Postharvest Biology and Technology 143 (2018) 58–67

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Factors contributing to increased bruise expression in avocado (*Persea americana* M.) cv. 'Hass' fruit

M. Mazhar[a,*], D. Joyce[a,b], P. Hofman[c], N. Vu[a]

[a] The University of Queensland, School of Agriculture and Food Sciences, Gatton, Queensland 4343, Australia
[b] Department of Agriculture and Fisheries, EcoSciences Precinct, PO Box 267, Brisbane, Queensland 4560, Australia
[c] Department of Agriculture and Fisheries, PO Box 5083, SCMC Nambour, Queensland 4560, Australia

ARTICLE INFO

Keywords:
Dry matter
Duration
Firmness
Maturity
Temperature
Time

ABSTRACT

Mesocarp bruising is an important postharvest problem of avocado fruit. Bruise expression may be influenced by inherent fruit characteristics, and pre- and postharvest handling practices and conditions. In this supply chain focused study, the putative effects on avocado cv. 'Hass' bruise expression and severity of fruit maturity, temporal duration before or after impact injury, fruit firmness, and fruit holding temperature were examined. Mesocarp bruising in ripening fruit decreased in a linear fashion with advancing fruit harvest maturity over 20 weeks. Bruise severity increased progressively in fruit kept for up to 5 weeks before impact injury and also for those kept for up to 7 days after injury. Hard green mature stage fruit did not express bruising at ≤100 cm drop height (~1.36 J energy absorbed). However, softening, firm ripe, and soft ripe stage fruit impacted from 50 cm (~0.8 J energy absorbed) developed progressively greater levels of bruising. Keeping fruit at temperatures of 2.5 °C and 5 °C as compared with 20 °C at the time of impact resulted in less bruise expression. Similarly, fruit kept at post-impact temperatures of 2.5 °C and 5 °C as compared with 7.5 °C, 10 °C, and 20 °C also resulted in less bruise expression. Fruit kept at 5 °C for the first 8 h after impact and then at 25 °C for 40 h developed less bruising than fruit kept at 25 °C for 8 h after impact and then at 5 °C for 40 h. Overall, it is proposed that harvesting fruit at ≥23% dry matter concentration, passing them quickly through the supply chain such that bruising has less time to express, and keeping the fruit 'at' or 'below' 5 °C in the supply chain could reduce bruise expression levels in ripening 'Hass' avocado fruit.

1. Introduction

World avocado production exceeded 5.6 million tonnes in 2016, representing ~56% increase in a decade (FAO, 2018). Annual trade of avocado was 1.2 million tonnes in 2013, representing ~3-fold increase in trade figures over a decade. In the same period, average global consumption of avocado fruit almost doubled, reaching ~0.7 kg per capita per year. However, despite growing production, trade, and consumption, delivering high quality fruit to consumers has remained a challenge for the world avocado industry (Anon., 2018; Hofman, 2011). Mesocarp bruising is one of the most important negative issues experienced by avocado consumers (Gamble et al., 2010).

Visible symptoms of mesocarp bruising in avocado fruit result from cell and tissue damage (Van Linden et al., 2006). Cell walls and membranes deform under external impact or compression forces above their bio-yield threshold. Cellular decompartmentalisation allows polyphenoloxidase (PPO) activity to catalyse browning of the affected mesocarp tissue. The rate of browning is dependent on the concentration of phenolic substrates and mesocarp pH (Lurie, 2009). Factors considered to affect visible bruise expression in avocado include fruit maturity (Arpaia et al., 1987), fruit firmness (Baryeh, 2000), fruit holding duration (Marques et al., 2009), and fruit holding temperature (Ahmadi et al., 2010).

