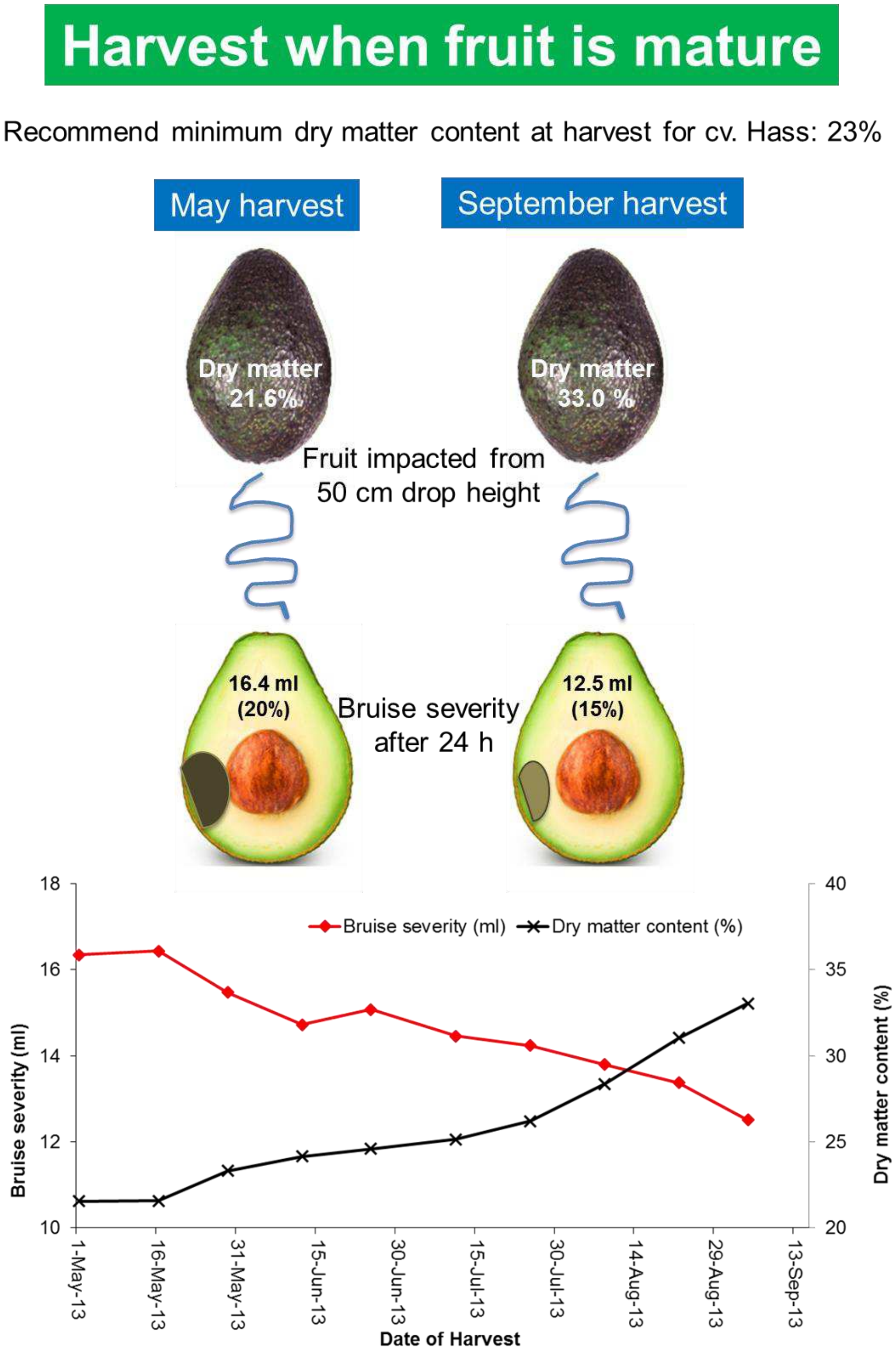
D: Magazine article 2: Mazhar, M., D. Joyce, P. Hofman, R. Collins, M. Gupta. 2014. Bruising by hand in softening avocado fruit – Preliminary study. Talking Avocados. 24, 29-31.

E: Proceeding abstract 1: 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

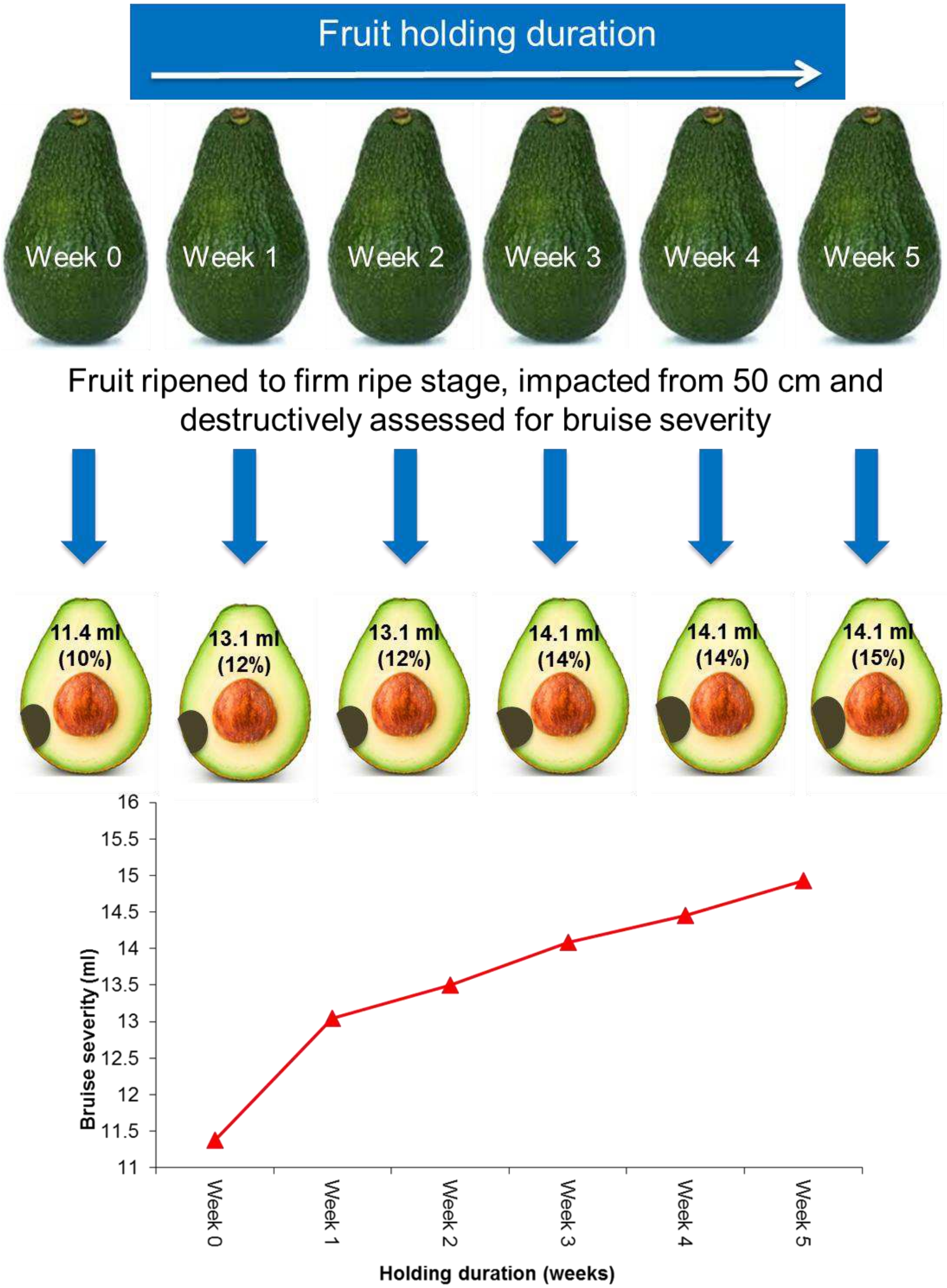
F: Proceeding abstract 2: Mazhar, M.S., D. Joyce, P. Hofman, R. Collins, T. Sun., N. Tuttle. 2013. Reducing flesh bruising and skin spotting in 'Hass' avocados. Online abstracts of 5th New Zealand and Australian avocado grower's conference. Tauranga, New Zealand. . http://www.avocadoconference.co.nz/speakers/abstracts

G: Presentation: Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains: from the ripener to the consumer. Thesis review seminar. University of Queensland, Australia.

Appendix A: Avocado fruit handling through the supply chain and 'point of sale' guides

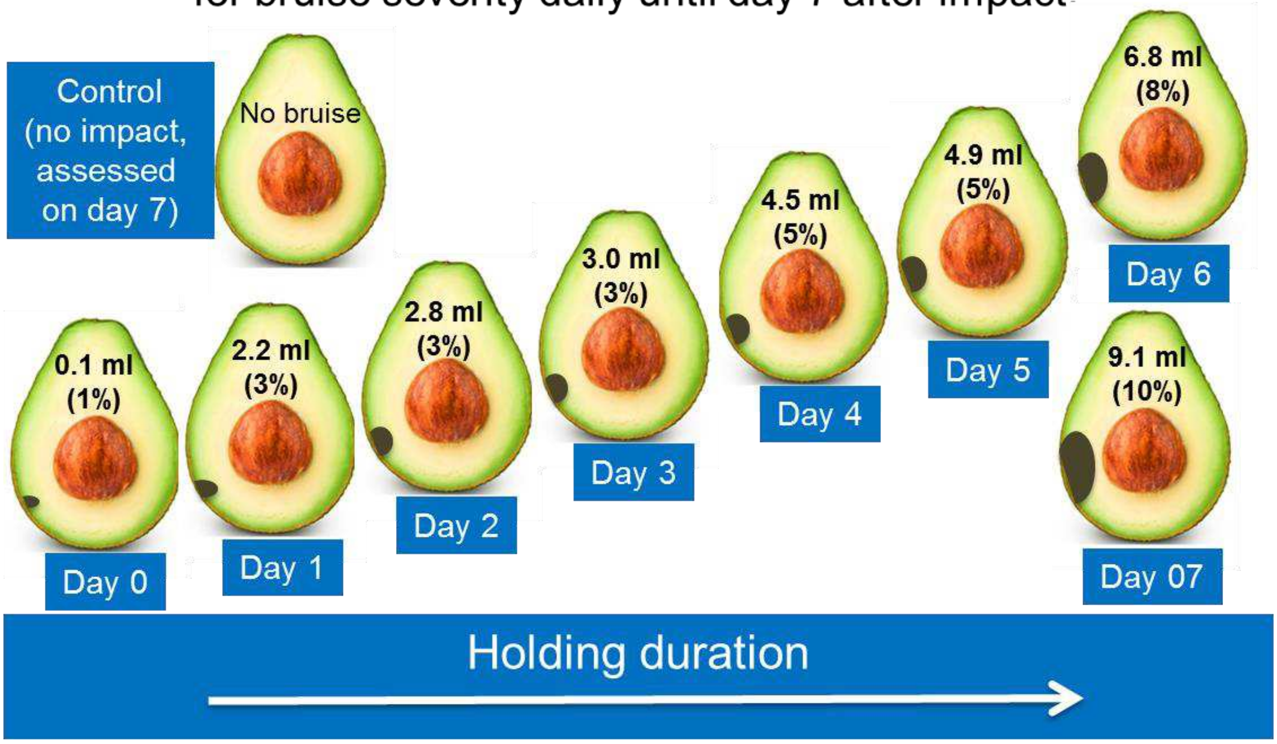


Minimize pre-ripening holding

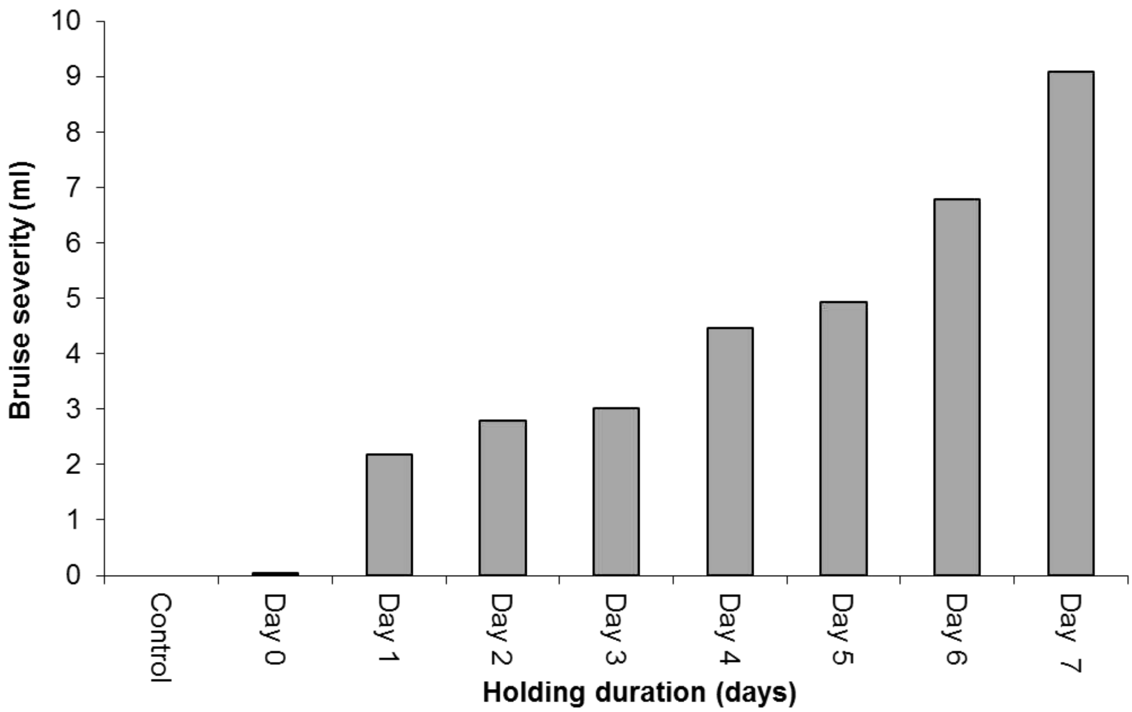


Minimize post-impact holding

Firm ripe fruit impacted from 50 cm and destructively assessed for bruise severity daily until day 7 after impact

