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Quality Evaluation of Strawberry Bruised by Simulated Drop Heights

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Strawberry production in Florida continues to increase, with acreage exceeding 4400 ha in the 2017–18 growing season. Fruit are manually harvested and field packed due to extreme sensitivity to mechanical injury. The difficulty of finding enough people to harvest has increased interest in the development and implementation of mechanical harvesting. However, mechanical harvesting enhances the potential risk of mechanical injuries (i.e., bruises). Previous studies have reported that bruise incidence and size are lower for samples submitted to low impact energy and low storage temperature. The objective was to study the postharvest quality of strawberries impacted by three different drop height energies, simulating those that might occur during robotic harvest. Freshly harvested strawberries ('Florida127') were individually impacted by a 61 g pendulum from 38°, 54°, or 68° angles, simulating respective vertical drops of 15 cm, 30 cm, or 45 cm (impact energies of 0.037, 0.074, or 0.110 J, respectively) and were stored in vented, hinged clamshell containers for 8 d at 5 °C. After 4 d of storage, fruit from equivalent drops of 15 cm, 30 cm, and 45 cm showed bruise incidences of 22, 39, and 72%, respectively. Hue angle, weight loss, and bruise area were significantly different for control fruit and those impacted from 45 cm. Total anthocyanin content increased gradually for all treatments from 12 mg to 17 mg perlargonidin-3glucoside per 100 g (fresh weight). There were no differences in soluble solids content, total titratable acidity, pH, or ascorbic acid content.

Strawberry (*Fragaria ×ananassa* Duch) production in Florida reached 4400 ha (11,000 acres) in the 2017–18 growing season (Karst, 2017). In 2016, the crop represented 19% of total production value of Florida products, which corresponded to $450 million dollars (FDACS, 2017). Florida is the second largest producer of fresh-market strawberries in United States (USDA–NASS, 2018). To help Florida growers remain competitive in the market, new varieties are constantly being introduced by the University of Florida breeding program. In addition, strawberries destined for fresh market are hand-harvested to reduce postharvest losses due to extreme strawberry sensitivity to mechanical injury. However, hand picking has become a challenge due to lack of availability of enough labor in the United States, and the amount bureaucracy combined with high costs to hire extra foreign labor via guest worker programs. These difficulties have increased growers interest in development and implementation of mechanical harvesting (Wishnatzky, 2018; Wu and Guan, 2016).

There are several advantages linked to mechanical harvest, such as full-time working at higher speed, reduction of labor in the field, lower production costs, and the possibility of monitoring plant health (e.g. diseases, color, and temperature) (Okumura, 2015). However, implementation requires a high capital investment, prior economic analysis, and potential risk for increased mechanical injuries (i.e., bruises) to sensitive crops such as strawberry, which in turn also increases postharvest decay (Chitarra and Chitarra, 2005; Pelletier et al., 2011).

Bruising is caused by different types of pressure such as impact, compression, and vibration (Brusewitz et al., 1991; Ferreira, 1994; Vergano et al., 1991). Impact bruises from a robotic strawberry harvester could be related to the moving harvest implement (harvest grabbers), or the movement of the fruit itself when it falls into a basket or container. Compression bruises could occur when excessive layers of strawberries are placed a container, compressing the bottom layers. Vibration bruises could occur as a result of repeated high-frequency impacts at low energy levels caused when the fruit rub each other or some other surface during mechanical harvest movement in the field (Chaiwong and Bishop, 2015; Ferreira, 1994; Ferreira et al., 2009).

Susceptibility to bruising may depend on physical properties of the strawberry fruit, preharvest (soil nutrition, cultivar, climate, harvest maturity) and postharvest conditions (handling, cooling rate, storage temperature) (Brusewitz et al., 1991; Ferreira, 1994; Kader, 1991; Vergano et al., 1991).

