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Factors affecting avocado flesh bruising susceptibility

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Avocados are prone to flesh bruising, especially once they reach retail shelves (*Figure 1*). This issue is a major concern to the Australian avocado industry, with flesh bruising being responsible for around half of all avocado internal defects detected at the retail level[1]. A problem for shoppers is that they can't tell if a fruit is bruised internally until they cut it open at home. The end result in many cases is consumer disappointment and a reluctance to purchase avocados in the future[2].

What is it that makes avocados susceptible to bruising and can anything be done to make them more resilient? Mechanisms involved in avocado flesh bruising and factors that govern them are discussed here with a view to reducing bruising.

Figure 1. Flesh bruising in Hass avocado fruit at the retail level is a major quality issue.

What is bruising?

Physical injury of avocado fruit tissues occurs in response to applied mechanical force. Damage that leads to bruise expression is caused by impact (e.g. dropping), compression (e.g. squeezing) and/or vibration (e.g. transport) injuries. The walls of cells comprising fruit tissue are elastic to a limited degree. As such, they can absorb some of the physical shock without permanent injury being caused. However, when cells experience stress beyond their elastic limit, the cell walls fail and permanent damage occurs. In this circumstance, cell contents previously separated within compartments in the cell will mix together as the cells rupture. This brings phenolic compounds into contact with the enzyme polyphenoloxidase (PPO), which triggers enzymatic browning resulting in polymerised phenolics. These are brown in colour and are responsible for the typical dark discoloration recognised visually as a bruise.

How is bruising measured?

Flesh bruising in fruit has been described and measured in various ways[3]. **Bruise incidence** can be defined as the number of bruised fruit in a given sample (e.g. tray) of fruit. It can be expressed as a percentage of the total number of fruit affected within the sample. Alternatively, it can be measured and expressed as the number of bruises on any individual fruit. Bruise incidence data do not indicate the degree to which fruit are bruised. **Bruise severity**, on the other hand, indicates the size of a bruise. It is generally quantified as either the area or the volume of the affected flesh in individual fruit. The value may also be converted to a percentage of the total fruit flesh area or volume. The avocado industry recognises the importance of both bruise incidence and severity, and tracks the percentage of fruit at retail with more than 10 percent affected flesh area[1] (the level generally considered to be unacceptable to consumers[2]). **Bruise intensity** is a measure of the relative darkness of a bruise. It can be scored visually (e.g. light brown to black) or measured with a colour meter. The latter involves recording three colour coordinate values (e.g. L, a, b) that pinpoint a particular colour in a three-dimensional colour space of all possible colours[4]. **Bruise susceptibility** is the relative degree to which a fruit bruises when given a specific damaging pressure. It is expressed as the amount of flesh showing damage per unit of absorbed impact or compression energy.

What affects bruise susceptibility?

Anecdotal and experimental evidence suggest that the susceptibility of avocados to bruising is related to fruit firmness, dry matter content, flesh temperature, and time in the supply chain.

Firmness is an indicator of cell wall strength in fruit tissue and a way to determine the ripeness of avocado fruit. Firmness decreases during ripening and has been characterised into the stages of hard, rubbery, sprung, softening, firm-ripe, soft-ripe, overripe, and very overripe[5]. Bruise susceptibility increases as firmness decreases. For example, injury due to a "very slight" thumb compression of 5 Newtons produced twice as much bruising (in terms of bruise area) in soft-ripe than firm-ripe Hass avocados (unpublished data; *Figure 2*). For impact injury, the drop height at which Hass avocados began exhibiting bruising was 5cm for sprung fruit and 2.5cm for firm-ripe fruit[6]. Mathematical modelling for Collison avocados suggested that the critical drop height for bruising was approximately 3cm in fruit that the authors referred to as "ripe"[7]. In contrast, hard fruit are resistant to bruising. No permanent bruising was recorded for hard green mature Hass avocados after impact from a drop height of 100cm. Initially damaged tissue in green mature fruit was apparently able to recover over time[8].