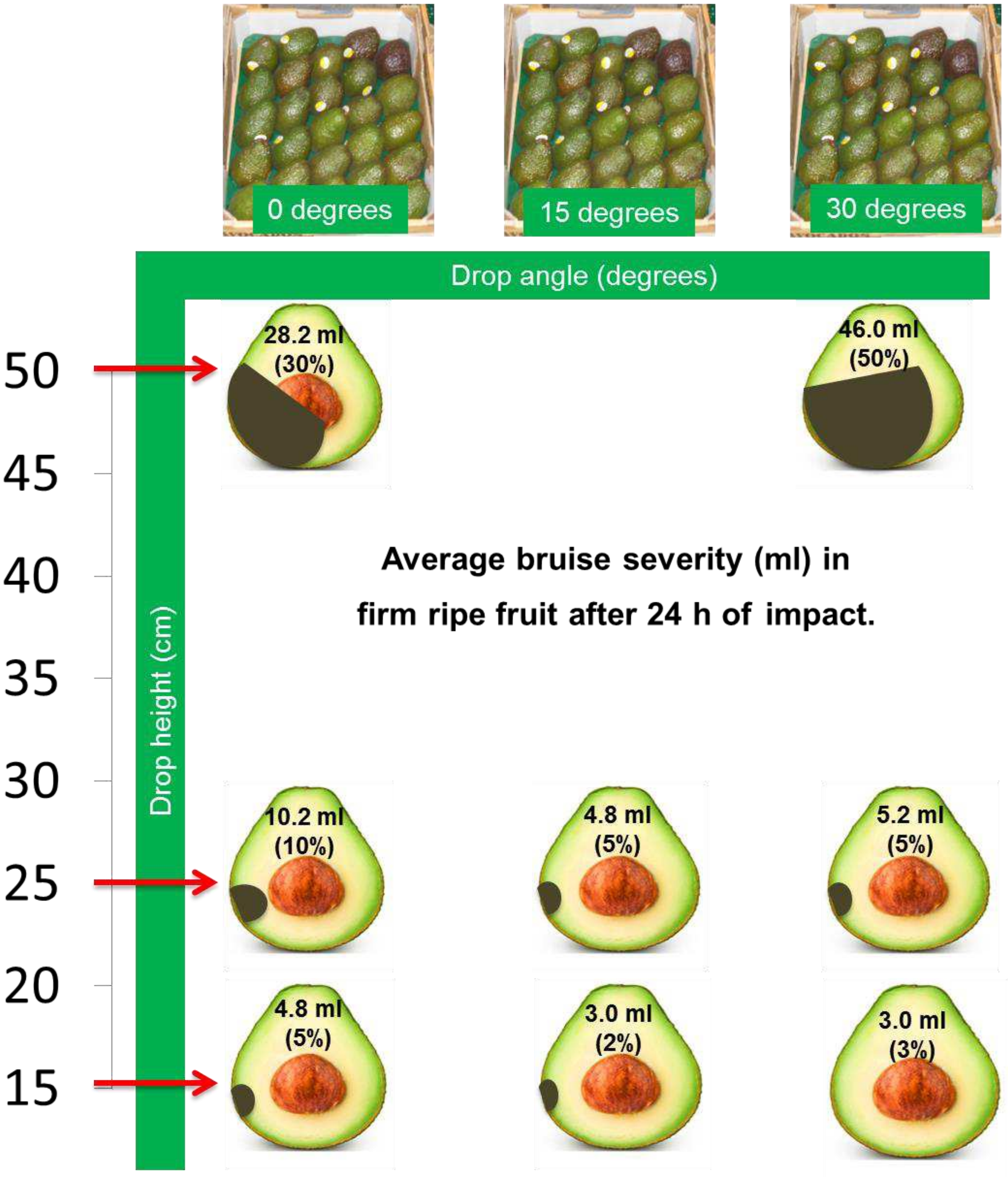


Bruise severity increases with longer post-impact holding duration



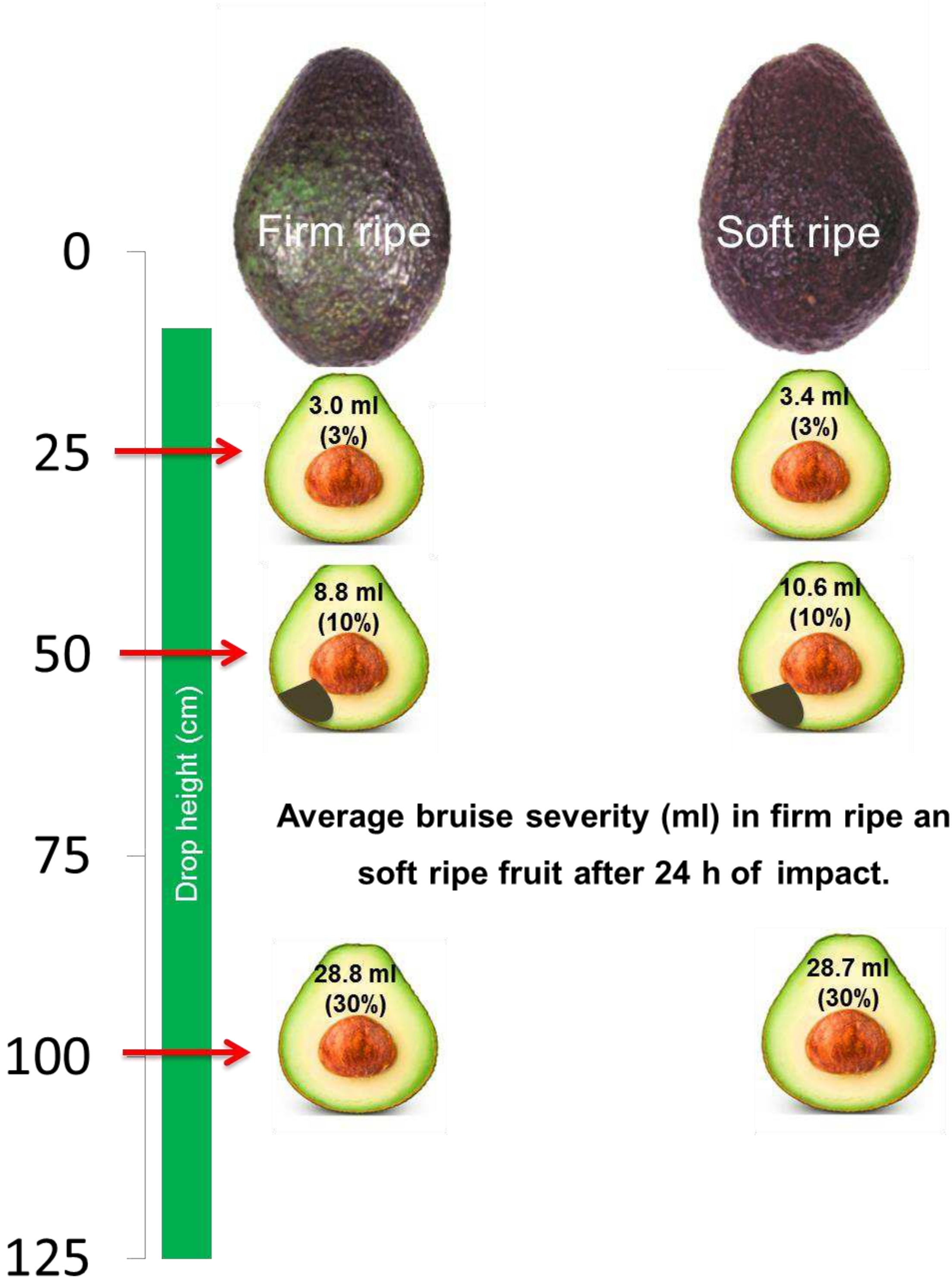
Handle avocado trays with care

Both the tray drop height and drop angle affect bruise susceptibility of the fruit.



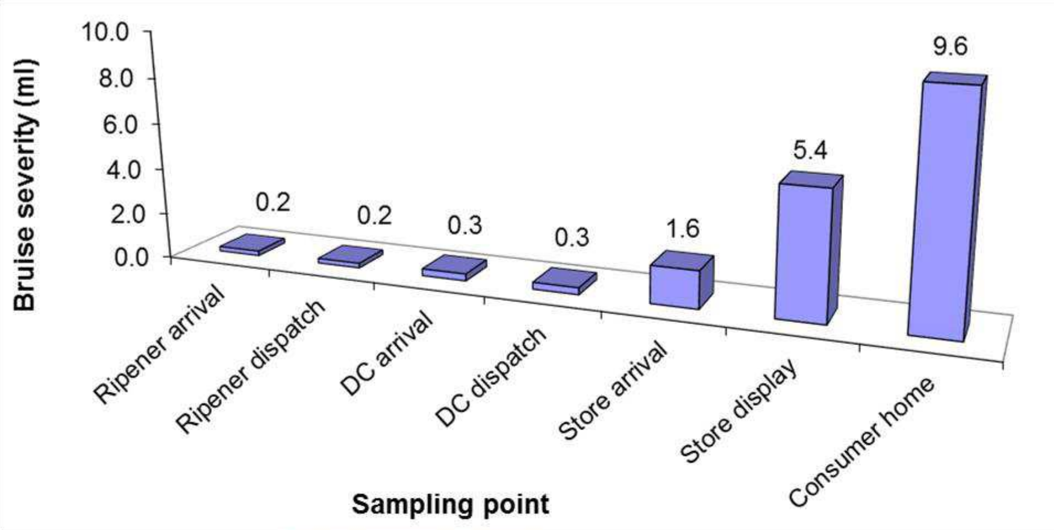
Greater drop height, more bruising

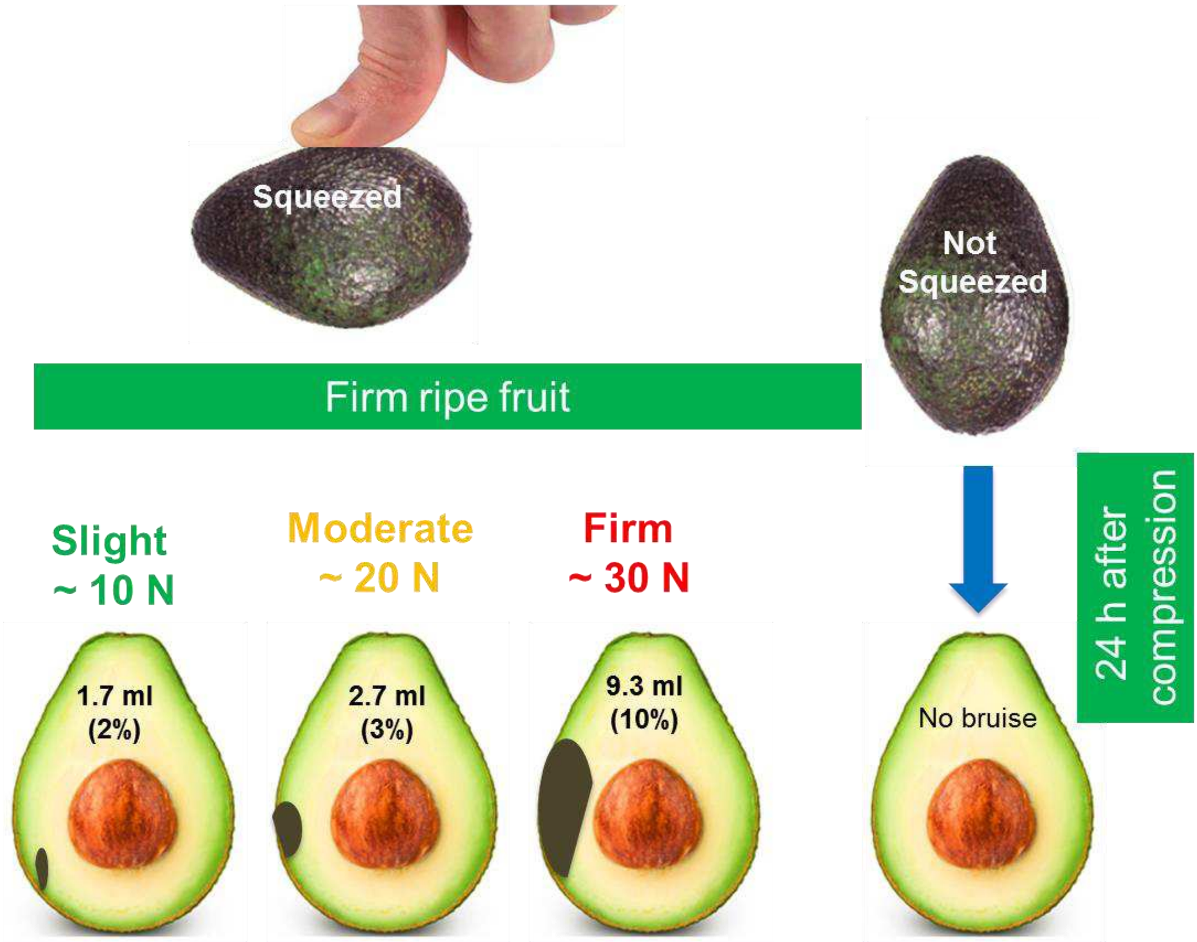
Firm ripe and soft ripe fruit subjected to impact from several drop heights and destructively assessed for bruise severity.



Average bruise severity (ml) in firm ripe and soft ripe fruit after 24 h of impact.

Do not squeeze…

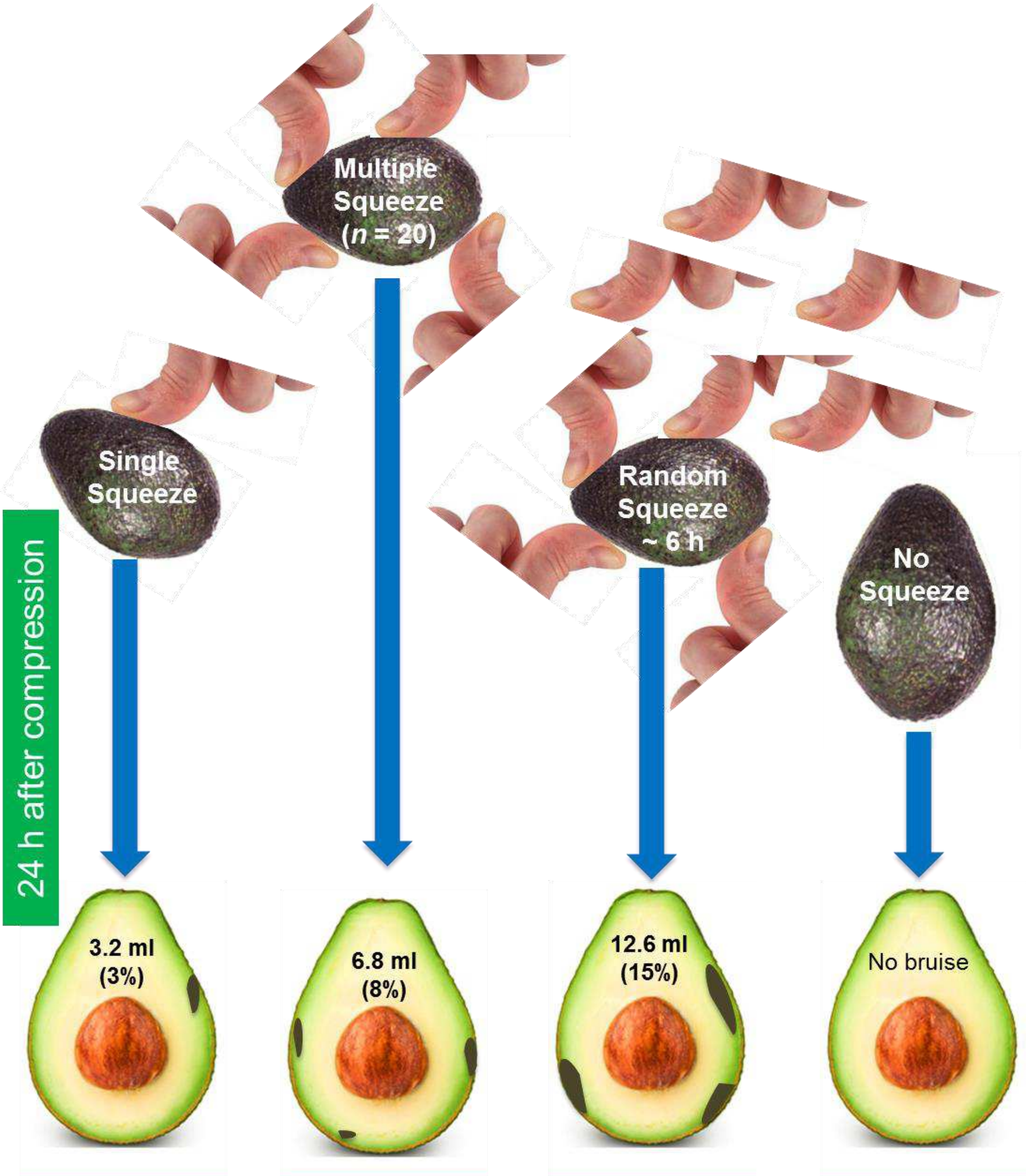




These results are due to single squeezing.
Every squeezing event continues to add to the ultimate bruise severity at the time of fruit consumption.

