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Bruising of Avocado (*Persea americana* Mill.) as Affected by Impact Energy, Fruit Temperature, and Storage Temperature

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Abstract

Bruising of avocado fruits occurs during post harvest due to physical impact like dropping. This study aimed to determine the effects of impact energy, fruit temperature, and storage temperature on avocado bruising. An experiment on the impact process was done using a pendulum impact tester, which measured the impact energy and absorbed energy on the impacted avocado fruit samples. It was found out that as the drop angle increased, the bruise area and volume also increased. Cold storage prior to impact made cell stiffer and easily damaged, while cold storage after impact reduced bruise area. Finally, some recommendations are made so that industry threshold for bruise area (100 m^2) would not be exceeded: (1) avocado fruit should not be dropped at or over 60.97 cm, the equivalent free fall drop height to 100° drop angle; (2) cold storage of fruit resulting in flesh temperature of 15°C is not advisable; and, (3) the storage temperature for avocado at 13°C as recommended in PAES 417: 2002 is iterated.

Keywords: Avocado fruit bruising, *Persea americana* Mill., impact energy, fruit temperature, storage temperature

Introduction

Surveys on the quality of retail avocados have shown that the most prominent internal damage present in the fruit is flesh bruising (Mazhar et al., 2011). Occurring at any point of the postharvest life of the commodity due to physical impact like dropping, bruising is a type of damage that is well-disliked by consumers and was found to be an even greater hindrance to purchase than price (Gamble et al., 2010). The problems of product quality and income associated to bruising are even more magnified when avocado fruits have potential for export (FAO, n.d.).

Flesh bruising often does not appear visible at the peel of the fruit, unless the impact is severe. This is noticed only upon opening the fruit. Thus, consumers are left dissatisfied upon discovering that the fruit, which appeared edible at retail, is actually unsuitable for consumption (Sandoval, 2002). In fact, a study by Harker and Jaeger (2007) showed that bruise damage of more than 10% of the fruit volume negatively influenced the consumers' desire to buy again.

Understanding susceptibility of avocado to bruising is important. This study aims then to evaluate the effects of impact energy, fruit temperature, and storage temperature on the bruising of avocado. This should lead to the determination of standards that could be followed by farmers and retailers in order to minimize bruising of avocado fruits.

Materials and Methods

Preparation of Samples

Avocado samples were harvested on June 21, 2016 in the province of Batangas, Philippines. One hundred eighty (180) pieces of fruits were hand-picked (or were picked using a wooden pole) at hard ripening stage with firmness level 0 (refer to Table 1). A day after harvest, the samples were packed in sack bags and transported to the grain laboratory of University of the Philippines Los Baños (UPLB). The samples were stored at 27°C and 65 % relative humidity (RH). The fruits were tested after five days of storage when the samples reached firmness level score of 2 (sprung stage of firmness).

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

Scale	Description
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 (1/10 inches) with moderate thumb pressure; whole fruit deform with extreme hand pressure
5	Soft-ripe, whole fruit deforms with moderate hand pressure
6	Overripe, whole fruit deforms with moderate hand pressure
7	Very overripe, flesh feels almost liquid

Determination of Physical Properties

The linear dimensions and peel thickness of 50 samples were measured using a digital caliper (accuracy ± 0.02 mm; refer to Figure 1). On the other hand, a digital balance (readability = 0.01