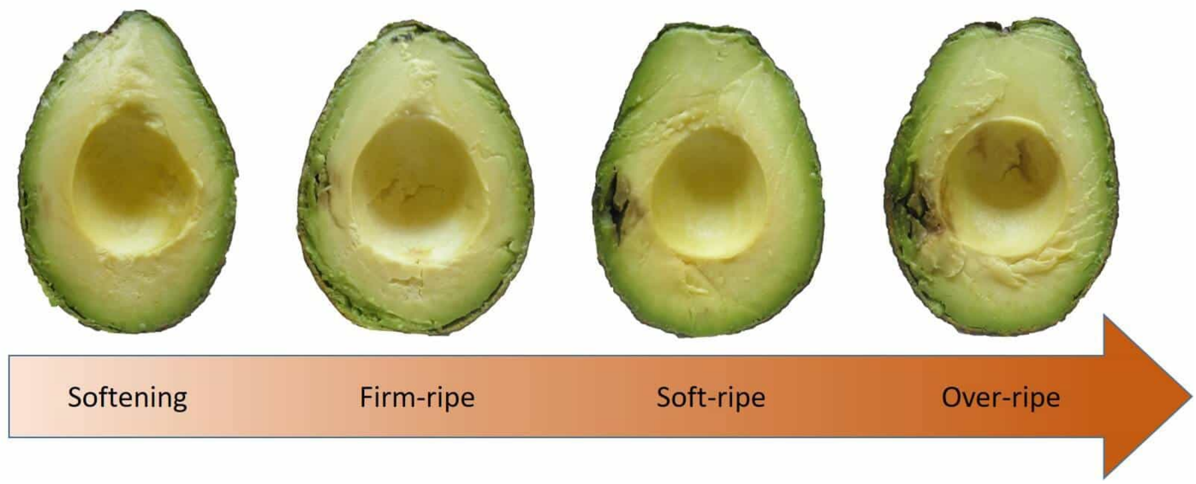

Figure 2. Bruising in Hass avocados subjected to a "very slight" thumb compression of 5 Newtons at different stages of ripeness.

Dry matter content tends to increase over the harvest season and is a reliable measure of avocado maturity. Fruit with higher dry matter were less susceptible to bruising in a study that subjected firm-ripe Hass avocados to a 50cm drop height[8]. Bruise volume progressively decreased as dry matter increased from 22 to 33 percent.

Relatively high fruit dry matter can offer consumers a better eating experience[2]. On the other hand, waiting to harvest unusually high dry matter avocados might lead to a less desirable eating experience. For example, a slight decline in consumers' intentions to purchase avocados was observed when dry matter exceeded 40 percent[2]. Furthermore, a very late harvest may deplete carbohydrate reserves in the tree and increase the risk of biennial bearing[9]. Delaying harvest to 'meet and beat' the minimum recommended dry matter level for harvest (i.e. 23 percent+ for Hass) is likely to be a good compromise towards reduced bruise susceptibility.

The **temperature** of the fruit following an impact is a potentially important factor in lessening avocado flesh bruising. Hass avocados held at 5°C for 48 hours after being impacted did not show bruising[8]. In contrast, holding impacted fruit at 15 or 25°C for the same period resulted in 90 and 95percent bruise incidence, respectively. Moreover, bruise intensity was higher (i.e. darker) in fruit held at 25°C than at 15°C. The data suggested that flesh temperature during the first eight hours after impact is critical in determining visible bruising. Relatively greater PPO activity was considered to be the likely cause for greater bruise incidence observed at higher temperatures. Note, however, that chilling injury may occur in Hass avocados at 3°C or lower. Also, refrigeration of fruit at retail level may have cost and other marketing considerations.

Prolonged **time in the system** has been shown to increase the susceptibility of Hass avocados to bruising. When subjected to impact at the firm ripe stage, fruit stored at 5°C for one to five weeks prior to ripening tend to exhibit greater bruise volumes than un-stored control fruit[8]. A trend of increasing bruise volume was observed with increasing cold storage duration.

Any other factors?

Although not specifically researched to date, other factors are likely to affect bruising susceptibility by influencing the physical properties of cell walls and/or enzymatic browning processes.