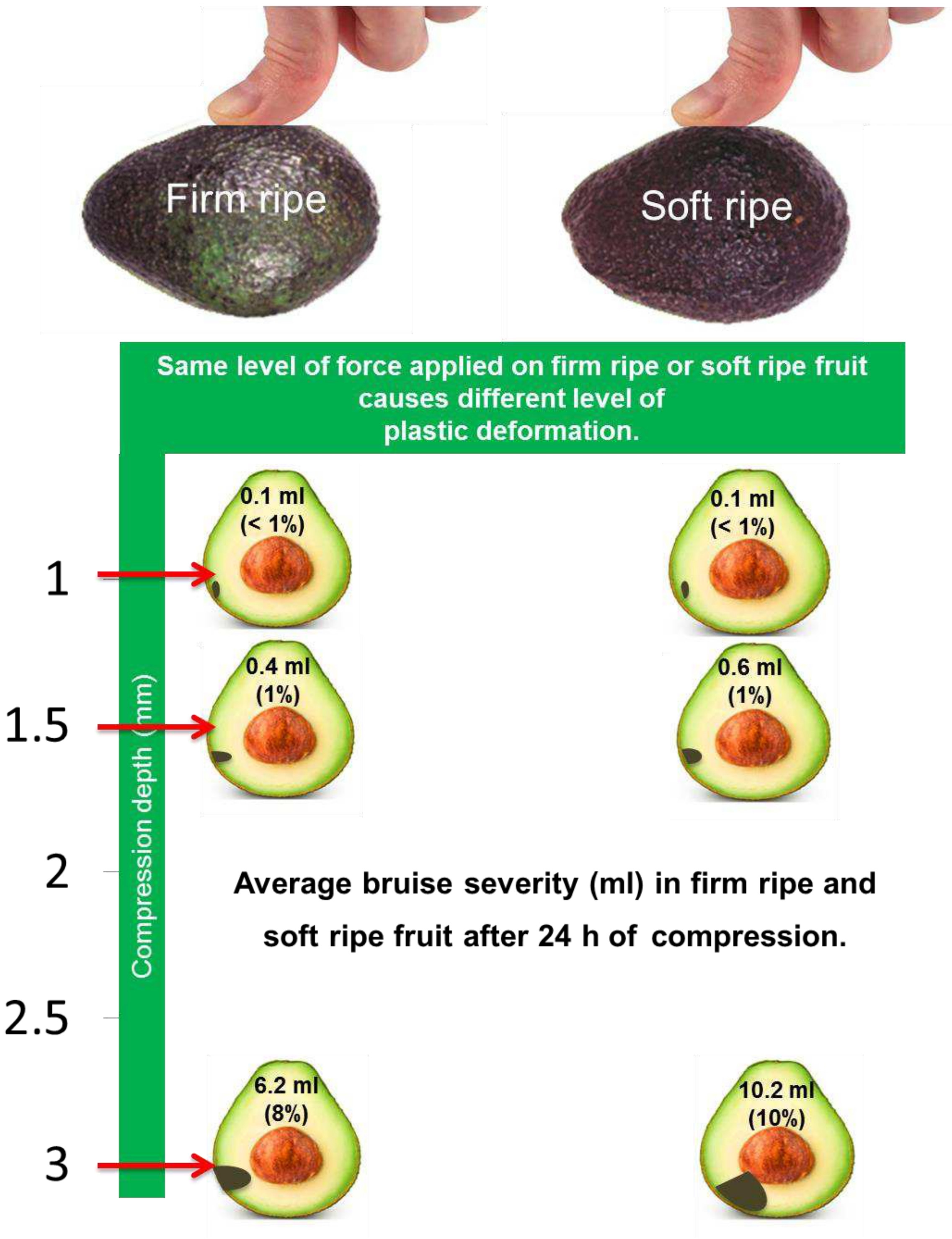
Single, multiple and random squeezing

Average bruise severity in firm ripe avocado fruit subjected to single, multiple and random squeezing compared with a control.



Every squeezing event continues to add to the ultimate bruise severity at the time of fruit consumption.

Deep compression, more bruising

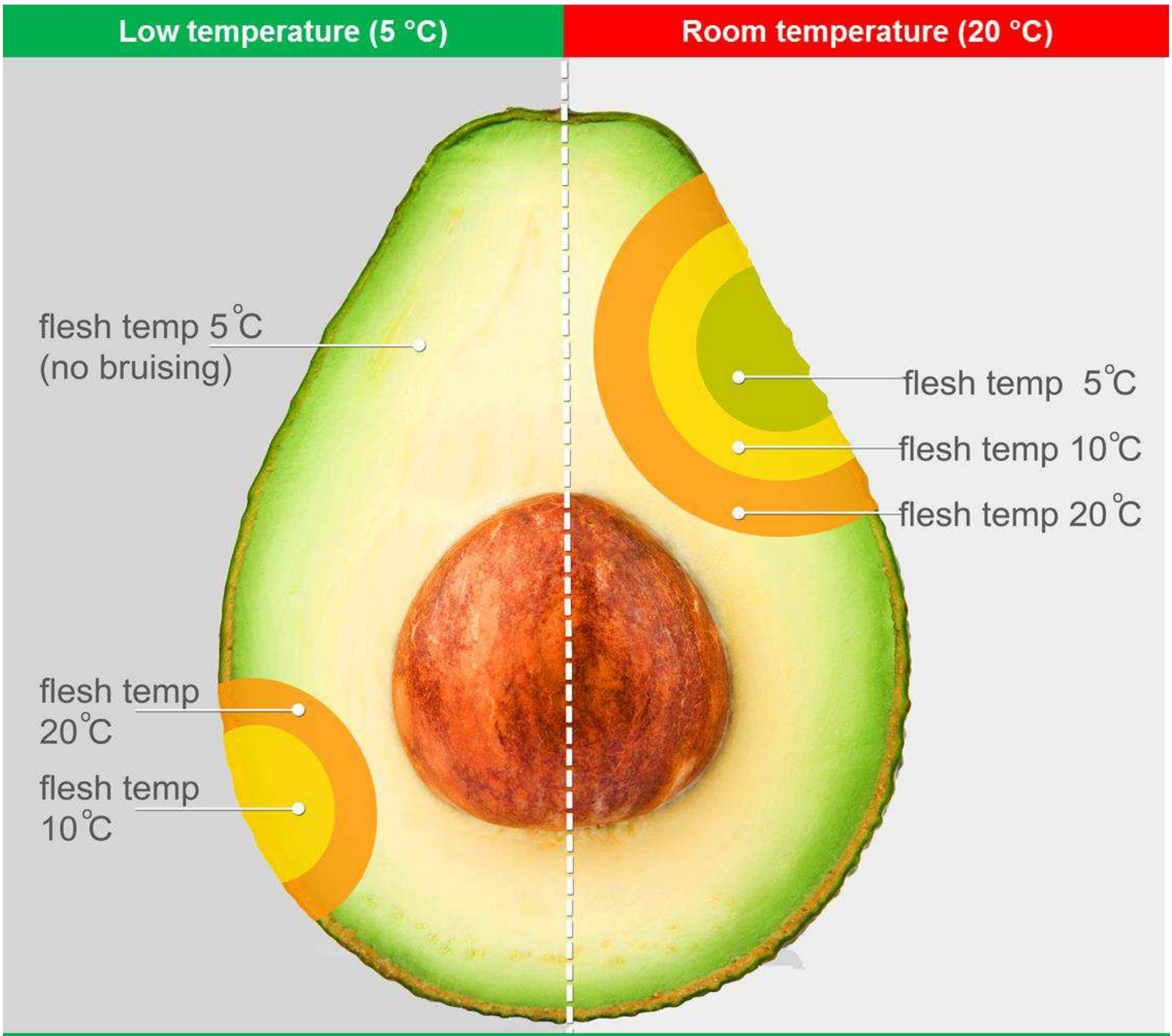


Temperature management can reduce bruise expression

in an avocado fruit subjected to an impact or compression

Flesh bruising is the expression of the activity of polyphenol oxidase enzyme.

Holding avocado fruit at low temperature of 5 °C masks the bruise expression compared with any of the higher temperature of 10 °C , or 20 °C .



Bruise expression in firm ripe avocado fruit impacted from 50 cm height and held at 5 °C, 10 °C , or 20 °C .

Appendix B: 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 C: Bruising and rots development in impacted hard green mature avocado cv. 'Hass' fruit

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Introduction

Australian avocado fruit production, consumption and exports continue to increase, with 'Hass' being the leading cultivar (HAL 2011). However, despite overall growth of the industry, consumers are dissatisfied with the internal quality of fruit on retail display (Harker et al. 2007; Gamble et al. 2008; Harker 2009).

Flesh bruising and rotting are the main reasons for poor internal avocado fruit quality (Hofman & Ledger 2001). Bruising happens in response to mechanical impact or compression damage. Bruise expression involves discolouration associated with enzyme activity on phenolic compounds within the bruise area (Linden & Baerdemaeker 2005). Rotting reflects the activity of fungal plant pathogens that mostly infect fruit in the field and typically remain dormant until the fruit starts to ripen (Everett & Pushparajah 2008).

Various approaches to minimise flesh bruising and rotting have been devised. Flesh bruising can be reduced by handling fruit less ripe and using protective packing (Arpaia et al. 2005). Measures to reduce rotting include utilising appropriate rootstocks, practicing good orchard hygiene, and applying pre- and postharvest fungicides (Everett & Pushparajah 2008). However, such measures have not eliminated flesh damage in the ripe fruit.

Anecdotal evidence suggests that hard green mature avocado fruit do not bruise in response to common levels of impact. In this regard, Hofman (2003) reported that only a little bruising was evident upon ripening of hard green mature fruit collected from the end of a packing line. Mazhar et al. (2013) used magnetic resonance imaging (MRI) to visualise differences between the impact zone and the surrounding sound mesocarp in hard green mature avocado fruit impacted from a 100 cm drop height (energy absorbed ~1.68 J). The impact site was initially evident as high (viz., bright) contrast in MRI images, but faded over time. Consequently, no bruising was observed in the ripened fruit.

Flesh bruising and rotting continue to be the major quality concerns with avocados (Gamble et al. 2010; Hofman 2011). Therefore, studies are ongoing towards better managing these problems. The present work was conducted to more fully understand flesh bruising in impacted hard green mature fruit. Rotting at the impact site in the mesocarp of the green mature fruit was also evaluated.

Methods

About 250 'Hass' avocado fruit were harvested at horticultural maturity from a commercial orchard in the Toowoomba region. The green mature fruit at the hard stage of firmness (White et al. 2009) were given the following treatments:

T1: control (no impact),

T2: fruit dropped from 100 cm height onto a hard surface (average of 9.36 Joules of absorbed energy),

T3: fruit dropped from 50 cm height onto the same surface (average of 9.27 Joules of absorbed energy).

The fruit were dropped using a purpose-built mechanical swing-arm (Figure 1). Each fruit was secured in a holder at the end of the arm and allowed to free fall from the desired height onto a solid surface. Impact sites on individual T2 and T3 fruit were marked. After treatment at the orchard, the fruit were transported to a postharvest laboratory on the University of

Queensland's Gatton campus. They were held at 20ºC for daily assessment from day 0 after harvest and treatment until day 14. Five fruit for each treatment were sub-sampled from the holding room for destructive bruising assessment. With a sharp smooth-bladed knife, these fruit were cut along the longitudinal axis through the impact site into two pieces. 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. Briefly, affected flesh was removed from the surrounding sound flesh and placed into water in a measuring cylinder to record the volume change difference. 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 were statistically analysed with Minitab® 16 and images were taken with a Nikon Coolpix digital camera.

Findings

Dropping hard green mature fruit against the solid surface of the drop equipment did not cause any visual damage to the fruit skin. Neither non-impacted control fruit nor any of those impacted from different heights showed any visible bruising, even at 2 weeks after impact. Significantly, however, fruit dropped from 50 cm showed visible rots at the impact site from day 7 after impact. This timing was co-incident with when the fruit started to soften during natural ripening. Nine (9) % of the fruit dropped from 50 cm developed rots at the impact site by the time the fruit were ripe, and 5% of the fruit dropped from 100 cm developed rots at the impact site. The rots at the impact site were significantly higher in fruit dropped from 50 cm than in fruit that were not dropped. There was no significant difference in results between the two drop heights.

The rot-affected area (Figure 2) had a relatively leathery texture that was discrete within the bounding flesh. This texture was in contrast to the smooth watery appearance typical of bruised flesh tissue. The margins of the bruised area were less well defined (Figure 3) as compared to the rotted area. Some fruit impacted from 50 cm and 100 cm drop heights remained clean from any type of internal quality problem over the assessment period of 15 days. However, disease expression in terms of the extent of flesh decay worsened over time in those fruit which showed any incidence of rotting.

Conclusion

This work supports the proposition that hard green mature avocado fruit do not bruise readily in response to impacts. This response is in marked contrast to the relative ease with which firm ripe fruit flesh can develop bruises (Mazhar et al. 2012). The research also shows that the impact can become a site for the out-growth of pathogens as the fruit begins to ripen (soften). Impact may cause mechanical strain to the skin that reduces the fruit's natural capacity to delay pathogen development. Also, the pathogens could potentially more readily infect flesh tissue in the impacted area as compared with non-strained flesh tissue in non-impacted areas of the fruit. Gaining further understanding of the physicochemical mechanisms involved should help to better inform recommendations aimed at further reducing the incidence and severity of postharvest rots with a view to increased consumer satisfaction and avocado industry prosperity.