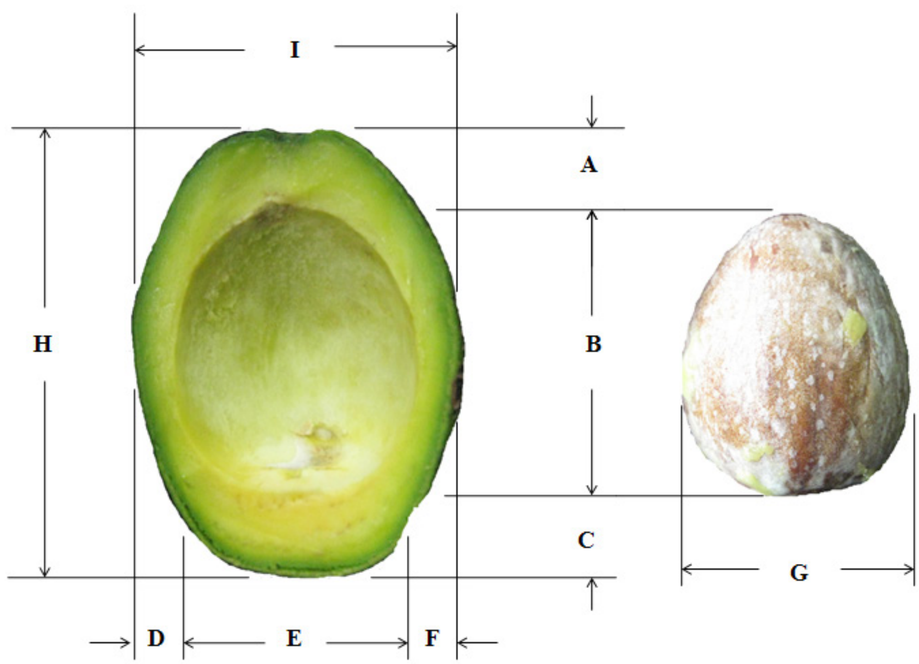

Figure 1. Measured dimensions of avocado.

g) was used to determine the fruit mass, total fruit weight, and the contribution of the seed, flesh and skin to the total fruit weight.

Pendulum Impact Tester and Impact Process

The pendulum impact tester consisted of a 38.10 cm long cold-rolled steel (CRS) pendulum arm with a CRS sphere impactor (2.54 cm diameter; 221. 77 grams) attached to the end. The pendulum arm was welded to a shaft and is free to swivel. A fabricated GI sheet sample holder, used to secure the samples during impact, was welded to the base. The circular plate attached to the head of the impactor was marked with an angular scale to show the drop angle and rebound angle. A pointer moves with the pendulum arm.

The pendulum arm was raised and released at desired drop angles to impact the samples. Following Curada (2009), the impact process of each sample was video recorded for further examination of the rebound angle. The rebound angle is the maximum angle of rebound produced by the sphere impactor as a result of impact. The video recording of the impact process of each sample was examined in slow motion using the VLC media player. The rebound angle was determined to compute for the amount of energy absorbed by the fruit.

Determination of Impact Energy and Absorbed Energy

Impact energy is the amount of energy applied to the fruit while absorbed energy is the amount of impact energy absorbed by the fruit. The impact energy was determined using Equation 1 (Kitthawee et al., 2011) and the absorbed energy was determined using Equation 2 (Mazhar et al., 2011).

$$E = mgh \qquad \text{Equation 1}$$

$$E_A = mg(h_1 - h_2) \qquad \text{Equation 2}$$

where E is the impact energy applied to the fruit (J), E_A is the energy absorbed by the fruit (J), m is the mass of the pendulum arm and spherical impactor (0.3321 kg), g is the constant of acceleration due to gravity (9.806 m-s^{-2}), h or h_1 is the drop height (m), h_2 is the rebound height (m). Drop height and rebound height are shown in the schematic diagram (refer to Figure 2).

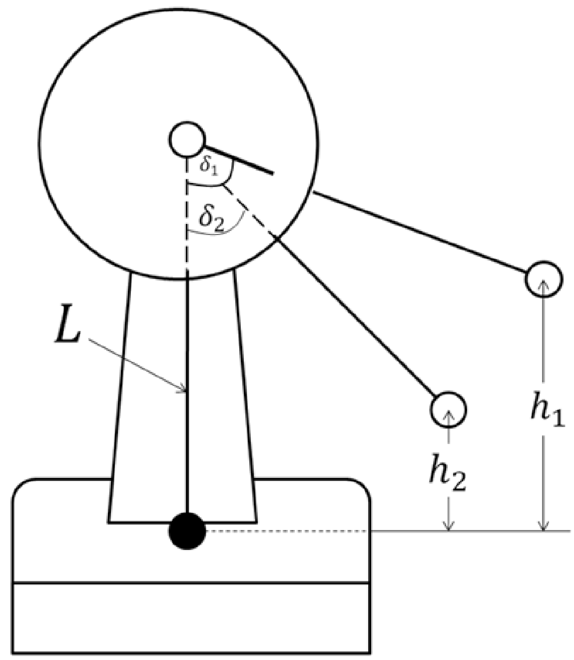

Figure 2. Schematic diagram of the pendulum impact tester.
NOTE: drop height (h_1), rebound height (h_2), drop angle (δ_1), rebound angle (δ_2), and pendulum arm length (L).