Fruit harvested at an early degree of maturity typically have a relatively short postharvest life (Lewis, 1978) and are more susceptible to decay (Perez et al., 2004) and other quality issues such as pink discolouration (Arpaia et al., 2018). They may also fail to ripen evenly, such that skin colour at ripe is non-uniform, showing patches of green. Moreover, in comparatively immature fruit, the seed may not separate 'cleanly' from the mesocarp (White et al., 2009). Advancing fruit maturity is reported to reduce the bruise susceptibility of avocado fruit (Arpaia et al., 1987). However, evidence is limited for the purported relationship between fruit maturity assessed as dry matter concentration (DMC) and bruise expression in ripening 'Hass' avocado fruit.

Fruit firmness is the basic parameter used by supply chain stakeholders, including shoppers and consumers, to judge the stage of fruit

* Corresponding author.
E-mail address: m.mazhar@uq.edu.au (M. Mazhar).

https://doi.org/10.1016/j.postharvbio.2018.04.015
Received 24 August 2017; Received in revised form 23 April 2018; Accepted 23 April 2018

ripening in avocado (White et al., 1997). Consumers want to purchase ripening avocado fruit for consumption (Gamble et al., 2010), and accordingly, the commercial supply chain stakeholders need to determine fruit firmness at all stages of the supply chain for making decisions related to forwarding fruit in the chain or to hold the fruit for further ripening. Avocado fruit becomes more susceptible to mesocarp bruising in an event of tissue damage at later stages of fruit ripening (Arpaia et al., 2006). In a study of the commercial supply chain Hofman (2003) found that in over 185 consignments from various sources representing typical industry practices, 55% of hard green stage fruit sampled at the end of the packing line showed no bruising when assessed at ripe. Moreover, substantial bruising (affecting > 15% of the mesocarp by volume) occurred in fewer than 1% of the 3700 'Hass' avocado fruit examined. Based on his findings, Hofman (2003) proposed that further research should be conducted on fruit bruising from ripening onwards in avocado supply chains. However, no supply chain study of the change of fruit firmness affecting its susceptibility to mesocarp bruising has been carried out.

In global trade, avocado fruit holding in terms of 'time in the system' is an integral aspect of shipping to distant markets (Marques et al., 2009). Low temperature management during holding and transport is employed to delay the ripening process and extend the postharvest life of avocado fruit. Although Everett (2003) found that fresh green hard mature avocado fruit can be kept at 5 °C for up to 6 weeks without adversely affecting the eating quality of the ripened fruit or expression of rots, Zauberman and Jobin-Decor (1995) reported that fresh green hard mature avocado fruit kept at 5 °C started to express mesocarp discoloration during the fourth week of storage. It is not known whether keeping unripened 'Hass' avocado fruit at 5 °C increases bruise susceptibility. Effects of temperature at and after mechanical impact on bruise expression in avocado fruit is an important aspect in supply chain management. There is limited information in the literature on temperature and bruising in 'Hass' avocado fruit. The published knowledge relates mainly to the effect of temperature on fruit softening in relation to firmness and mesocarp bruising (Mizrach et al., 2000; Paull, 1999; Zauberman and Fuchs, 1981).

In the light of the issues described above, relationships between mesocarp bruising in 'Hass' avocado fruit and maturity, holding duration, firmness, and temperature were examined in this study. Experiments were conducted in a through-the-supply-chain context to examine the hypotheses that lesser fruit maturity, lower fruit firmness, longer pre- and post- ripening fruit holding durations, and higher fruit holding temperatures each enhance bruise susceptibility and ultimately increase bruise expression and severity in ripening avocado cv. 'Hass' fruit.

2. Materials and methods

This study involved 12 experiments on avocado cv. 'Hass' fruit: one on each of maturity and pre-ripening holding duration, two on each of firmness and post-impact holding duration, and, six on temperature effects on bruise severity.