Acknowledgements

This research was conducted under project 'AV12009 – Understanding and Managing Avocado Flesh Bruising' funded by Horticulture Australia Limited (HAL) using avocado industry levy and matched funds from the Australian Government. Support was also provided by the Department of Agriculture, Fisheries and Forestry (Queensland) and The University of Queensland.

Figure 1

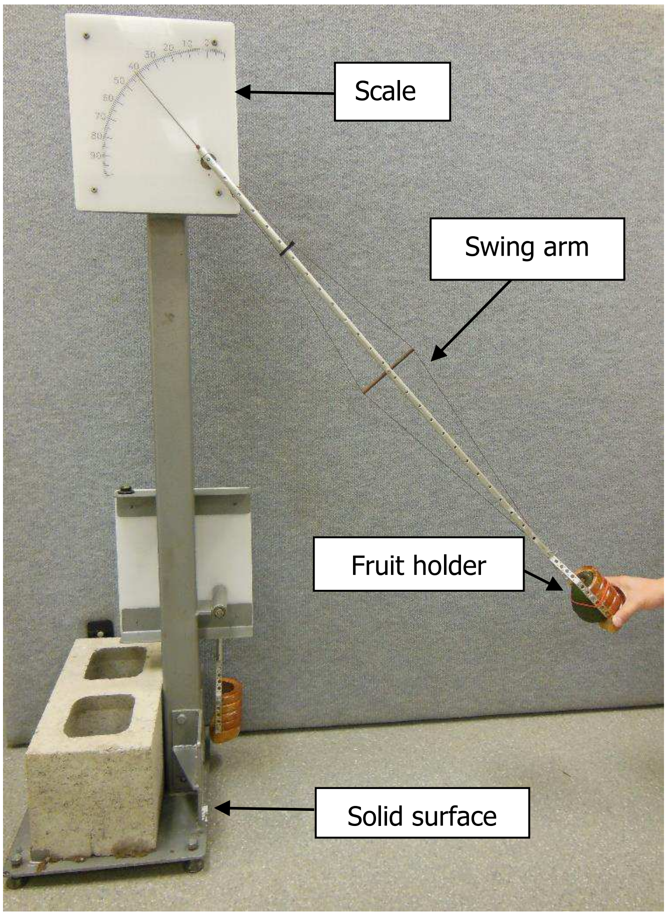

Figure 1: Individual avocado fruit drop equipment. A single fruit is placed in the holder attached at the distal end of the swinging arm. The fruit is raised to the desired drop height for release and free fall onto the solid metal plate surface. The rebound height of fruit is viewed and recorded against the measuring scale.

Figure 2

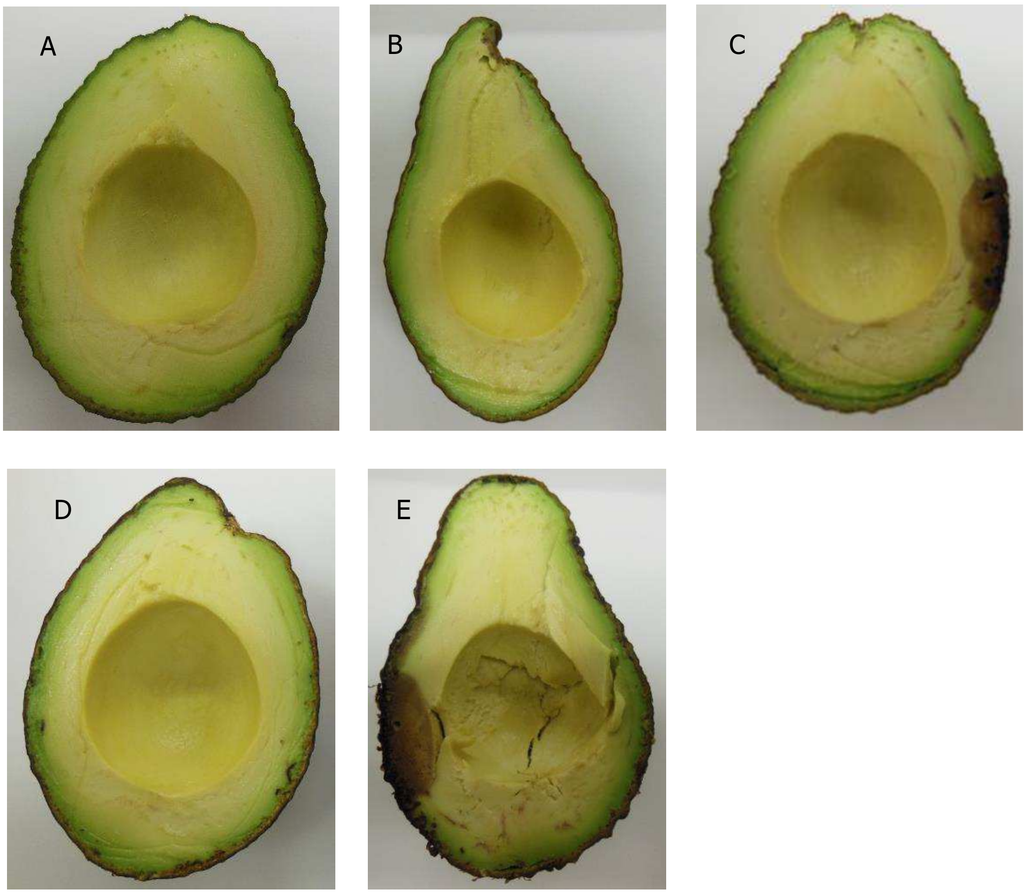

Figure 2: Images of a typical control fruit without any internal fruit quality problems symptoms (A), a fruit impacted from 50 cm drop height that did not develop any rotting (B), a fruit impacted from 50 cm drop height that developed rotting (C), a fruit impacted from 100 cm drop height that did not yield any internal quality problems (D), and a fruit impacted from 100 cm drop height that produced rotting (E).

Figure 3

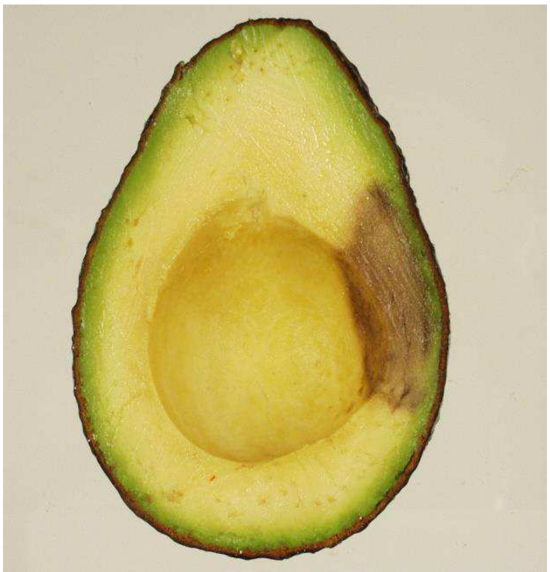

Figure 3: Image of a typical bruise in an avocado fruit. The margin of the bruised flesh merges with the surrounding sound flesh as opposed to being distinct, as is the case with rotting.

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Appendix D: Bruising by hand in softening avocado fruit - Preliminary study

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Introduction

Firmness is the most important widely accepted indicator of avocado fruit ripeness. There are various techniques of measuring fruit firmness, but hand firmness is widely considered reliable and convenient. The different stages of avocado fruit ripening based on hand firmness are listed in Table 1. Each individual person likely has a somewhat different hand grip strength and style developed over time based on their personal experience. Individuals may well apply quite different levels of force through their palm, fingers and / or thumb to gauge firmness when they grip the fruit in hand (Figure 1).

Past research shows that the susceptibility of avocado fruit to bruising increases with advancing ripening. By the time that ethylene-treated fruits reach the retail shelf, their firmness is decreasing as handling by store staff and shoppers commences. Since the firmness of each ripening avocado fruit is manually assessed by hand squeezing and / or thumb force pressure, the flesh tissue beneath the compressed area can deform and develop into a bruise. However, the actual hand compression forces giving rise to bruising in firm ripe avocado fruit are essentially unknown. This paper outlines a preliminary experiment conducted to evaluate the effect on flesh bruising of simulated thumb forces applied to ripening avocado fruit.

Material and methods

Mature green 'Hass' avocado fruit were harvested from an orchard in the Toowoomba region and transported to the postharvest laboratory at The University of Queensland's Gatton campus. The fruit were initiated to ripen by dipping into ethephon solution followed by holding in a darkened shelf life room at 20°C and 85% RH until they reached the firm ripe stage of hand firmness (Table 1). The fruit were then carefully sorted into matched samples for each treatment. In this context, their firmness was measured non-destructively with an iQ Benchtop fruit testing instrument before compression was applied. Fruit were compressed either manually (i.e. qualitative assessment measure) by thumb pressure (Figure 2) or mechanically (i.e. quantitative assessment measure) by a strain gauge assembly (Figure 3A). The purpose-built assembly was comprised of a precision machined screw threaded rod to move the fruit forward or backward by manually turning a crank handle, a fruit holder to firmly support half of the fruit set into Plaster of Paris, an artificial silicone thumb moulded around a metal T-piece together representing the flesh and bone of a human thumb, a strain gauge, and a data logger to record the force applied onto the fruit by the silicone thumb (Figure 3B).

This preliminary experiment consisted of six treatments: T1 - slight thumb pressure, T2 - moderate thumb pressure, T3 - firm thumb pressure, T4 - 1 kg force applied with the strain gauge assembly, T5 - 2 kg force applied with the strain gauge assembly, and, T6 - 3 kg force applied with the strain gauge assembly. Three individual fruit replications were maintained for all six treatments. The experiment was conducted as a completely randomized design. After 48 h from compression, the resultant bruise volumes were measured by a conventional water volume displacement in a measuring cylinder method. The data were statistically analysed using MS Excel® 2010.

Findings

Both the slight manual compression treatment and the minimal mechanical compression treatment at 1 kg caused flesh bruising in the firm ripe avocado fruit. Expectedly, the severity of bruising rose with increased manual compression (i.e. moderate and firm) and increased mechanical compression (i.e. 2 kg and 3 kg; Figure 4).

Slight manual compression caused a bruise volume of 1.7±0.4 ml (Figure 5). The bruise volumes were 2.7±0.3 ml for moderate and 9.3±0.7 ml for firm thumb pressure. The mechanical compression treatment of 1 kg caused 0. 7±0.2 ml bruise volume. The bruise volumes were 3.3±0.4 ml with 2 kg mechanical compression and 9.5±0.3 ml with 3 kg mechanical compression. Thus, the bruise volumes for slight, moderate, and firm manual compression were correlated with those for 1 kg, 2 kg, and 3 kg mechanical compression force. Nonetheless, the degree of bruising was not significantly different for either the slight and moderate manual compression level treatments or for the 1 kg and 2 kg mechanical compression force treatments. However, there was a significant increase in bruising upon firm manual compression as compared with slight and moderate manual compression and also upon 3 kg mechanical compression as compared with 1 kg and 2 kg mechanical compression.

The results reported herein concur with findings of earlier research that bruising in softening avocado fruit increases with increased levels of energy absorbed by the fruit. At the lowermost level of compression either manually or mechanically, only the flesh close to the skin was bruised. This is presumably because the compression forces are only just enough to affect the fruit tissue close to the skin. In contrast, at the firm manual and 3 kg mechanical levels, the external compression forces against the seed inside the fruit evidently led to almost all of the flesh thickness manifesting bruising.

This promising albeit limited preliminary research will be expanded in HAL projects AV12009 and AV10019 to ultimately inform best management education and decision aid tool practices for avocado supply chain stakeholders, particularly retailers and shoppers.

Acknowledgements

This research was conducted under project 'AV12009 – Understanding and Managing Avocado Flesh Bruising' funded by Horticulture Australia Limited (HAL) using avocado industry levies and matched funds from the Australian Government. Support was also provided by the Department of Agriculture, Fisheries and Forestry (Queensland) and The University of Queensland.

Table 1. Levels or stages of avocado fruit firmness (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

Figure 1. Avocado shopper determining fruit firmness by squeezing a fruit on retail display (source: http://filippamalmegard.wordpress.com/2013/01/11/avocados-crowdsourcing/).

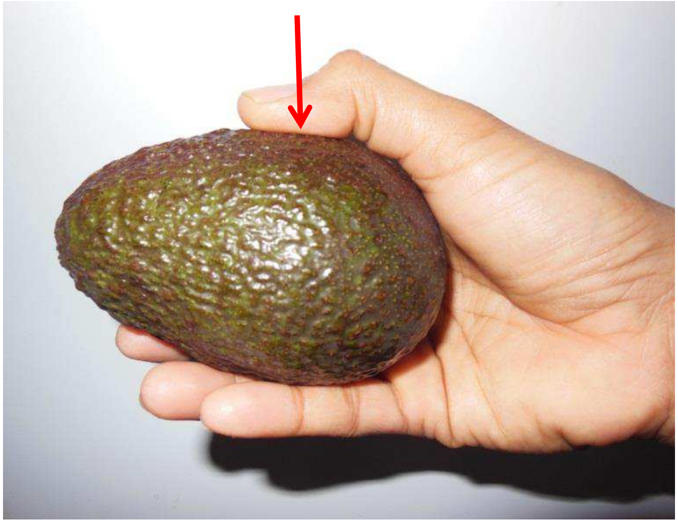

Figure 2. Manual thumb compression test on a firm ripe avocado fruit. The red arrow indicates the point of force applied to the avocado fruit.