Equation 3 (Lee, 2005) was used to determine the drop height and rebound height.

$$h_{1,2} = L - (L * \cos\delta_{1,2}) \qquad \text{Equation 3}$$

where $h_{1,2}$ his the drop height or rebound height (m), L is the pendulum arm length (0.381 m), $\delta_{1,2}$ is the drop angle or rebound angle (degrees).

Conversion of Pendulum Drop Height to Equivalent Free Fall Drop Height (Lee, 2005)

$$h_a = \frac{m_p h_p}{m_a} \qquad \text{Equation 4}$$

where h_a is the drop height of avocado (m), m_a is the mass of avocado sample (0.2436 kg), m_p

is the mass of the pendulum arm and spherical impactor (0.3321 kg), h_p is the drop height of the pendulum impactor (m).

Fruit Impact Treatments

Below is the flowchart of the fruit impact treatments (refer to Figure 3). Six temperature treatments were used:

a. RT – RT: stored at room temperature (RT, where T = 27°C) before impact and then stored at RT after impact.
b. RT – CT: stored at RT before impact and then stored at cold temperature (CT, where T = 13°C) after impact.
c. CT1 – RT: stored at -20°C for 20 minutes before impact and then stored at RT after impact.
d. CT1 – CT: stored at -20°C for 20 minutes before impact and then stored at CT after impact.
e. CT2 – RT: stored at -20°C for 40 minutes before impact and then stored at RT after impact.
f. CT2 – RT: stored at -20°C for 40 minutes before impact and then stored at CT after impact.

On each temperature treatment, the samples were impacted at three drop angles (angle at which the pendulum was released to impact the fruit) 80°, 90° and 100°. These were equivalent to impact energy of 1.03 J, 1.24 J and 1.46 J, respectively.

The total number of treatment was 18. Each sample was impacted twice on opposing sides to achieve the prescribed sample size of greater than 10 (Yaptenco, 2007).

Determination of Bruise Damage

Bruise area and volume determine the bruise severity. After three (3) days of storage that allowed for full bruise development in the fruit sample, the bruise area was measured using digital calliper. The shape of the external bruise was assumed to be circular. Equation 5 (Dagaas, 2001) was used to calculate the area of circular bruises,

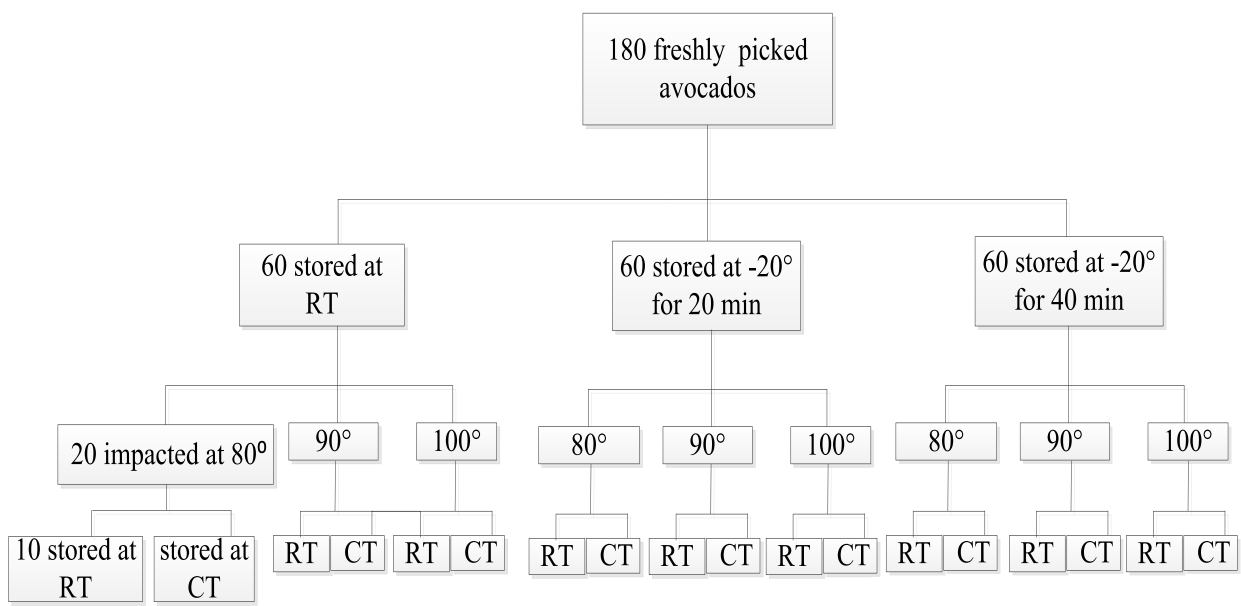

Figure 3. Fruit impact treatments
where RT = room temperature and CT = cold temperature

$$A_B = \frac{\pi d^2}{4} \qquad \text{Equation 5}$$

where A_B is the bruise area (mm^2), and d is the bruise diameter (mm).

