Bruising in the Queensland Supply Chains of Hass Avocado Fruit

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Abstract

High levels (viz., incidence and severity) of internal defects in avocado fruit have a negative impact on the consumers' intent to purchase. Bruising, in particular, is prominent among the various types of internal defects (cf., disease and chilling injury). Postharvest research has historically and consistently shown that bruise susceptibility increases markedly as avocado fruit ripen (i.e., soften). Despite this basic technical understanding, surveys of 'ready to eat' avocado supply chains and of consumer perceptions show that a major commercial problem with bruising persists. To strengthen understanding and to increase awareness throughout the supply chain, strategic research is currently being undertaken with Avocados Australia Limited and through Horticulture Australia Limited to define the expression of browning symptoms in Hass avocado fruit in a temporal context. Parallel applied experimentation is examining relationships between impact events (i.e., force and number) during commercial handling of softening Hass fruit from the ripener, via the distribution centre, and in the retail store. The relevant background literature is briefly reviewed and the preliminary findings are presented with respect to on-going studies on bruising of Hass avocado in south east Queensland supply chains.

Key Words: avocado, bruising, expression, impact, physiology, supply chain

Introduction

Avocado is one of the more rapidly expanding fruit commodities in Australia (FAO, 2009). Its production has increased from 28,458 tonnes in 2001-02 to 46,148 tonnes in 2009-10, representing an increase of 1.62-fold over the 8 years. Avocados Australia Ltd. (AAL) has projected that avocado production could reach 65,000 tonnes by 2014. Despite this growth trend, supplying the expected level of quality and the anticipated consistency of quality to the consumers remains a challenge for the avocado suppliers.

Previous studies report that the consumers are generally not receiving the expected value against what they spend on buying avocados from the retail store. The first Australian studies of avocado consumers (Dermody, 1990) revealed that 53% of the avocado consumers considered that avocado fruit which looked satisfactory at the time of purchase had unsatisfactory levels of flesh defects at the stage of consumption. Smith et al. (1990) reported that about 40% of the consumers were having bad experiences in the buying and consumption of avocados. Ledger (1993) and Story and Rudge (1995) also conducted retail surveys and reached similar conclusions. A Horticulture Australia Limited (HAL) project entitled 'Avocare' established that about 80% of the fruit had flesh bruising to some extent. About 25% of the total fruit sampled was considered unusable because of bruising (Hofman and Ledger 2001). Harker and Jaeger (2007) established that if recently purchased fruit had more than 10% of their flesh volume affected by defects, then there are negative effects on the next intent to purchase. Results of another HAL project on 'Avocado Retail Quality Surveys' conducted in 2008 indicated that 63% of the fruit had flesh defects and that 29% of these fruit had more than 10% of the flesh volume affected by the defects. The consumer research by Gamble et al. (2010) based on 107 consumers revealed that the incidence and the level of bruising were the two most important factors in lowering the consumer's intent of future purchase.

Many other retail surveys confirm that consumer expectations are not being met by the quality of fruit presented on the retail shelves and that their future buying decisions are adversely affected by the available quality leading to bad experiences (Embry 2008). This historical work has so far led to only a little improvement in the quality of 'Hass' avocado being offered to the consumer (Hofman and

Ledger 2001). To date, there is only a limited understanding of how and when bruising occurs in the supply chain and of how to minimise it.

Bruising has been studied in a variety of fruits and vegetables, including stone fruit (Hung and Prussia 1989; Brusewitz et al. 1992; Ahmadi et al. 2010), apple (Ericsson and Tahir 1996; Blahovec, 1999; Bollen et al. 1999), pear (Kabas 2010), tomato (Linden et al. 2006), potato (Wouters et al. 1985; Esehaghbeygi and Besharati 2009) and banana (Akkaravessapong et al, 1992). Given the importance of this issue for avocado, surprisingly little has been documented in the published literature on the incidence and severity of bruising.

Studman (1996) described the bruise as an area of damage within a fruit that is usually caused by compression or impact. The symptoms of bruising are typically dark-grey in colour and in a well defined area of the flesh, usually close to where the impact occurred. Other forms of bruising, such as very light-coloured discolouration often associated with hairline cracking of the flesh, have been observed in avocado fruit sampled from the end of the packing line (Hofman 2002).