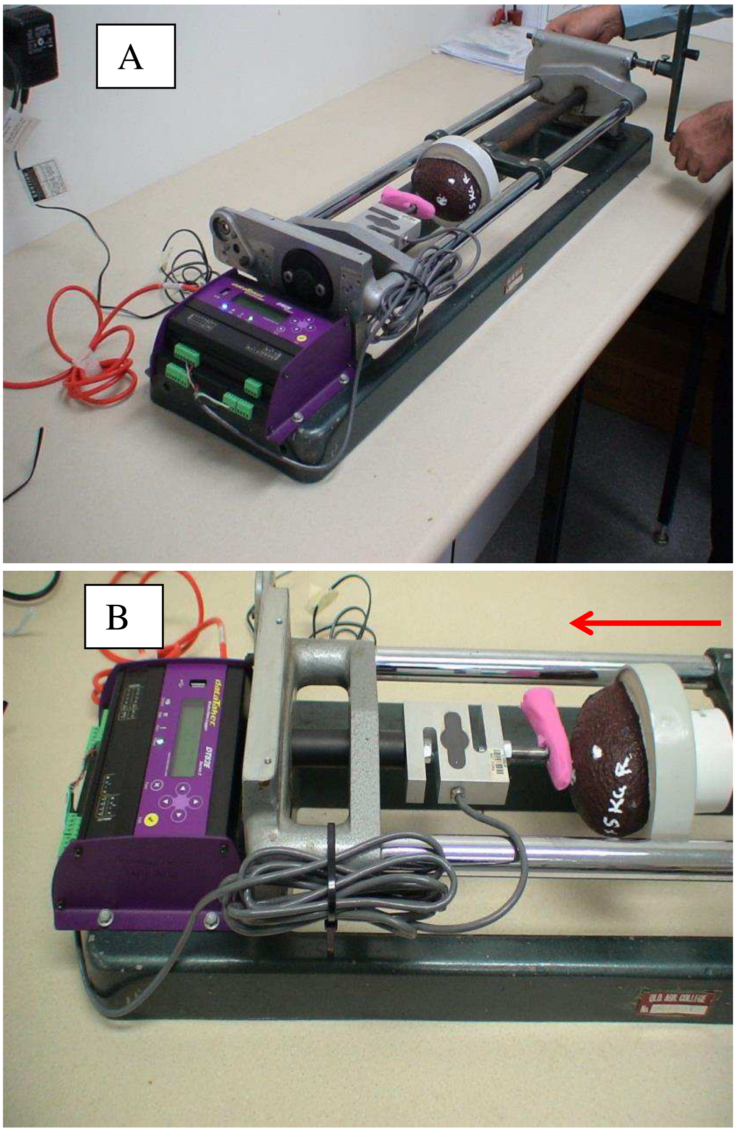

Figure 3. (A) Mechanical compression test assembly comprised of a frame, a fruit holder, a moulded silicone thumb, a strain gauge and a data logger; and, (B) A close-up of the mechanical compression applied via the moulded silicone thumb onto the firm ripe avocado fruit. The red arrow indicates that the avocado fruit in the holder is moved towards the stationary silicone thumb.

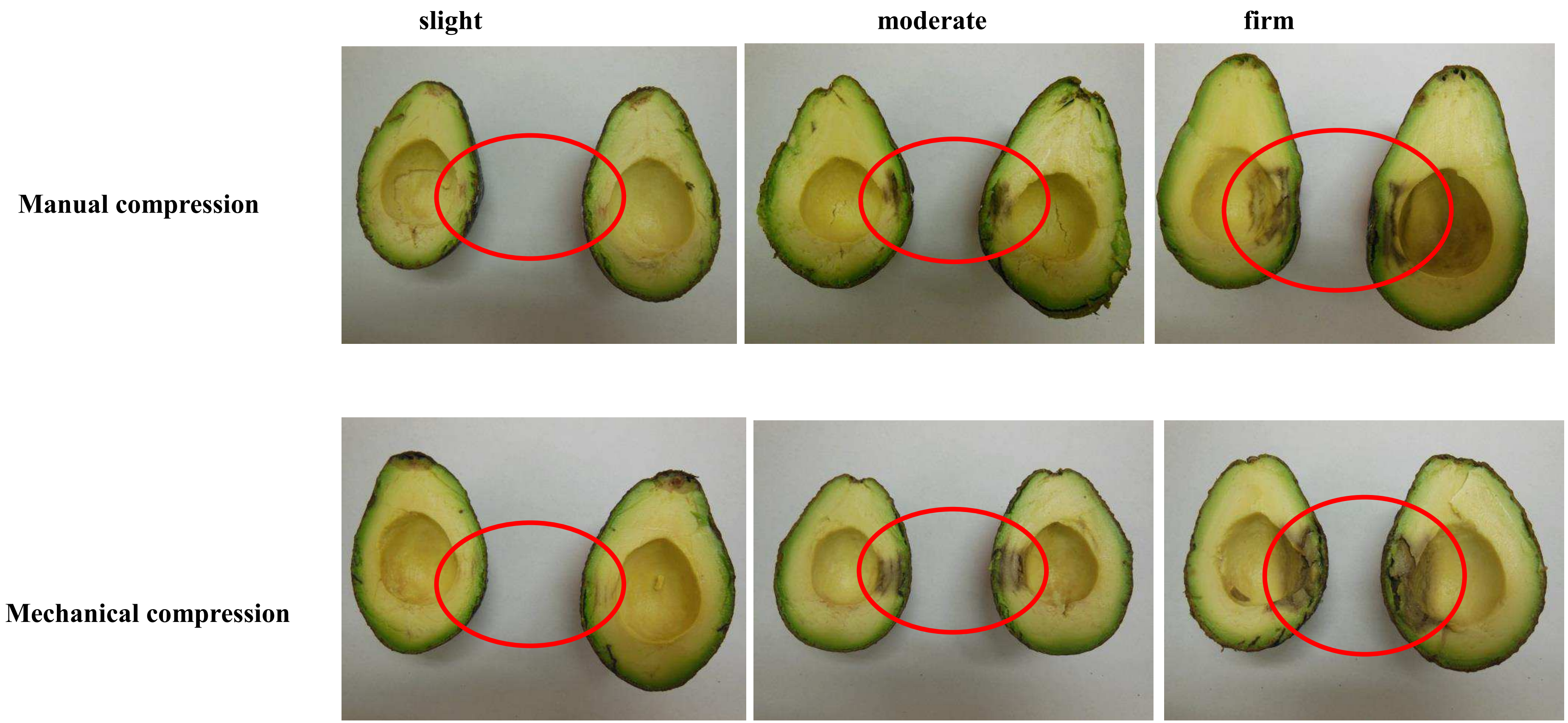

Figure 4. Bruising in firm ripe avocado fruit as caused by manual and mechanical compression. The red circles highlight by enclosure the compressed bruised flesh. Top left: slight thumb compression. Top centre: moderate thumb compression. Top right: firm thumb compression. Bottom left: 1 kg mechanical compression. Bottom centre: 2 kg mechanical compression. Bottom right: 3 kg mechanical compression.

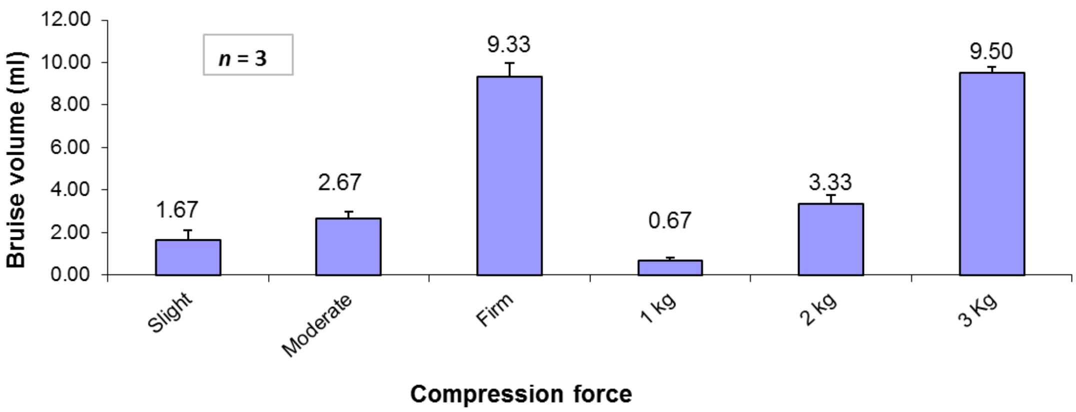

Figure 5. Average bruise volume (*n* = 3) due to manual and mechanical compression of firm ripe avocado fruit.

Appendix E: Bruising in 'Hass' avocado supply chains in Queensland, Australia

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The 'Hass' avocado supply chains in Queensland Australia are designed and practiced to meet the quality standards demanded by the consumers. The industry players implement a whole of the supply chain system, up until the retail, which is equipped with systems to ensure that the fruit quality delivered to their buyer is the same what they receive from their supplier. The quality losses at each stage in the supply chain are recorded for continuous improvements in the system. However, when the fruit arrives in the consumer's hands, there is no quantitative evidence of losses due to the consumers own fruit handling practices that can distinguish the fruit quality at the time of consumption from what is received from the retail shelf. The incidence and severity of bruising in ripening 'Hass' avocado fruit as it travels through the supply chain has been described in this paper. The objective of this research is to identify where and how much bruising does occur at different stages in the 'Hass' avocado supply chain extended to the consumers. Fruit at serial sampling points (ripener arrival, ripener dispatch, distribution centre arrival, distribution centre dispatch, retail store arrival, and the retail display) along the supply chain was collected and its destructive bruising assessment was conducted after 48h. The results of two consecutive years of research exhibited that the bruising keeps increasing throughout the supply chain and reaches at its maximum level at the retail display, which is significantly higher than at the previous sampling point. A detailed study focused on the potential contribution of avocado purchasers who interact with the ripening fruit and possibly cause bruising by transferring impact energy through applying force in the process of squeezing the fruit to determine the level of fruit ripeness is being conducted and will be communicated in due course.

Appendix F: Flesh bruising in Queensland avocado (*Persea americana* M.) cv. 'Hass' supply chains

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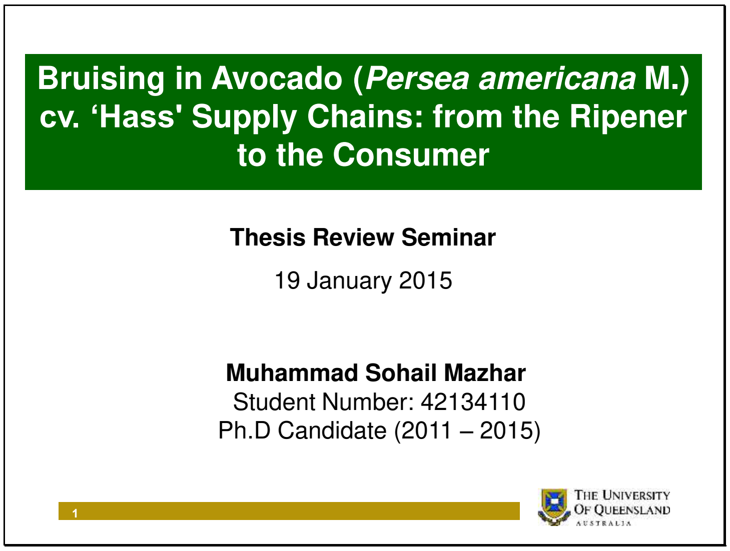
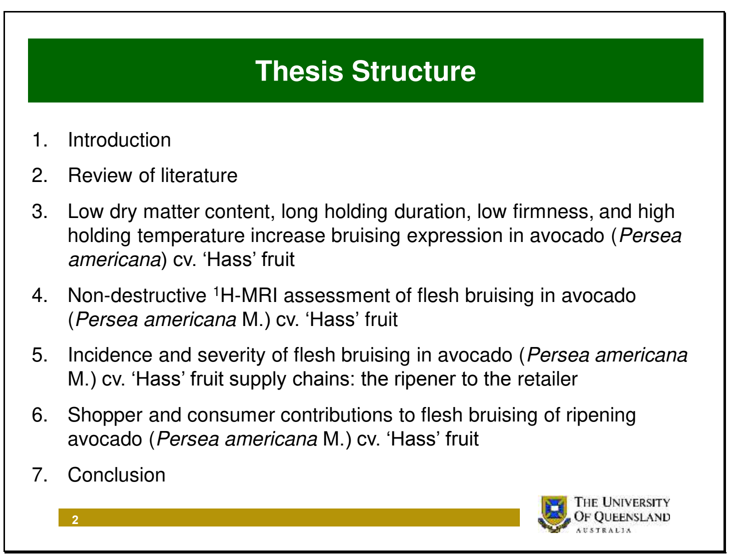
'Hass' avocado supply chains in Australia aim to supply the fruit quality demanded by consumers. However, frequent assessments of 'Hass' avocado flesh quality on the retail shelf confirms ongoing concerns with flesh quality, resulting in continued consumer dissatisfaction. Bruising is one of the main causes of this poor 'Hass' fruit quality. Fruit handling practices throughout the supply chain could contribute to flesh bruising; however no holistic research has been conducted to determine the incidence of bruising at successive stages in the supply chain. Hence there is little certainty which practices in the chain are the major contributors to bruising. The objective of our current research was to establish where and how much bruising occurs in the 'Hass' avocado fruit supply chain, from ripener to retailer display. Preliminary experiments on the effects of fruit firmness, impact energy absorbed, temperatures and post-impact holding duration on flesh bruising were conducted under laboratory conditions. The results of experiments on post-impact fruit holding temperature indicated that the biochemical browning processes which result in visible bruising were lessened at low flesh temperatures and thus, managing fruit temperature through to the consumer could help to reduce symptoms of bruising and thereby improve consumer satisfaction. In the supply chain studies, fruit samples (n=20) at serial sampling points from ripener arrival to the retail display of two major retailers for six retail stores each were collected and flesh bruising severity assessed. Decision aid tools (impact recording device and shock logger) were evaluated in the supply chain studies. The results of two consecutive years of research established that, while bruising increases through the supply chain, most of it occurs in softening fruit at the retail store. The relative contributions of retail staff and consumers to bruising will be studied in the next phase of the research project. The results will help the avocado industry develop best practice fruit handling guidelines to help supply chain members reduce the risk of 'Hass' avocado flesh bruising.

Appendix G: Bruising in avocado (*Persea americana* M.) cv. 'Hass' supply chains: from the ripener to the consumer

Slide 1



Slide 2



Slide 3

Explanation 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 / used interchangeably in / with bruise volume.
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 (Horticultural)	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.

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Slide 4

Explanation of terminology

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.
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.
Bioyield	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.

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Slide 5

Chapter 1 – Introduction

- Research problem
- AV10019 & AV12009
- Research questions

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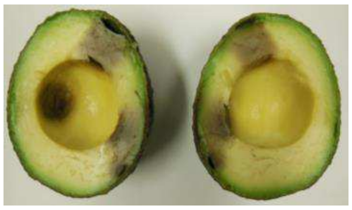
Slide 6

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*

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Slide 7

AV10019 & AV12009

Reducing flesh bruising and skin spotting in 'Hass' avocado
&
Understanding and managing flesh bruising in avocado

… projects were commissioned by Horticulture Innovation Australia Ltd (HIAL) through Avocados Australia Ltd (AAL) using avocado industry levy and matched funds from the Australian Government with a primary **objective** of reducing flesh bruising in ripening avocado fruit so as to deliver better quality fruit to consumers.

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Slide 8

Research questions

RQ1: What are the causative factors of bruising in 'Hass' avocado fruit?

RQ2: What, if any, is the contribution of each stakeholder, including the consumer, to bruising in 'Hass' avocado supply chain?

RQ3: How are the consumers' level of satisfaction and their intention to repeat purchase affected by bruising in 'Hass' avocado fruit?