To examine the internal bruising, the sample was sectioned at midpoint of the bruise and perpendicular to the skin. The damage was quantified in terms of bruise volume (V_B). This was calculated using Equation 6 (Kitthawee et al., 2011),

$$V_B = \frac{\pi}{8} w^2 D \qquad \text{Equation 6}$$

where w is the bruise width (mm), and D is the bruise depth (mm).

Statistical Analysis

Kruskal-Wallis test, a non-parametric method that does not require normality assumption, was conducted to assess the median differences among the treatments. Pair-wise comparisons were then carried to investigate which of the treatments differed. All statistical analysis were undertaken using SAS version 9.1.

Results and Discussion

Bruise Area and Volume Damage

No external and internal browning was observed on samples as they were impacted at sprung stage of firmness. This was expected because according to White et al. (2009), no visible external browning would develop when the fruit is impacted on such stage.

Shatter cracks and permanent deformation were noted. Shatter cracks refer to tortuous cracks radiating from a point of impact (Mohsenin, 1986). These were caused by impact and not a product of bruising. Nevertheless, the damages were measured for the calculation of "bruise area" as it left visible damage on the samples.

The types of damage (Fig. 4) observed in the flesh can be grouped into three: (1) white region, (2) sunken and corky area, and (3) air space. In most cases, the shatter cracks filled the depression caused by impact. The "bruise" was assumed circular. However in some samples, the shatter cracks formed no measurable region. In these cases, the diameter of the depression was measured instead. Still, some samples did not develop any visible sign of damage.

The presence of an oval, compact, white region was found in some samples (Fig. 4A). It was notable that the white region was situated in the middle of the flesh under the impact area. This position is unlike the sunken damage on some samples, which started from the surface of the seed cavity and caved outward towards the impacted skin.

Another type of damage was the formation of hollow air spaces in the flesh under the impacted portion (Fig. 4B). The cavities were oval-shaped and found in the middle of the flesh under the impact portion. The location of air spaces was somewhat similar to that of the white regions. Arpaia et al. (1987) observed a similar damage that they called "air pocket" and described as "sometimes circular in form and with striation which radiated throughout the injured tissue." While there were no striations observed in the current research's samples, the air spaces have also frequently developed at the "near center of the bruise tissue" similar to what Arpaia et al. (1987) noted. The air pockets were observed when the avocado samples were impacted at flesh firmness of below 4.5 $kg_{f.}$

The third type of damage was a portion of the seed cavity turning sunken and corky (Fig. 4C), which was observed on most samples. The corky portion was dark-colored and sunken. Interestingly, the damage did not appear in the underside flesh of the epidermis where the impact happened, but on the opposite flesh forming the seed cavity. After removing the seed for bruise inspection, portion of the flesh on the seed cavity was discovered to have sunken into a circular concavity. In other samples, some part of the seed coat adhered to the sunken portion. When touched, the portion was rough and corky.

The samples of this study were impacted at firmness level. While most studies conduct impact at ready-to-eat stage as in DeMartino et al. (2002), the avocado samples were not allowed to reach such stage because prolonged storage at