Mechanical injury sensitivity can also be affected by the cultivar; a recent strawberry, a cross between 'FL05-107' (Winterstar™) and 'FL02-58' ('Sweet Charlie' × 'Treasure'), was released in 2013 as 'Florida127' (Sweet Sensation®) by the University of Florida. 'Florida127' has been shown to be more attractive, tasty, and with better performance in terms of firmness and shelf life (Kelly et al., 2016). Although strawberry mechanical harvest has become attractive to Florida growers, there is still lack of information on the potential damages associated with mechanical

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injuries as well as their effects on postharvest quality and shelf life. According Kader (1991), minor blemishes that would not detract from eating quality are acceptable, but more serious defects can turn the fruit unmarketable. Other authors hypothesize that bruise incidence and size are less evident for samples submitted to low impact energy, low storage temperature, and high relative humidity (Nunes et al., 2003; Shin et al., 2008; Shrestha et al., 2001).

The objective was to study the effects of impacting strawberries with different simulated drop height energies that correspond to one-step of a commercial robotic harvester, followed by commercial storage conditions.

Materials and Methods

The strawberries ('Florida127') were obtained from a commercial grower in Floral City FL (lat. 28°44' 59.96"N, long. 82°17'48.34"W) during mid-season (22 Feb. 2018). The fruit were hand harvested at three-quarter color ripe into foam trays in the morning and immediately transported at ambient temperature to the Postharvest Horticulture Laboratory at the University of Florida in Gainesville, about 75 min away. After the first visual evaluation to remove visually damaged strawberries, the randomized samples were subjected to a pendulum impactor (Fig. 1a) to simulate the desired drop heights (Fig. 1b) at ambient temperature (25° C).

The strawberries were impacted by simulated drop heights of 15 cm, 30 cm, or 45 cm (plus non-impacted control), according to respective impact energies of 0.036, 0.073, or 0.110 J), following the formula:

$$m \cdot g \cdot r = M \cdot g \cdot h$$

where:

- m = mass of the chrome steel ball pendulum (60.56 g, diameter 2.68 cm)
- r = L –rcos Θ (L = 30 cm), height that the steel chrome ball is raised from the zero point,
- g = gravitational acceleration (9.8 m/s^2),
- M = strawberry mass (assumed 25 g), and
- h = strawberry drop height (15, 30, and 45 cm)

The impacts were accomplished by suspending a single berry in a plastic pouch and releasing the pendulum from the predetermined angle for a single impact at the equatorial region. Following impacts, samples were stored under simulated commercial conditions (packed in hinged, one-pound capacity clamshell containers) for eight days at 5 °C and 90% relative humidity (RH) ± 1.0. Fruit were evaluated every two days (0, 2, 4, 6, 8 days); bruise area evaluations were made every four days (0, 4, 8 days). Thus, the four treatments were: control = non-impacted fruit, and impacts equivalent to 15 cm, 30 cm, or 45 cm. The experimental design was completely randomized, in a 4 × 5 factorial scheme (treatment × days of storage), with 3 replicates of 6 strawberries in each plot, totaling 18 strawberries per treatment per day.

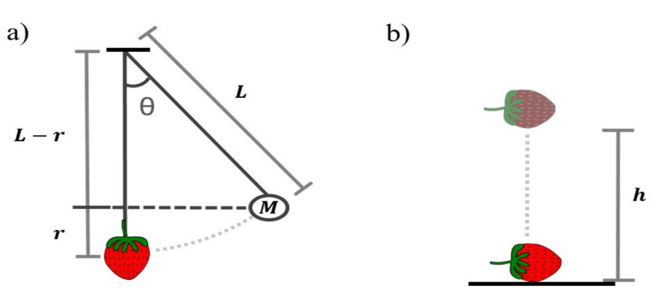

Fig. 1. Diagram of pendulum impactor showing equation variables (**a**) and equivalent drop height (**b**).