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Slide 9

Chapter 2 – Review of literature

- Importance of avocado fruit
- Bruising in avocado fruit
- Bruising physiology
- Bruising in fresh horticultural produce
- Bruising studies in avocados
- Consumer satisfaction model
- Gaps in theory

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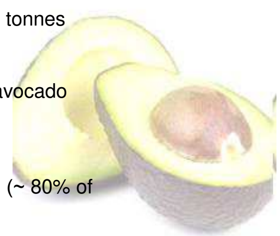
Slide 10

Importance of avocado fruit



- Annual production in Australia ~ 70,000 tonnes
- Queensland alone produces ~ 80% of avocado production in Australia
- ‘Hass’ major avocado variety worldwide (~ 80% of world avocado production)

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FAO (2014), AAL (2013), Anonymous (2012)

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Slide 11

... Importance of avocado fruit

- 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 ~ a decade

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

Slide 12

Bruising in avocado fruit

Retail surveys over the last > 20 years confirm that avocado fruit quality does not meet consumers' expectations…

For example:

- **40-50% of consumers having bad purchase experiences because of poor internal quality**
- **~ 63% of fruit having flesh defects & ~ 29% with >10% of the volume affected**
- **Consumers' intention to repeat purchase is negatively affected if >10% of the flesh volume is discoloured**

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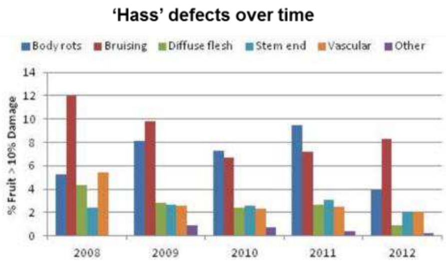
Lee and Coggins (1982), Dermody (1990), Harker and Jaeger (2007), (HAL 2008), Gamble et al. (2010)

Slide 13

Bruising in avocado fruit



~ 80% of the avocado fruit on display have some degree of bruising, and ~ 25% of the sampled fruit are unusable because of bruising

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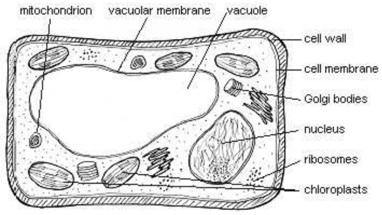
http://www.avocadoconference.co.nz/images/articles/PDFs/Presentations/NZ_Conference_Supply_chain_information_Sept_2013_V2.pdf

Slide 14

Bruising physiology



- Impact and compression
- Stress and strain mechanism
- Mechanical injury
- Cell physiology – increased rate of respiration and ethylene generation
- Symptoms of bruising - browning

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

Slide 15

Bruising in fresh horticultural produce

Fruit / Vegetable	Reference
Tomato	Fluck and Halsey, 1973; Linden et al. 2006
Potato	Noble, 1985; Esehaghbeygi and Besharati 2009
Stone fruit	Hung and Prussia 1989; Ahmadi et al. 2010
Banana	Banks et al., 1991; Akkaravessapong et al, 1992
Cherries	Blahovec et al., 1996
Apple	Ericsson and Tahir 1996; Javadi, 2010
Persimmon	Lee et al., 2005
Pear	Baritelle and Hyde, 2001; Kabas 2010
Watermelon	Sadrnia et al., 2008
Strawberry	Ferreira et al., 2009
Coconut	Kitthawee et al., 2011
Longan	Pholpho et al., 2011
Olive	Saracoglu et al., 2011

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Slide 16

Bruising studies in avocados

- Bruising highlighted with the advent of marketing ripe fruit
- Bruise susceptibility increases with increased impact, decreased firmness, and early maturity
- Very little to no bruising has been reported unless fruit starts softening
- Bruising at different levels of severity at different stages in the supply chain is continuously reported
- Consumers are continuously dissatisfied with the available quality of avocado fruit

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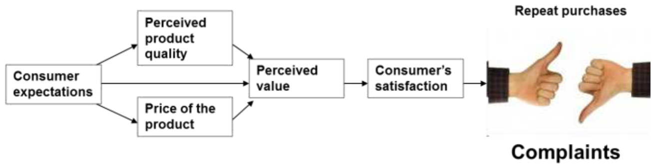
Curtis (1949), Embleton and Jones (1964), Eaks (1983), Arpaia et al. (1987), Hofman (2002), Gamble et al. (2010), Hofman (2011)

Slide 17

Consumer satisfaction model



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expanded model of the American Customer Satisfaction Index.jpg

Slide 18

Gaps in theory

- **Where** in the supply chain, from the ripener to the consumer, does bruising events happen to avocado fruit?
- **How much** does each step in the supply chain, from the ripener to the consumer, contribute towards the ultimate proportion of bruising in the avocado fruit at the time of its consumption?
- **How** does the flesh bruising affect consumers' level of satisfaction and repeat purchase intention?

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Slide 19

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

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White et al. (2009)

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Chapter 3 – Low dry matter content, long holding duration, low firmness, and high holding temperature increase bruise expression in avocado (*Persea americana* M.) cv. 'Hass' fruit

- Effect of fruit maturity
- Effect of pre-ripening holding duration
- Effect of fruit firmness
- Effect of post-impact fruit holding duration
- Effect of pre- and post-impact fruit holding temperature

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Slide 21

Effect of fruit maturity on bruise severity

- Fruit (n = 25) fortnightly harvested, each from two tagged trees
- Dry matter content (%) was determined in n = 5 fruit for each tree
- Fruit (n = 20) were ripen by treatment with ethephon followed by holding in shelf life room at 20°C
- Fruit impacted from 50 cm at firm ripe and held at 20°C
- Destructive assessment for bruise severity at 48 h
- Data on bruise severity and intensity were recorded

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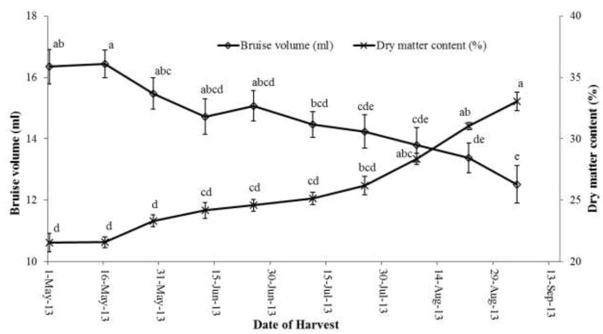
Effect of dry matter content on bruise severity



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Effect of pre-ripening fruit holding duration on bruising

- 150 fruit harvested and stored in shelf life room at 5°C
- Fruit (*n* = 25) drawn weekly, 5 weeks, and ripen by treatment with ethephon followed by holding in shelf life room at 20°C
- Fruit impacted from 50 cm at ripening and held at 20°C
- Destructive assessment for bruise severity at 48 h

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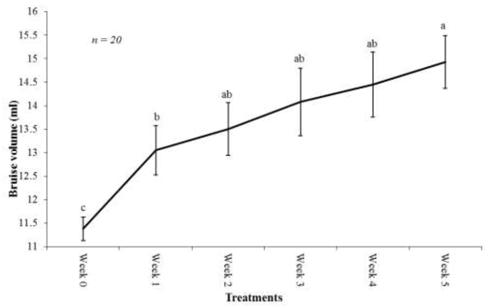
Effect of pre-ripening holding duration on bruise volume



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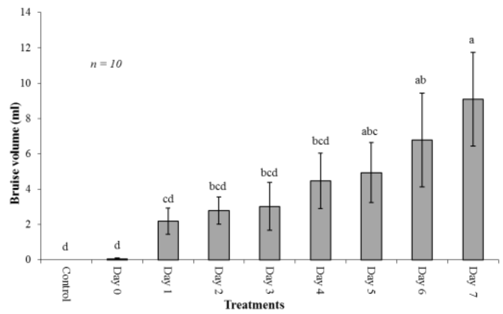
Effect of post-impact holding duration on bruise volume



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

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Bruise expression in fruit impacted at hard stage

50 cm

80% (8/10)

20% (2/10)

100 cm

90% (9/10)

10% (1/10)

Bruise assessment on d 10 after impacting the hard fruit at drop heights of 50 cm and 100 cm

No evidence of visible bruising. Pathogen infection starts on some fruit from day 7

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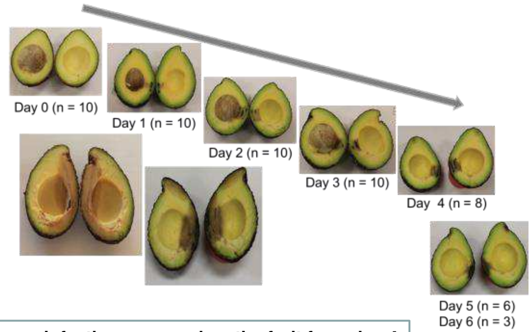
Bruise expression in fruit impacted at firm ripe stage

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



Pathogen infection appeared on the fruit from day 4

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Slide 28

Relationship of temperature with bruising

Five experiments conducted to determine if the pre- and post-impact fruit holding temperature affect bruising severity and intensity in avocado cv. 'Hass' fruit.

- Effect of fruit holding temperature on bruise severity
- Effect of fruit holding temperature on bruise intensity
- Effect of switching the fruit holding temperature on bruise severity
- Effect of the pre- and post-impact fruit holding temperature on bruise severity x 2

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Effect of fruit holding temperature on bruise severity

- Fruit (*n* = 20) at firm ripe stage
- Flesh temperature at impact: 20 °C
- Impacted by fruit drop from 25 cm
- Fruit holding temperature: 5 °C, 15 °C, 25 °C
- Destructive assessment for bruise severity at 48 h

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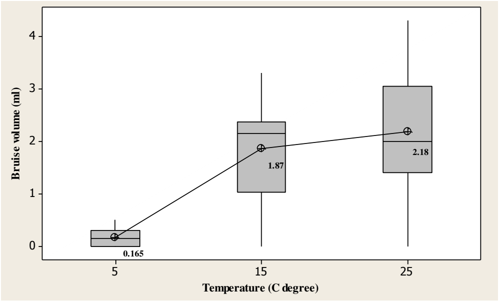
Slide 30

Effect of fruit holding temperature on bruise severity

Increasing post impact fruit holding temperature increased bruising severity in impacted ‘Hass’ avocado fruit



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Effect of fruit holding temperature on bruise intensity

- Fruit (n = 25) at firm ripe stage
- Flesh temperature at impact: 20°C
- Impacted by fruit drop from 50 cm
- Fruit holding temperature: 1°C to 30°C (In a temperature gradient)
- Hue and chroma measured immediately after impact and at 48 h after impact

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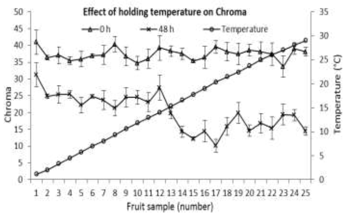
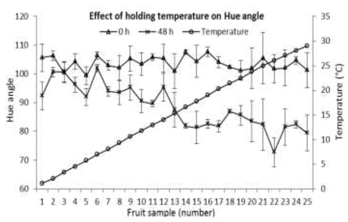
Effect of fruit holding temperature on bruise expression





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Effect of switching the fruit holding temperature on bruising

- Fruit (*n* = 20) at firm ripe stage impacted from 25 cm
- Flesh temperature at impact: 20°C
- Fruit holding temperature: 25°C for 8 h and 5°C for 40 h, and 5°C for 8 h and 25°C for 40 h
- Destructive assessment for bruise severity at 48 h

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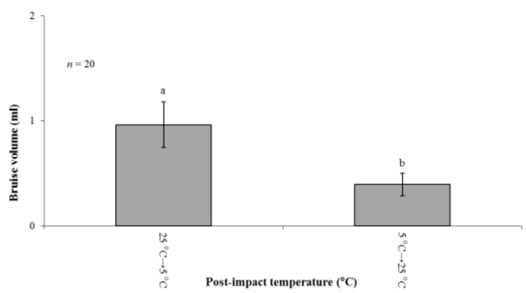
Effect of switching the fruit holding temperature on bruising

Lower the initial fruit holding temperature, lesser is the incidence of bruising



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Slide 35

Effect of pre- and post-impact holding temperature on bruise severity in ‘Hass’ avocado fruit

- Fruit (*n* = 20) firmness stage: Firm ripe
- Flesh temperature at the time of impact: 2.5°C and 20°C
- Drop height: 50 cm
- Post-impact holding temperatures: 2.5°C, 5°C, 7.5°C 10°C, 20°C
- Destructive assessment for bruise severity at 48 h after impact

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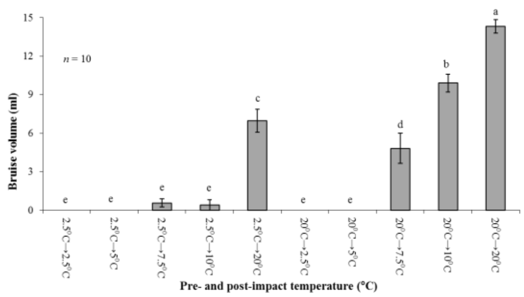
Effect of pre- and post-impact holding temperature



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Chapter 4 - Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea americana* M.) cv. 'Hass'

- Internal morphology
- Impact energy dissipation
- Bruise severity over time
- Potential of ^{1}H-MRI in pathogenicity studies

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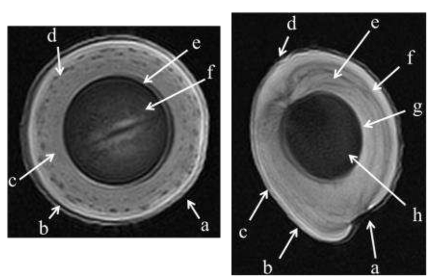
Slide 38

Internal morphology



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.

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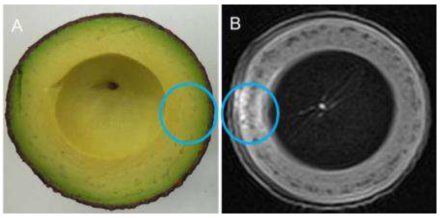
Slide 39

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.