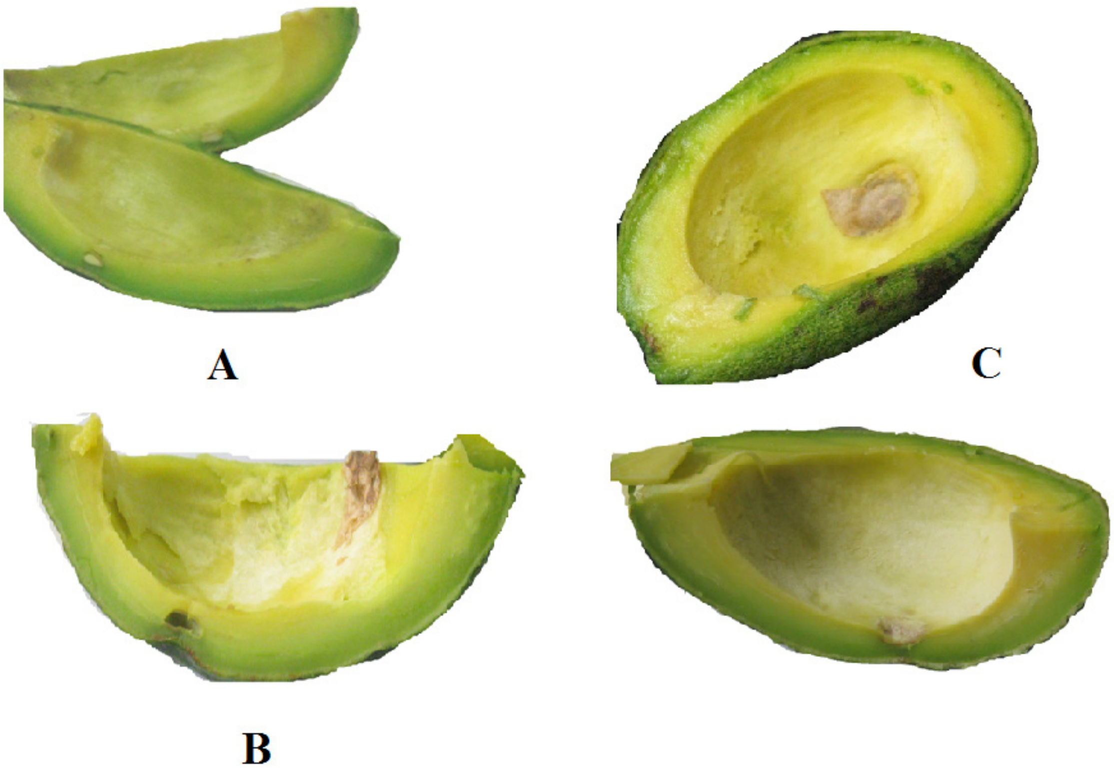

Figure 4. Type of flesh damage; A – white region on impacted flesh; B – air spaces under the impacted region; C – sunken and corky flesh of the seed cavity.

RT would have resulted in more samples getting infected with stem-end rotting. Samples with stem-end rot were discarded and not used for experimentation. The damages observed in this study were the symptoms caused by impacting the samples at sprung stage of firmness.

Effect of Impact Energy on Bruise Area and Volume

The high level of impact energy applied to the samples caused permanent deformation and shatter cracking. The samples dropped at an angle of 80°, 90°, and 100° have equivalent impact energy of 1.03 J, 1.24 J, and 1.46 J, respectively. Moreover, the amounts of energy absorbed were 0.84 J, 1.03 J and 1.24, respectively (Table 2). At the point of impact, the flesh temperatures of the samples were at 15°C, 19°C and 27°C. The storage conditions of the samples after impact were 27°C (RT: room temperature) and 13°C (CT: cold temperature). More than 80 % of the impact energy was absorbed by the samples for all drop angles setting with an equivalent free fall drop height that will produce the same impact energy caused by the pendulum. The absorbed energy increased slightly with increased impact energy.

Table 2. Impact energy absorbed and equivalent free fall drop height to pendulum drop height by the fruit.

Drop Angle (°)	Impact Energy (J)	Absorbed Energy (J)	Percent Absorbed (%)	Drop Height (cm)
80	1.025	0.840	81.92	42.92
90	1.241	1.033	83.22	51.94
100	1.456	1.231	84.51	60.97

Increased median bruise area and volume were observed at increased drop angles. The median bruise area and volume for each drop angle setting at 80°, 90°, and 100° were 91.36