The literature suggests that bruising is present in avocado fruit dispatched from the ripener and also from the distribution centre (DC), and presumably consequently in fruit displayed on the retail shelf (Hofman and Sandoval 2002). Avocado flesh is more easily bruised as the fruit soften (Arpaia et al. 1987; Ledger and Barker 1995; Arpaia et al. 2005; Arpaia et al. 2006) and bruise severity increases with increasing impact energy (Brusewitz et al. 1992; Mandemaker et al. 2006). Arpaia et al. (1987) reported that the external skin colour, rate of fruit ripening, firmness, respiration and ethylene production of Hass avocado were not affected by impact injury as compared with no impacts. They documented that the Hass avocado variety is relatively more susceptible to bruise injury as the fruit soften and as the impact energy absorbed by the fruit increases. Baryeh (2000) confirmed these findings, reporting that the avocado fruit becomes more susceptible to impact bruising with increased impact height and ripeness. Hofman and Ledger (2001) recommended that more work is needed to develop and apply a methodology to identify where and how bruising is occurring in order to improve postharvest practices. Hofman (2002) that for green mature fruit 55% out of 185 consignments from different sources and representing the average industry practices had not yielded any fruit with bruising. Only 7.4% of the total fruit number had minor damage to less than 5% of the fruit area. Moreover, only 0.6% of the 3700 Hass avocado fruit examined had more than 15% of total area affected by bruising. It was suggested that further research and development in the area should focus on from ripening onwards in avocado fruit supply chains.

Practical improvements are possible as has been demonstrated by preliminary trials indicating that trays and inserts providing more protection to the fruit significantly reduced bruising in fruit sampled from the retail shelf, particularly when compared with volume filling (Arpaia *et al.* 2005; Arpaia *et al.* 2006).

The current research project ‘Reducing Flesh Bruising and Skin Spotting in Hass Avocado’ was initiated with a primary focus on reducing flesh bruising in ripening avocado fruit so as to deliver better quality fruit to the consumers. The studies will include determining the time to expression of bruising after an impact to single fruit for a combination of different levels of fruit firmness and drop heights, as well as to commercially-packed fruit trays. Also, qualitative and quantitative surveys of commercial consignments will be conducted in close collaboration with the commercial stakeholders of fruit growers and suppliers, ripeners, DCs and retailers in order to determine the actual incidence and severity of bruising in ripening avocado fruit passing through supply chains in S.E. Queensland. Additionally, the Magnetic Resonance Imaging (MRI) technique will be employed to non-destructively visualise the extent of bruising as a function of different levels of impact at different levels of firmness. MRI has already been successfully used with avocado and various fruit and vegetables for maturity determination (Chen et al. 1993) and for internal product quality determination (Wang and Wang 1989; Gonzalez et al. 2001; Sanches et al. 2003; Huang and Lu 2010). However, its full potential for bruise assessment and management in avocado has yet not been explored (Hills and Clark, 2003). MRI work to compliment destructive assessment will help inform understanding of bruise mechanisms and expression in commercial supply chains. Also, a detailed consumer-focused study will be conducted in years 2 and 3 of the 3-year project in order to document the likely contribution of consumers in causing bruising in ripening and ripe avocado fruit. Overall, these studies will lead to recommendations and tools for the avocado industry to monitor and reduce the incidence and severity of bruising in fruit delivered to consumers. In this regard, commercially applicable decision aid tools, such as impact recording devices, will be employed to record the impact at different levels in the supply chain.

Methodology

Background summary: Consumers prefer to buy ripe and 'ready to eat' fruit (Williams 1961; Lee and Coggins 1982; Gamble et al. 2010). However, avocado fruit flesh defects become more severe as the fruit ripens (Arpaia et al. 1987; Arpaia et al. 2005; Arpaia et al. 2006). It is not clear as to when bruising symptoms first appear after a bruising event happens. Similarly, it is not clear how the symptoms of bruising develop over time. Thus, gaining a better understanding of when bruising expression peaks relative to the causative event would lead to increased assessment efficiency and also inform the development of monitoring and bruise reduction practices for incorporation into the commercial avocado supply chains.

General approach: Initially, experiments defining the times taken by the avocado fruit to express bruising in response to a series of different impact energies are being conducted. In concert, the calibration of two different (viz., automatic vs. manual) firmness-measuring devices is being undertaken. These studies are based at the Postharvest Research Laboratory of The University of Queensland's Gatton campus. A correspondent pilot study into the efficiency of MRI as a tool in avocado bruise development assessment is being conducted at the Centre for Advanced Imaging at The University of Queensland's St. Lucia campus.