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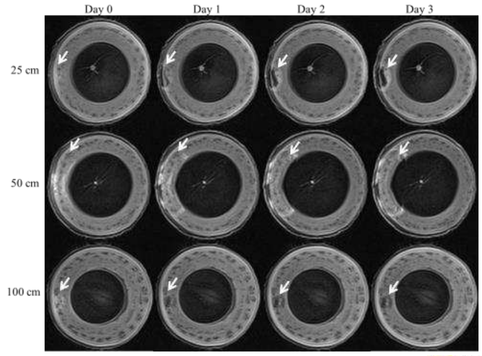
Slide 40

Bruising severity over time

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



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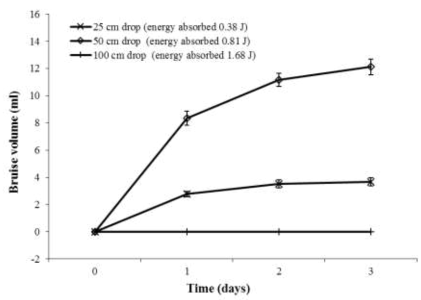
Slide 41

Bruising severity over time

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



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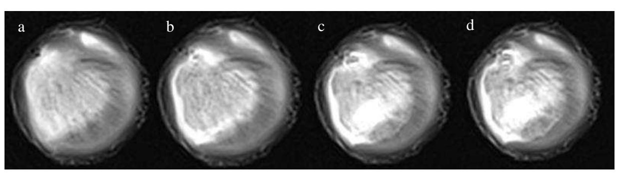
Potential of [1]H-MRI in pathogenicity studies



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

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Slide 43

Chapter 5 – Incidence and severity of flesh bruising in avocado (*Persea americana* M.) cv. 'Hass' fruit supply chains: from the ripener to the retailer

- Laboratory experiments
  - Bruise severity due to impact energy absorbed by individual fruit
  - Bruise severity due to impact energy absorbed by avocado fruit in trays
- Supply chain experiments
  - Sampling through the supply chain and bruising assessment
  - Application of instrumented spheres and impact indicator clips
  - Retail store staff contribution to bruising
  - Bruising in avocado fruit displayed in independent and supermarket retail stores

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Bruise severity due to energy absorbed by individual 'Hass' avocado fruit

- Fruit (n = 10) given a controlled impact against a solid surface with a swing arm device
- Fruit firmness: firm ripe
- Drop height: 25 cm, 50 cm, 100 cm
- Bruise severity was recorded after 48 h

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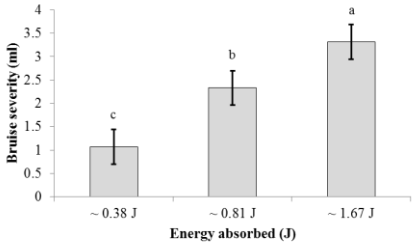
Bruise severity due to energy absorbed by individual 'Hass' avocado fruit



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Bruise severity due to impact energy absorbed by avocado fruit in trays

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

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

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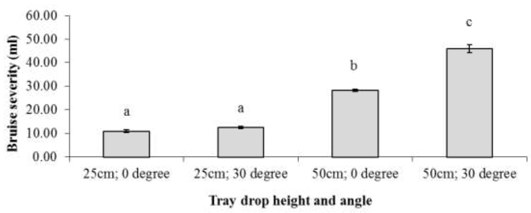
Interaction of drop height and drop angle



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

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Slide 48

'Through the supply chain' sampling and assessments

- Ripener: 1
- Distribution centre (DC): 2 (major supermarkets)
- Retail stores: 8 (4 for each supermarkets)
- Shoppers
- Consumers

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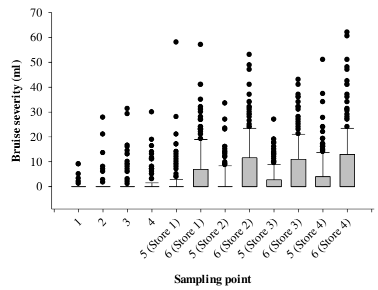
Sampling and bruise assessment



Boxplot of bruising 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.

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Slide 50

Decision aid tool evaluations

Shock indicator

Shock logger

Instrumented sphere

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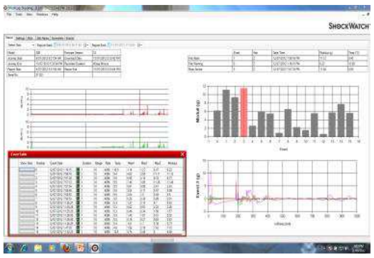
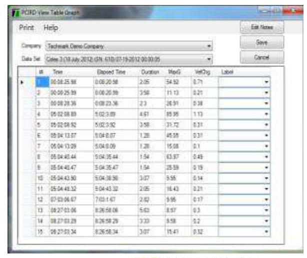
Slide 51

Decision aid tool evaluations

- Review of the decision aid tool data shows that impact forces of up and over 10 x g (g-force; acceleration due to gravity) have been recorded during tray handling in the supply chain from ripener to retail store
- No impacts were sufficient to activate 'ShockWatch' (5, 10, 25, 37 and 50 x g) indicators





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Retail store staff contributions to bruising in ripening fruit

- Control ripened fruit were entered into and collected from the fruit handling system of two supply chains
- Destructive assessments for bruise incidence and severity conducted 48 h after collection
- This study was repeated four times

Numbers		**Point**		**Activity**
Fruit trays (n = 2)	→	**Store arrival**	→	Fruit collected from display
Fruit (n = 40)	→	**Check out**	→	Fruit collected

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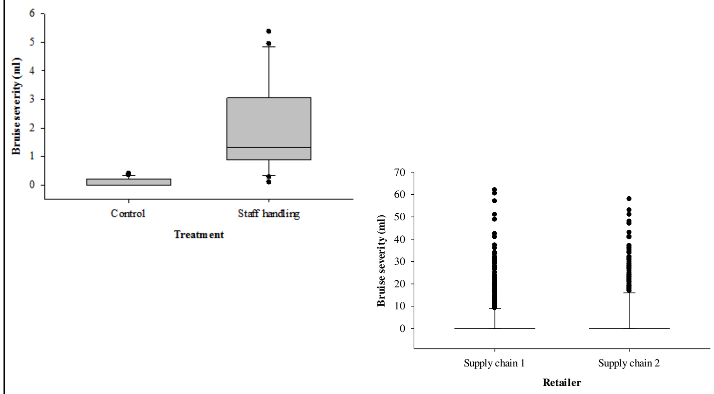
Retail store staff contributions to bruising in ripening fruit



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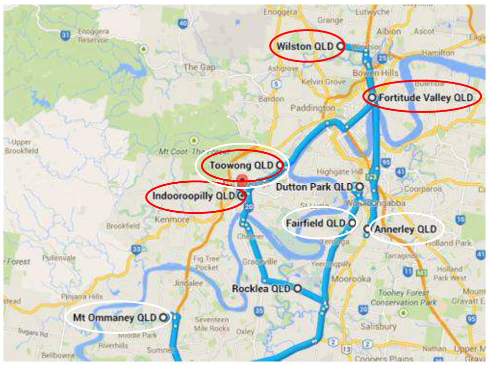
Slide 54

Bruising in avocado fruit displayed in supermarket and independent retail stores



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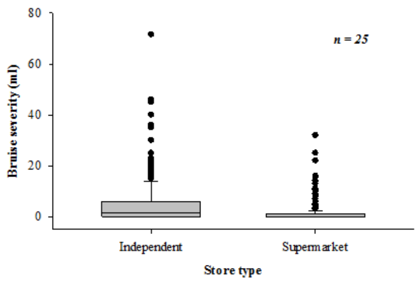
Slide 55

Bruising in avocado fruit displayed in supermarket and independent retail stores



Bruise severity (ml) in avocado cv. ‘Hass’ fruit (*n* = 25) sampled weekly, for four weeks, from four independent and four supermarket retail stores

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Chapter 6 – Shopper and consumer contributions to bruising of ripening avocado (*Persea americana* M.) cv. ‘Hass’ fruit

- Laboratory Experiments
  - Compression force applied to individual fruit by hand
  - Compression force applied to individual fruit measured with the force sensors
  - Compression force and resultant deformation in avocado fruit
- Shoppers contribution to bruising
  - Single fruit squeezed by a shopper
  - Random fruit squeezing by shoppers
  - Multiple fruit squeezing by multiple shoppers
  - Fruit squeezing by shoppers and compression force recorded by a force sensor
  - Assessment of an e-glove for measuring the shopper’s fruit squeezing pressure
    a. Pilot study b. In-store experiment
  - In-store observations of shopper’s fruit squeezing
- Consumer contribution to bruising
  - Fruit sampling through the supply chain
  - Bruise free fruit subjected to consumer handling practices
- Consumer’s attitude to bruising
  - Bruising in fruit used in consumer contribution to bruising
  - Bruising in fruit displayed at supermarket retail store
  - Bruising in fruit subjected to controlled impact

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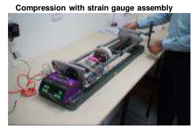
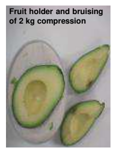
Bruise severity in firm ripe avocado fruit due to compression by hand

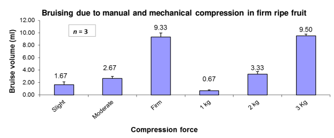
- Fruit (n = 5) at firm ripe stage
- Thumb compression: slight, moderate, firm
- Mechanical compression: 1 kg, 2 kg, 3 kg
- Destructive assessment for bruise severity at 48 h

Thumb compression

Compression with strain gauge assembly







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http://filippamalmegard.wordpress.com/2013/01/11/avocados-crowdsourcing/)

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Bruise intensity and severity in avocado cv. 'Hass' fruit subjected to hand compression measured with single force sensor

FSR 406 Interlink Force Sensor

Treatment	Replications	Force applied (N)	Hue angle	Chroma	Bruise severity (ml)
Firm ripe, control	20	0	104.3 ± 3.6 a	38.7 ± 1.7 a	0
Firm ripe, ~ 10 N	20	10.9 ± 0.5 c	104.9 ± 5.5 a	34.8 ± 5.5 b	0.9 ± 0.3 c
Firm ripe, ~ 20 N	20	21.1 ± 0.8 b	98.1 ± 9.2 b	28.4 ± 6.8 c	0.6 ± 0.4 ab
Firm ripe, ~ 30 N	20	30.9 ± 0.8 a	90.5 ± 20.6 c	25.8 ± 5.6 cd	0.8 ± 0.5 a
Soft ripe, control	20	0	104.3 ± 2.9 a	39.1 ± 2.2 a	0
Soft ripe, ~ 10 N	20	10.9 ± 0.6 c	105.3 ± 3.2 a	37.1 ± 3.5 ab	0.1 ± 0.1 c
Soft ripe, ~ 20 N	20	20.9 ± 0.9 b	96.7 ± 8.6 b	27.8 ± 4.9 cd	0.5 ± 0.2 b
Soft ripe, ~ 30 N	20	30.9 ± 0.6 a	90.2 ± 10.1 c	25.3 ± 2.2d	0.7 ± 0.4 a

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

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Deformation in 'Hass' avocado fruit due to compression

- Fruit (*n* = 5, 3) at hard, firm ripe and soft ripe stages
- Compression load cell: 4500 g
- Compression speed: 0.5 mm/sec
- Compression depth: 1 mm, 1.5 mm, 3 mm
- Deformation in fruit flesh calculated

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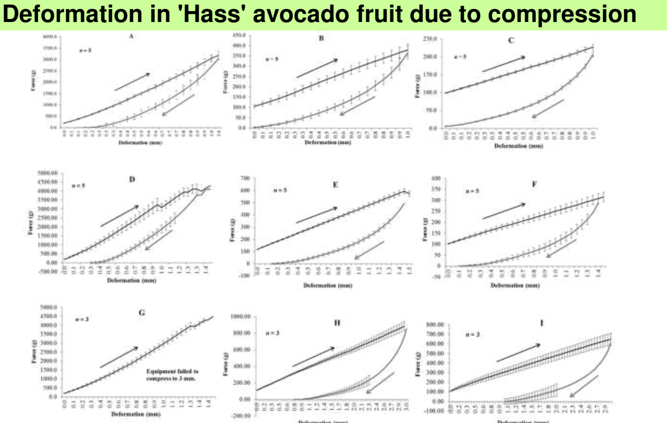
Deformation in 'Hass' avocado fruit due to compression



Relationship of force and displacement in flesh for fruit (n = 5) compressed to 3 mm. (A, D, G) Hard. (B, E, H) Firm ripe. (C, F, I) Soft ripe.

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Shopper's contributions to bruising in ripening avocado fruit

Fruit trays (n = 6) were placed on display in participating stores

SAMPLING STRATEGY 1

Shoppers randomly interacted with and bought the fruit

Left over fruit on the display were collected after ~ 6 h for bruise assessment

SAMPLING STRATEGY 2

Shoppers interacted with single fruit

The fruit picked by shoppers but left on the display was collected for bruise assessment

In store **visual observation** of shopper behaviour in terms of fruit handling were recorded

[Note: Shoppers were not intercepted in these experiments]

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Shopper's contributions to bruising in ripening avocado fruit

SAMPLING STRATEGY 3: Fruit (n = 20) squeezed by shoppers (n = 20). Each fruit was squeezed and subjected to bruise severity assessment after 48 h.

SAMPLING STRATEGY 4

Shoppers (n = 80) squeezed fruit with a single force sensor between the fruit and the shopper's thumb.

The fruit were assessed for flesh bruising and correlation of force applied with the resultant flesh bruising was developed.

SAMPLING STRATEGY 5

Shoppers (n = 50) squeezed one each of softening, firm ripe and soft ripe fruit with Grip™ sensor e-glove on.

Compression pressure spread across the hand was measured with Tekscan® software as coloured contour images.

Flesh bruising due to pressure applied on the fruit was assessed.

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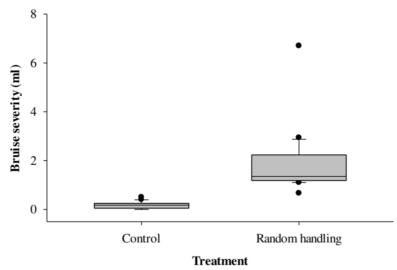
Shopper's contribution (Random squeezing)

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



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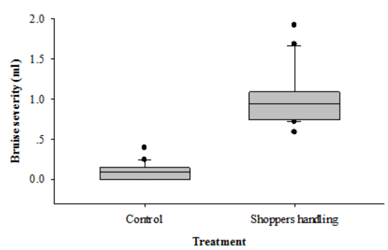
Shopper's contribution (Single fruit squeezed by a shopper)

Contribution of fruit handling practices of shoppers to bruising in firm ripe 'Hass' avocado fruit – each fruit handled by single shopper



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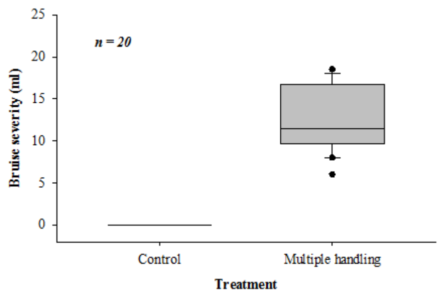
Shopper's contribution (Multiple fruit handling by shoppers)



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

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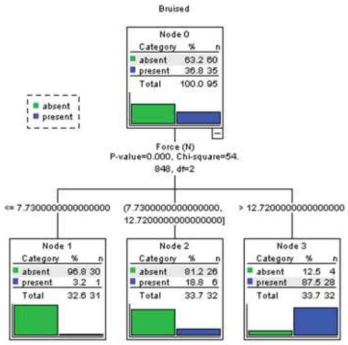
Shoppers contribution (Single zone force sensor)

FSR 406 Interlink Force Sensor



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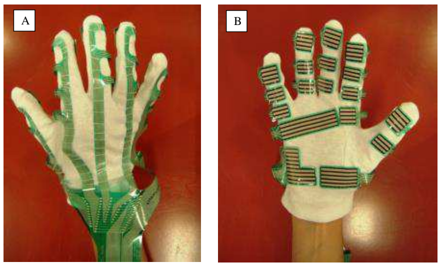
Shoppers contribution (Grip™ pressure sensor)



Grip™ sensor e-glove used to measure pressure applied by shoppers to assess the fruit firmness and resultant flesh bruising of avocado cv. 'Hass' fruit. (A) Top view of the e-glove. Grip™ sensor sewn onto a white cotton glove with cotton thread. (B) Bottom (palm side) view of the e-glove. After the hand shaped flexible plastic grip sensor platform was sewn to the back of the glove, the grip sensor pads were folded around the fingers of the cotton glove and attached to the palm side using double-sided tape.