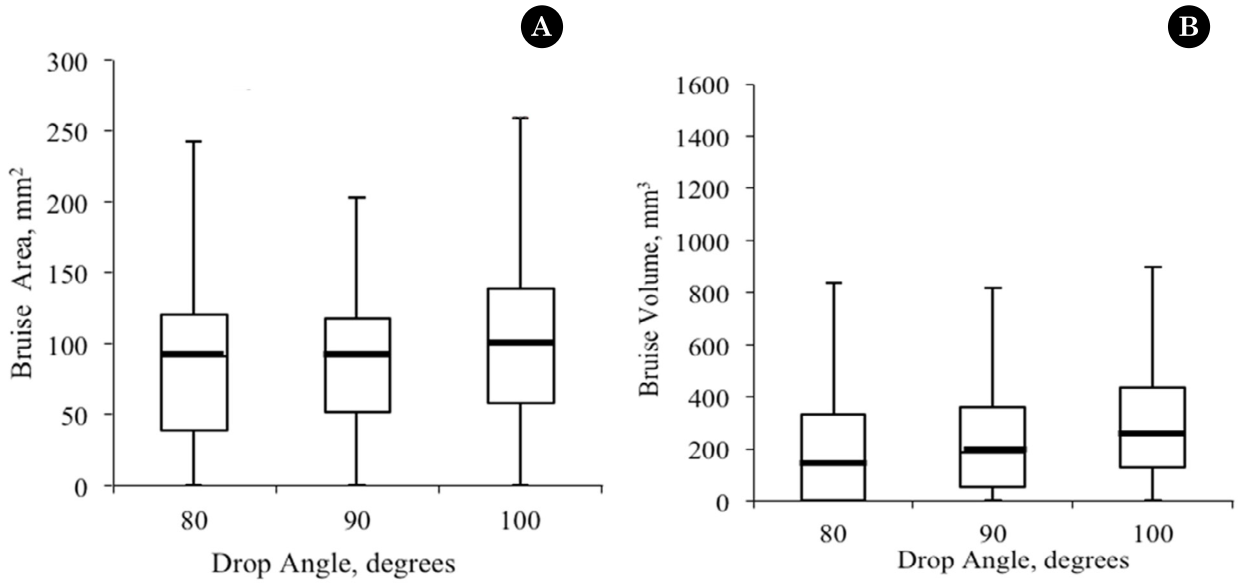

Figure 5. Effect of drop angles on median bruise area (A) and volume (B).

mm^2, 92.12 mm^2, and 100.29 mm^2 for the former (Fig. 5A); and 142.84 mm^3, 187.56 mm^3, and 252.24 mm^3 (Fig. 5B), respectively. According to Pang et al. (1994), cited by Tabatabaekoloor (2013), the avocado industry threshold for bruise area is 100 mm^2. Samples impacted at 100° drop angle exceeded the threshold level. Therefore, fruits should not be dropped at and beyond 60.97 cm, the equivalent free fall drop height. The tendency of avocado samples producing larger damage with increased impact energy has been consistently reported (Baryeh, 2000).

Effect of Fruit and Storage Temperatures on Bruise Area and Volume

Generally, decreasing fruit temperature before impact increased median bruise area and volume. The temperature setting at RT (27°C), CT1 (15°C), and CT2 (13°C) were 82.92 mm^2, 80.04 mm^2, and 106.60 mm^2 for median bruise area (Fig. 6A); and 57.2 mm^3, 196.33 mm^3, and 338.08 mm^3 for median bruise volume (Fig. 6A), respectively. Only the fruits impacted at fruit temperature of 15°C produced a bruise area of 106.60 mm^2 that exceeded industry threshold for bruise area of 100 mm^2. In this study, the predominant effect of temperature was on increasing cell stiffness and not on lagging metabolic activity. Therefore, cold storage of fruit resulting to a fruit temperature of 15°C or lower is not advisable.

Van linden et al. (2006) reported that temperature affects the bruising of fruits by lagging the softening rate, thereby decreasing bruise area, or making the cells stiff and less elastic, resulting to increased bruise area. In this study, the effect of temperature on the texture of the impact region was more predominant.

Storing the samples at 27°C and 13°C did not result to a bruise area that exceeds industry threshold (Fig. 6C). The median bruise volume for each storage temperature setting (Fig. 6D) was 178.45 mm^3 and 234.24 mm^3 for RT and CT. The effect of storage temperature with increased temperature after impact decreased bruise volume. However, according to PAES 417: 2002, the recommended storage temperature for avocado is 13°C.