Pre-harvest water stress has, for example, been found to promote PPO activity in avocado fruit[10]. Therefore, it might be reasonable to expect bruise expression to be greater in water deficit stress affected fruit. However, investigation is required to establish if this is the case.

Cultivar (i.e. genotype) is known to dictate the enzymatic browning potential of avocado fruit. For instance, the rate of cut flesh browning, as well as flesh total phenolic content and PPO activity, are greater in Fuerte than in Lerman[11,12]. For cultivars common in Australia, the peel of Hass avocados contains greater concentrations and diversity of phenolic compounds than does Shepard avocado peel[13]. The concentration of epicatechin, a known PPO substrate, exhibited a dramatic decrease in Hass avocados during a harvest season[14]. This trend may at least partly explain the decreasing bruise volumes observed with increasing dry matter over time as noted above.

Choice of **rootstock** cultivar has been shown to affect calcium (Ca) accumulation in avocado fruit. Ca is important for cell wall strength and membrane stability. Compared to fruit containing low Ca concentrations, Hass avocados with relatively high flesh concentrations at harvest show delayed ripening[15,16], greater firmness after storage[17], lower incidence and severity of body rots[15,18], decreased mesocarp discolouration[15,19], and reduced incidence and severity of vascular browning[19,20]. Grafting of Hass onto Velvick or A10 rootstocks produced fruit with high Ca concentrations[21]. However, variation in rootstock effects on postharvest fruit quality has been reported across different locations and seasons. Therefore, it is difficult to predict and remains to be proved which rootstock, if any, may reduce fruit susceptibility to flesh bruising.

High turgor pressure in flesh tissue has been linked to greater bruise susceptibility in fruits such as apple and pear[22]. However, no such studies have investigated the relationship between turgidity and bruising for avocado. Nonetheless, greater lenticel damage has been reported in avocado fruit with high cell turgidity[23]. It can be reasoned that, as turgor pressure rises, cell wall elasticity decreases and fruit tissues could become more 'brittle' and, therefore, susceptible to physical damage. Fruit that are wet from rainfall or dew are likely to have high turgor pressure. Harvesting fruit in wet conditions promotes vascular browning and lenticel damage in Hass avocados[24,25].

Precautions to reduce bruise susceptibility

Based on the above, recommendations for improved practices to reduce bruise susceptibility in avocado fruit have been summarised in *Table 1*. For some recommendations, a confirmed link with bruising susceptibility was established in the recent Hort Innovation project, *Reducing flesh bruising and skin spotting in Hass avocado (AV10019)*. On the other hand, some recommendations are based on anecdotal or indirect evidence. These, in particular, need to be further investigated for adoption or not into commercial practice.

Recommendation	Link to bruise susceptibility	Relevant stage(s) in supply chain
Select cultivars that produce fruit with low browning potential	Likely	Orchard establishment
Select rootstock cultivars that promote Ca accumulation in fruit	Likely	Orchard establishment
Ensure that trees receive adequate water	Likely	Fruit growth and development
Avoid harvesting fruit when wet	Likely	Harvest
Harvest when dry matter is above 23 percent	Confirmed	Harvest
Pass fruit through the supply chain as quickly as possible	Confirmed	Harvest, pack house, ripener, distribution centre, retailer, consumer
Hold ripened fruit at 5°C	Confirmed	Distribution centre, retailer, consumer

Table 1. Practices known or likely to reduce susceptibility to flesh bruising in avocado.

Future work

Producing more resilient fruit is one approach to addressing the flesh bruising problem. Another is to minimise exposure of the fruit to damage events that cause bruising, such as dropping or squeezing. The ongoing Hort Innovation project *Supply chain quality improvement – Technologies and practices to reduce bruising (AV15009)* will also identify tools, practices and other measures for reducing damage events in the supply chain. All project AV15009 findings are being incorporated into the Avocados Australia online Best Practice Resource (www.avocado.org.au/best-practice-resource/) and shared with two concurrent avocado supply chain quality improvement projects, *Cool chain best practice adoption (AV15010)* and *Retailer point of purchase improvemen*ts (*AV15011).*

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