Plant material: Avocado fruit at the green-hard stage were collected from the ripener's premises at the Brisbane Markets in Rocklea. The fruit were carefully transported to the Postharvest Research Laboratory, where they are triggered to ripen by dipping in 1000 $\mu L.L^{-1}$ ethephon (plus 0.01% Tween 80) for 10 minutes. Fruit are then air dried and kept in shelf-life evaluation rooms at 20ºC until they reached firmness level 4 (White et al., 2009; Table 1). The fruit are initially sorted on the basis of hand firmness and assigned to treatments on a matched-sample basis. The individual fruit were labelled with Pental white 100 WM markers and weighed with a Sartorius GMBH B100S digital balance.

Fruit firmness assessment: Various methods and equipment are reported in literature for the determination of avocado fruit firmness. Swarts (1981) used a manual avocado firmometer, Arpaia et al. (1987) used Effegi probes, Meir et al. (1995) used conicle probes, Macnish et al. (1997) used an analogue firmness meter, White et al. (1997) modified the manual avocado firmometer into the Anderson digital firmometer, and White et al. (2009) prescribed the hand firmness guide for avocado as used in the current work.

In the present study, the analogue firmness meter as a non-destructive firmness measuring device was tested in comparison with the Anderson digital firmometer as a faster and potentially more precise device. The firmness of 30 avocado fruit at a uniform stage of ripening was recorded with each of these two firmness measuring devices. Data were collected on the same fruit but on opposite sides. Statistical comparisons, including correlations, were made between the two devices.

Table 1: Avocado hand firmness guide from 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

Fruit impact treatments: Individual fruit were impacted by dropping in a pendulum device from a height of 50 cm against a solid surface. Pendulum-based impact devices have been used by Mohsenin (1986), Bollen et al. (1999), Baryeh (2000), Linden et al. (2006) and Opara et al. (2007). The impact area on each fruit was marked and the fruit kept at 20ºC for T1 = control (no impact and assessment at 96 hr), T2 = 0 hr, T3 = 2hr, T4 = 4 hr, T5 = 8 hr, T6 = 16 hr, T7 = 24 hr, T8 = 48 hr, T9 = 72 hr, and T10 = 96 hr after impact. The fruit were then cut and bruise volume assessed as described below.

Impact energy calculation: The energy applied to the avocado fruit was calculated using the following equation (Schoorl and Holt 1980; Hung and Prussia 1989; Akkaravessapong et al. 1992; Opara et al. 2007): E = m.g.(h1 - h2); where, E = Energy absorbed by the fruit (Newton), m = mass of fruit, g = the constant of acceleration due to gravity, h1 = drop height, and h2 = rebound height.

Bruise volume: Bruise volume was measured using the volume displacement method. The bruise-affected area fruit was removed and dipped into water within a calibrated flask and the volume displaced was recorded (Rashidi et al., 2007). Bollen et al. (1999) and Kabas (2010) considered various different mathematical calculations for measurement of bruise volume in apple and pear, respectively. They concluded that all the volume estimation methods induce errors in calculation of actual volume of bruise. The volume displacement method was selected for the present study because it would likely give an accurate value for the actual bruised area. The volume of cracks resulting from impact was taken separately by filling the cracks with a calibrated medical syringe. The crack volume was added in the volume of bruise calculated after Rashidi et al. (2007) to calculate the actual bruise volume caused by an impact.

Bruise intensity measurement: The intensity of bruise expression in individual fruit was recorded by measuring the colour parameters lightness (L*), hue angle (a*) and chroma (c*) using a Minolta colourimeter CR 400 after Darrigues et al. (2008) and Lim et al. (2011).

MRI: For the pilot study, an avocado with a small vial of water positioned over a white mark indicating an area of recent impact was placed in the 32-channel head coil and imaged. A series of turbo spin echo images were acquired in sagittal orientation. This test was in preparation for subsequent detailed non-destructive studies into practices contributing to bruising in avocado supply chains.

Industry surveys: Surveys of supply chains and targeted interviews of consumers will complement the laboratory-based methods described above. In particular, the surveys will help with understanding the extent and economic impact of bruising occurring in the supply chain and in the hands of consumers after the fruit are purchased (Szali 1973; Chin 2007).