The effect of cold storage in decreasing the bruise area was noted, further providing support to the same conclusion reached by similar studies on other fruits. For instance, the reduction of

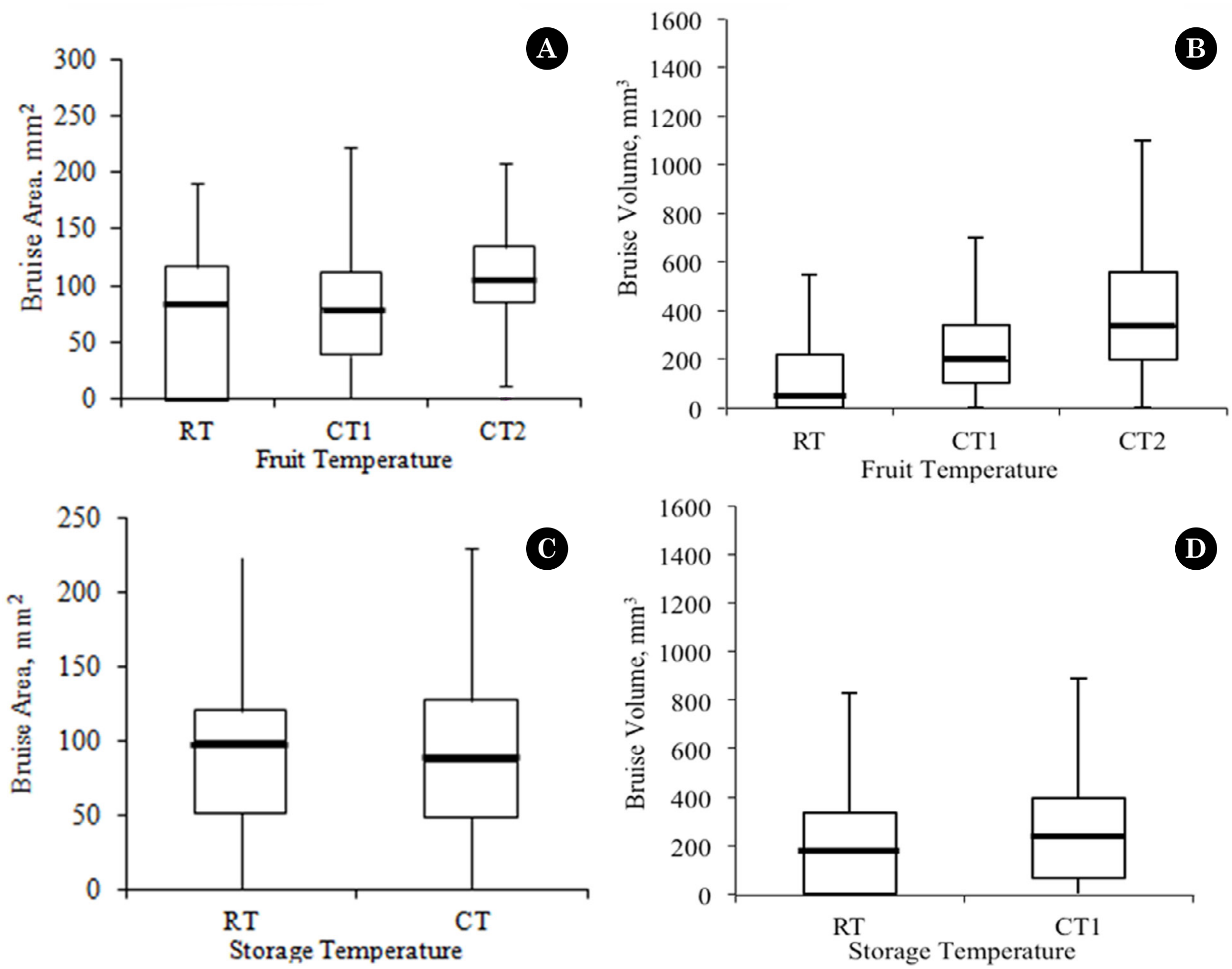

Figure 6. Effect of fruit and storage temperatures on median bruise area and volume.

storage temperature of impacted fruits likewise reduced the appearance of injury symptoms, as in the case of apricots (DeMartino et al., 2002) and kiwifruit (Mencarelli et al., 1996).

Conclusion

Dropping avocado fruits over 60.97 cm, with increased drop angle can increase the area and volume of bruising. The absorbed energy increases slightly with increased impact energy. Bruising observed are permanent deformation and shatter cracks on the skin and air cavities, white regions and sunken areas on the flesh. Cold storage temperature makes the cell stiffer and more susceptible to damage. For best practice, fruit should be handled as carefully as possible, drop heights kept to a minimum, and fruit stored at 13°C.

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