2.1. General

2.1.1. Plant material

Avocado fruit at the hard green mature stage were either harvested from a commercial orchard in the Toowoomba region (27° 26′ S, 151° 59′ E) of South-East Queensland (Australia) or collected from a ripener's premises at the Brisbane Produce Market in Rocklea (27° 31′ S, 153° 00′ E), also located in South-East Queensland. The sampled fruit were transported in an air conditioned vehicle in ~2 h to a postharvest laboratory at The University of Queensland, Gatton (UQG) (27° 32′ S, 152° 20′ E).

2.1.2. Fruit ripening

As required, the fruit were given a ripening induction treatment of dipping into 1000 μL L^{-1} of the ethylene releasing agent Ethrel® (480 g L^{-1} 2-chloroethylphosphonic acid; May & Baker Rural Pty Ltd., Homebush Bay, NSW Australia) plus 0.01% wetting agent Tween® 40 (polyoxyethylenesorbitanmonopalmitate, Sigma-Aldrich Inc., St. Louis, MO USA) wetting agent for 10 min, followed by air drying. The fruit were then kept in a shelf life room at 20 °C and 85% RH until the required stage of firmness (White et al., 2009). This general fruit preparation was not consistent for all experiments reported in this study. Depending on circumstances, specific details are described below in relevant experiments.

2.1.3. Fruit firmness assessment

Fruit were initially sorted on the basis of subjective hand firmness, (0 (Hard), 1 (Rubbery), 2 (Sprung), 3 (Softening), 4 (Firm ripe), 5 (Soft ripe), 6 (Over ripe), and 7 (Very over ripe)). Objective measurement of firmness was obtained with an analogue firmness meter (AFM) (Macnish et al., 1997), an electronic firmometer (EF) (White et al., 1997), or a Sinclair Internal Quality Firmness Tester (SIQFT) (Howarth and Ioannides, 2002). Different firmness measurement devices were necessarily used in different experiments depending on current availability of the most efficient non-destructive option.

2.1.4. Fruit impact treatments

A pendulum based impact device similar to those used in previous studies by Baryeh (2000); Bollen (2001), and Opara et al. (2007) was employed. Individual fruit were secured to the end of a swing arm which was raised to a specified height and released to impact the fruit against a solid steel strike plate. The impact site of the fruit was marked with a white marker. Impact energy absorbed by the fruit was calculated after Schoorl and Holt (1980); viz. E = m. G. (h1-h2); where, E = energy absorbed by the fruit (J), m = mass of fruit (kg), G = constant of acceleration due to gravity (G = 9.8 m sec^{-2}), h1 = drop height (m), and h2 = rebound height (m). For fruit of average 205 ± 19.7 g mass dropped from 25, 50, or 100 cm, the impact energies absorbed were ~0.38, ~0.81, and ~1.68 J, respectively.

2.1.5. Bruise intensity

Impacted fruit were cut longitudinally through the impacted area. After Darrigues et al. (2008) and Lim et al. (2011), bruised mesocarp colour was determined with a Chroma meter (CR 400, Minolta Ltd. Japan) as Hue and Chroma. Both Hue and Chroma typically decrease as bruise intensity increases in terms of browning (McGuire, 1992).

2.1.6. Bruise severity

Bruise severity as volume of bruised mesocarp was measured using the volume displacement method (Rashidi et al., 2007). The bruise affected mesocarp of fruit was removed, immersed into water within a graduated measuring cylinder, and the displaced volume recorded. Volumes of cracks at the impact site were measured separately by filling with water from a graduated syringe. Crack volume and discoloured mesocarp volumes were summed to give the total bruise volume from an impact.

2.1.7. Statistical analysis

Data was recorded in MS Excel® (Microsoft, North Ryde, Australia). Analysis of variance (ANOVA) for bruise severity (mL) and intensity (Hue and Chroma) data was conducted with Minitab® 16 (Minitab Pty Ltd, Sydney, Australia). Where treatment effects were significant ($P \leq 0.05$), LSD ($P = 0.05$) tests were applied to compare treatment means. Pearson Chi-Square analysis was used for bruise incidence (number counts of the occurrence of mesocarp bruising) data to compare treatments.