Results and discussion

The results from preliminary research on this project are presented herein.

Evaluation of fruit firmness assessment devices: Correlation analysis of the electronic Anderson digital firmometer data and the manual analogue firmness meter gave a significant linear relationship at the 95% level of confidence (Figure 1).

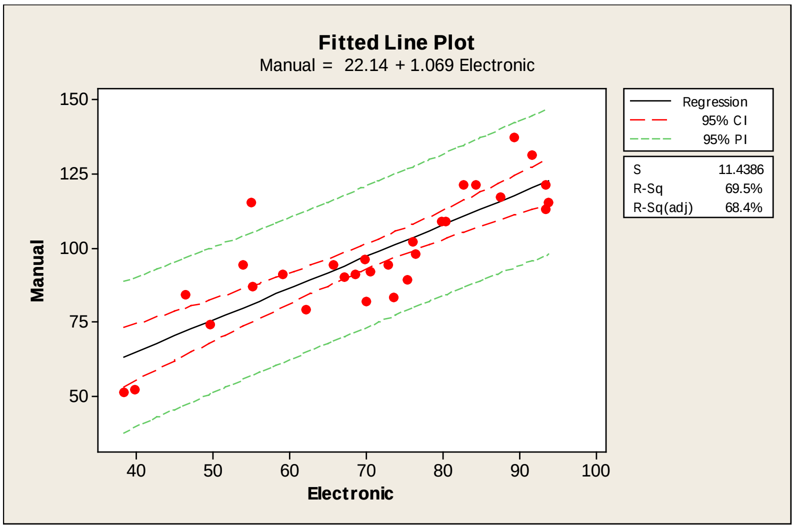


Figure 1: Fitted line-plot of the relationship for 30 individual avocado fruit at hand firmness stage 4 between values of firmness taken with the analogue firmometer (manual) and those taken with the Anderson digital firmometer (electronic).

Being a relatively non-destructive firmness measuring device, the gentler manual analogue firmness meter will be used in the future assessments in this project. By virtue of the reasonably good correlation between the two devices, the firmness values recorded with this equipment can likely be related to the Anderson digital firmometer and the hand firmness scale used by White el al. (2009).

Evaluation of bruise development: The severity of visible flesh bruising in avocado worsens with increasing time after the impact event (Figure 2). For avocado fruit at hand firmness stage 4 and impacted from 50-cm height (absorbing 0.85± Newton energy), tissue discolouration was not obvious until 16 hours after impact. The damage initially appeared in the form of cracks and the more voluminous damaged tissues changed colour to brown as time passed and even beyond 96 hours from impact.

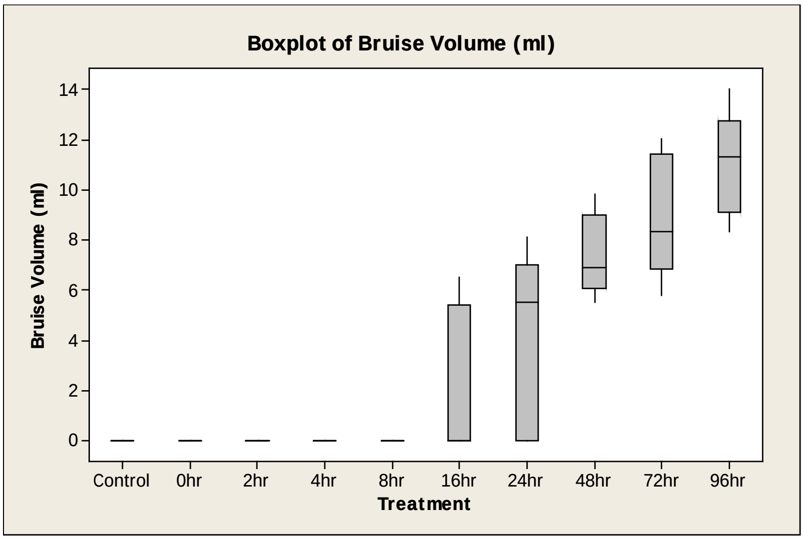


Figure 2: Change in the bruise volume over time in avocado fruit (n=10) impacted at hand firmness stage 4 with 0.85± N energy

Also, the average hue angle of bruised tissue decreased markedly (that is, became less yellow) over time (Figure 3). The data logically reflect temporal physiological and biochemical changes taking place within the avocado flesh tissues (Biale and Young 1971).