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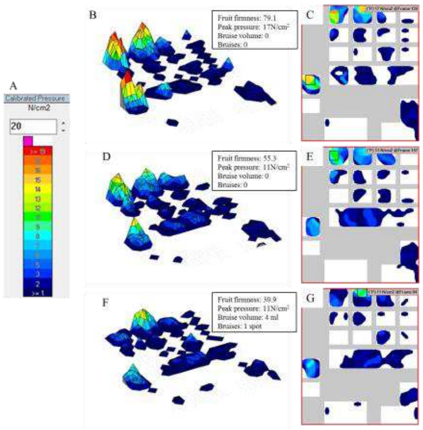
Shoppers contribution (Grip™ pressure sensor)



A: Calibration of pressure applied by GripTM sensor in N.cm^{-2}

B, D, F: 3-D contour view of spread of pressure applied by different parts of shopper's right hand on softening, firm ripe, and soft ripe fruit, respectively.

C, E, G: 2-D contour view of the spread of pressure on different parts of the pressure sensor pads of Grip™ sensor e-glove for softening, firm ripe, and soft ripe fruit, respectively.

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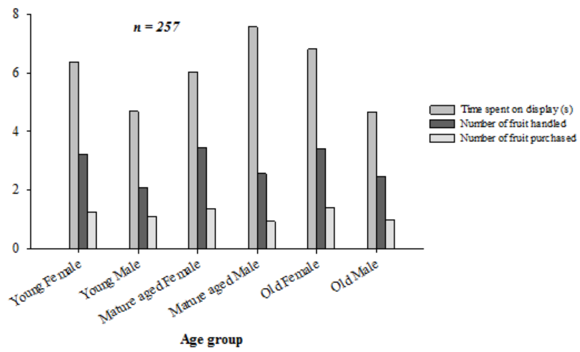
In-store observations of avocado fruit handling by shoppers



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Consumer research

SAMPLING STRATEGY 1

- Sampling from through the store to home chain
- Consumers invited to purchase double the number of fruit they buy
- Half the number of fruit collected back

SAMPLING STRATEGY 2

- Sampling of control ripened fruit
- Consumers afforded twice the number of fruit they buy after the retail check out point
- Half the number of fruit collected back

Consumers …

- selected following the '**snow ball strategy**'
- kept simple **diary notes** on fruit handling

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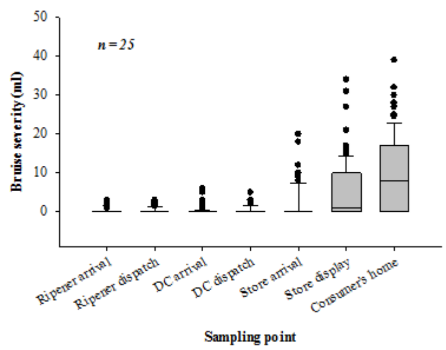
Consumer contribution



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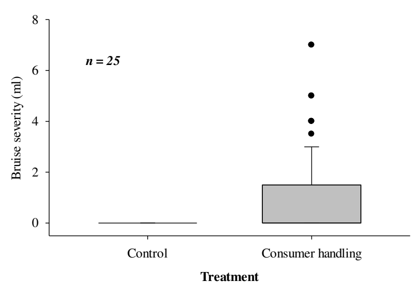
Consumer contribution



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Consumers attitude to flesh bruising

SAMPLING STRATEGY 1 & 2

- Consumers completed the diary notes for fruit they consumed for the experiments conducted to determine their contribution to flesh bruising.

SAMPLING STRATEGY 3

- Fruit were ripened in laboratory.
- Pre-impacted from 50 cm drop height
- Half the number of fruit subjected to bruising assessment to determine the extent of flesh bruising.
- Other half the number of fruit given to consumers for their consumption experience.

SAMPLING STRATEGY 4

- Consumers collected fruit from retail display of a supermarket retail store and take their home subjected to normal handling practices.
- Consumed the fruit and completed the diary notes for the consumption experience.

Consumers …

- selected following the '**snow ball strategy**'
- kept simple **diary notes** on their **satisfaction** upon consumption, and decision to **repeat purchase**

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Diary note questions

1. Where did you keep your avocado fruit after they reached your home?

----

2. What proportion of the total number of avocados, if any, had flesh bruising at your time of consumption?

----

3. What percentage (%) of the avocado fruit flesh was bruised? Please note your observations.

----

4. What is your level of satisfaction with the quality of your avocado fruit in terms of the flesh bruising?

1. Very Satisfied 2. Satisfied 3. Just OK 4. Dissatisfied 5. Very dissatisfied

5. Has your decision to repeat purchase the avocado fruit affected with your recent experience of flesh bruising?

Note: Kindly make photographs of bruising in avocados and send me at sohail@uq.edu.au

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Consumers attitude to flesh bruising

- 244 consumer responded.
- Consumers' level of satisfaction affected by the bruising.
  - 47% consumers: very satisfied
  - 22% consumers: satisfied
  - 13% consumers: just OK
  - 11.5% consumers: dissatisfied
  - 6.5% consumers: very dissatisfied
- Consumers' repeat purchase intention as affected by bruising.
  - 84% consumers: not affected
  - 16% consumers: affected
- Amongst the consumers whose intention was not affected even if they had experienced flesh bruising, about 15% had experienced between 10 and 25% bruising severity of small sized bruises.

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Chapter 7 –

- Findings
- Recommendations

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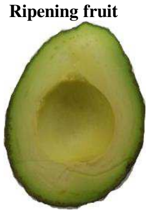
Findings (Research summary)

A

Ripening fruit



+ **Force applied**

(Impact / Compression)

Causes plastic deformation in mesocarp and triggers PPO activity

Holding duration

Temperature

Harvest maturity

Firmness

Bruised fruit

B

➡ ➡Ripener ➡ Distribution centre ➡ Retail Store ➡ **Retail display** ➡ Consumers' home

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Other expected outcomes

- In-store firmness tester
- Point of sale fruit selection guide

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Publications

- **Mazhar, M.,** D. Joyce, G. Cowin, I. Brereton, P. Hofman, R. Collins. and M. Gupta. 2015. Non-destructive ^{1}H-MRI assessment of flesh bruising in avocado (*Persea Americana* M.) cv. Hass. *PHBT*, 100: 33-40.
- **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).
- **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
- **Mazhar, M.,** D. Joyce, P. Hofman, R. Collins, I. Brereton, G. Cowin, and M. Gupta. 2011. Bruising in the Queensland supply chains of Hass avocado fruit. Proceeding of the VII World Avocado Congress 2011, Cairns, Australia. 665-672.
- **Mazhar, M.,** D. Joyce, P. Hofman. 2015. Low temperature management can reduce bruise expression in avocado cv. 'Hass' fruit flesh. Talking Avocados. (Submitted).
- **Mazhar, M.,** D. Joyce, P. Hofman. 2015. Bruising and rots development in impacted hard green mature avocado cv. 'Hass' fruit. Talking Avocados. 25, 30-33.
- **Mazhar, M.,** D. Joyce, P. Hofman, R. Collins, M. Gupta. 2014. Bruising by hand in softening avocado fruit – Preliminary study. Talking Avocados. 24, 29-31.
- **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.

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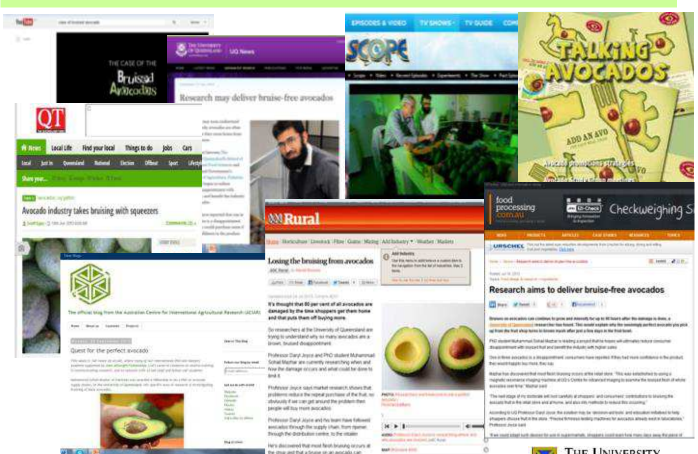
Dissemination



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Future research

- Threshold of compression force that lead to flesh bruising in avocado.
- Energy absorption and dissipation in avocado fruit.
- Temperature management through the supply chain.
- Effect of plastic packaging compared with loose fruit on the retail.
- Effect of store staff and shopper's education on fruit quality.
- Shoppers preference of in-store decision aid tool.
- Association between flesh bruising and body rots.
- Bio-chemistry of flesh bruising.
- Skin spotting as affected by handling practices, and stage of fruit firmness.

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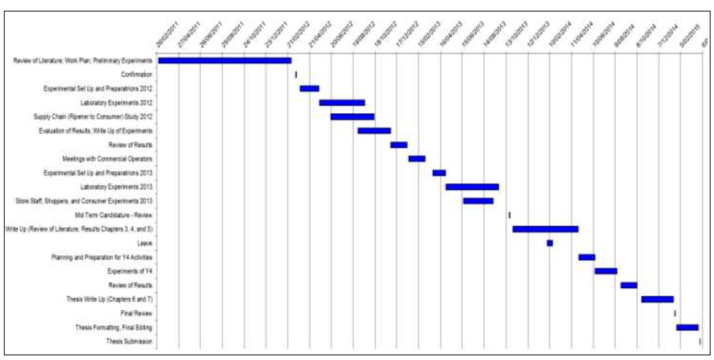
Gantt chart: Ph.D candidature



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Acknowledgements

Advisers: Prof. Daryl Joyce, Prof. Ray Collins, Dr. Peter Hofman, Dr. Madan Gupta, Dr. Tim Sun

Co-workers: Leanne, Guoqin, Lauren, Hunter, Nga, Ian, Christine

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Research associates: Growers, Ripeners, Supermarket chains, Independent retailers, Consumers

Family: Mother, wife, kids

Australian Government
Australian Centre for International Agricultural Research

Horticulture Innovation Australia

Avocados Australia

Queensland Government

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The University Of Queensland Australia

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Evaluation and correlation of firmness measuring devices

Measurement of fruit firmness with analogue firmometer (L), IQ Benchtop firmometer (M), and Anderson Electronic firmometer (R)

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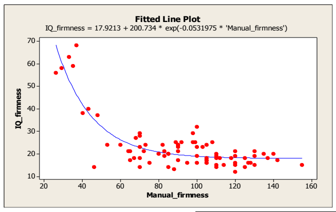
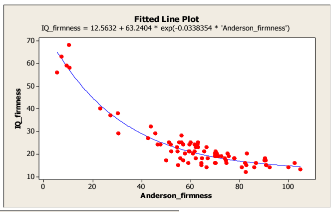
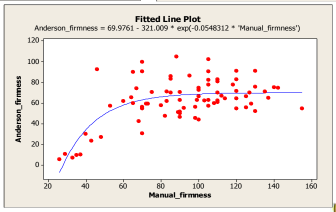
Correlation of firmness values







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Bruising caused by firmness measurement

Comparison of measurement of bruise incidence with analogue firmometer, IQ Benchtop, and Anderson Electronic firmometer

Firmness Devices	Chi^2	Significance
iQ & Anderson	140.823	Significant
iQ & Analogue	0.118	Not significant
Anderson & Analogue	137.243	Significant

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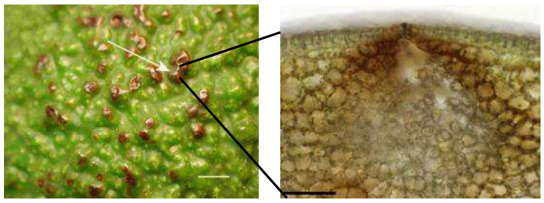
Skin spotting



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

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Everett et al., 2008

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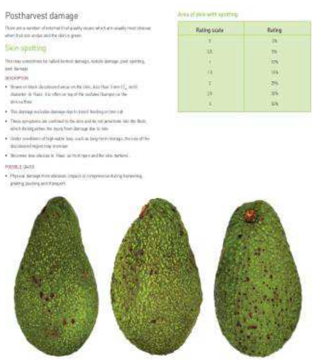
Skin spotting rating scale



1 = 10% 2 = 25% 3 = 50%

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)

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White et al., 1999

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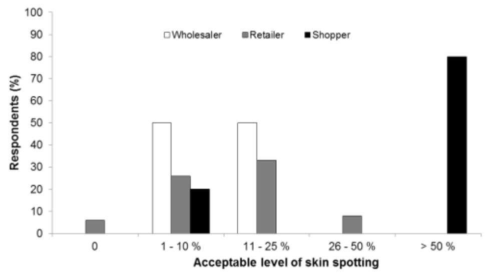
Stakeholders responses



Acceptance of different levels of skin spotting.

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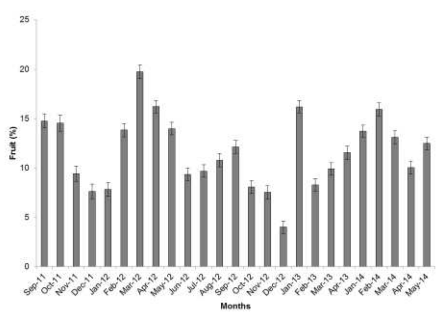
Distribution of skin spotting



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

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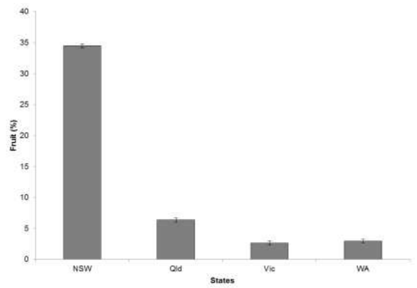
Distribution of skin spotting



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

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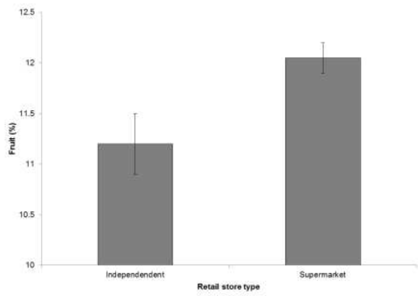
Distribution of skin spotting



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

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