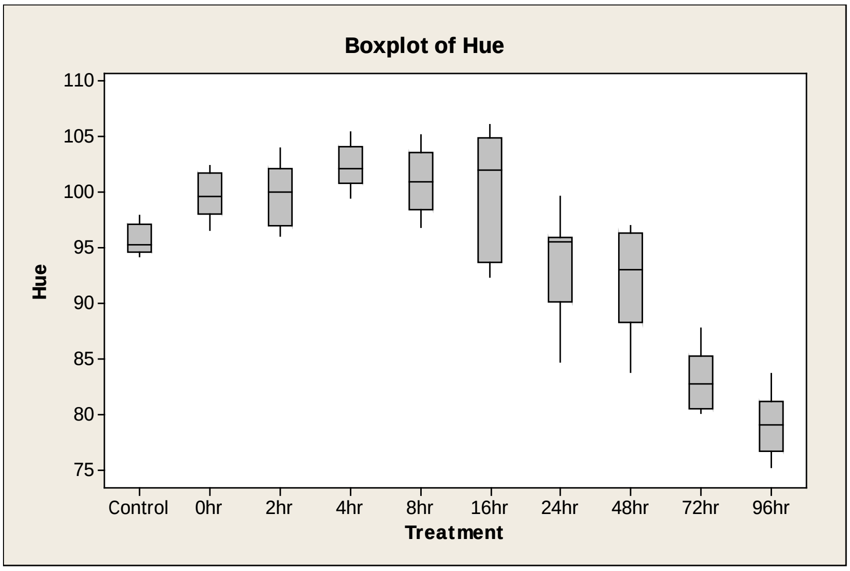
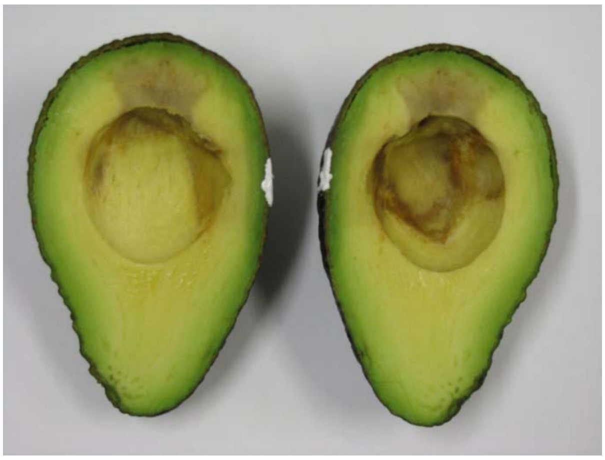


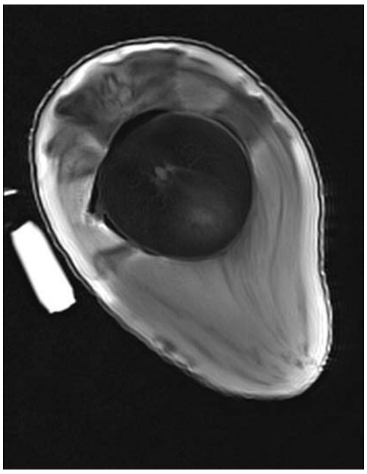
Figure 3: Decrease in Hue angle over time in avocado fruit (n=10) impacted at hand firmness stage 4 with 0.85± N energy

Further experimentation will explore the treatment combination of firmness level and the impact force (i.e., drop height) on bruise development over time after the event. The fruit study will be extended to trays in order to help better understand the influence of commercial practice upon ripening fruit through the supply chain in terms of bruise incidence and severity.

MRI analysis: MRI analysis of impacted avocado fruit has revealed bruising within 24 hours of impact (Figure 4), which supports the laboratory-based study reported immediately above.



Visual image of impacted avocado fruit (white-marked area). The discolouration at the distal end are from unknown cause.



MRI of the whole avocado fruit wherein the controlled impact area was hyperintense. The area of brown flesh at the top of the avocado image from an unknown cause appears as a hypointense region.

Figure 4: Sagittal view of avocado with impact bruising

In conclusion, future work on avocado bruising in this project will lead to recommendations derived from laboratory-based experimentation and from commercial supply chain practice evaluations to help the avocado industry in SE Queensland to significantly reduce postharvest losses due to bruising and to enhance consumer satisfaction.

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