Nondestructive Analyses

Bruise evaluation. At the initial evaluation, the number of strawberries with bruises were noted and recorded as percentage background bruising. Bruise area was determined on days 0, 4, and 8 using a caliper from bruise edge-to-edge of the bruise on two perpendicular axes, and mean area (cm^2) was calculated for the circle($A = \pi \cdot r^2$), where r = the mean of two diameter values.

Weight loss. Weight loss was calculated based on initial weight and expressed as percentage of the initial weight.

Color assessment. The surface color was determined using a digital colorimeter (Chroma Meter CR-400, Konica Minolta Sensing Americas, Inc., Ramsey, NJ) set for CIELAB color space and D65 light source. Readings were performed on unbruised opposite sides of six fruit (n = 18 fruits per treatment), which were expressed in terms of chroma (C*), hue angle (h*), lightness (L*), and redness (a*) values.

Fruit firmness. Measurements were performed on the opposite side of the impacted site of each fruit with a flat plate using a FirmTech Fruit Firmness (FirmTech2, Bioworks, Wamego, KS) and results were converted from g/mm to Newtons (N)

Destructive Analyses

After firmness measurements, the samples were blended, homogenized, and then centrifuged at 12,000 rpm for 20 min at 4 °C. The supernatant was filtered through cheesecloth, and the filtrate (juice) was used to assess soluble solids content (SSC) and total titratable acidity (TTA).

Soluble solids content (SSC). SSC was determined by dripping small amounts of fruit juice onto the prism of a refractometer (Model r2i300 Compact Digital, Reichert Technologies, Buffalo, NY) and reported as percent.

Total titratable acidity and pH. TTA and pH were determined using the same automatic titrimeter (Metrohm, Model 814 USB Sample Processor, Herisau, Switzerland). Aliquots (3 mL) of strawberry juice were diluted with 50 mL distilled water and pH was determined before starting the titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2, for the TTA determination. The TTA was expressed as percent citric acid.

Total anthocyanins content (TAC). TAC was determined according to Nunes et al. (2006). Aliquots (2 g) of homogenized strawberry tissue were mixed with 18 mL of 0.5% hydrochloric acid (HCl) in methanol (CH_3OH) (v/v). Anthocyanin pigments were extracted by holding samples at 4 °C for 1 h in darkness after the tissue was decanted and the supernatant was carefully collected. Solution absorbance was measured at 520 nm in spectrophotometer (Model Power Wave X52, Biotek). Pigment concentration was calculated using the following formula: Abs520 × dilution factor × (molecular weight (MW) of pelargonidin-3glucoside (PGN)/ molar extinction coefficient) where MW of PGN = 433.2 and the molar extinction coefficient = 29,080. Results were expressed as mg/100 g fresh weight of PGN.

Total ascorbic acid (TAA). The TAA was quantified by mixing 1 g of homogenized fresh tissue with 20 mL metaphosphoric acid (HPO_3) mixture [6% HPO_3containing 2 N acetic acid CH_3COOH)]. Samples were centrifuged at 12000 rpm for 20 min at 4 °C and 1 mL of supernatant was collected. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1987). The concentration of TAA was calculated per 100 g of fresh weight tissue from absorbance (Spectrophotometer, Model Power Wave X52, Biotek) measured at 540 nm using a standard curve.

Statistical analyses. Data were analyzed by two-way analysis of variance (ANOVA) and means were compared using the Tukey test at a significance level of $\alpha = 0.05$ with Infostat Software (University of Córdoba, Argentina).

Results and Discussion

Bruise incidence and area. Strawberry is a sensitive fruit characterized by large cells with thin cell walls (Szczesniak and Smith, 1969) and excessive impact pressure can subject the fruit to stress and distortion of individual cells, leading to cell wall over-extension and breakage (Ferreira, 1994). Bruises can appear as an area flattened, sunken, mushy, or discolored (USDA–AMS, 2004). Immediately after pendulum impact (day 0), fruits showed a flattened bruise deformation. For impact energies equivalent to 15, 30, and 45 cm, bruise incidences (Fig. 2a) were 5, 11, and 17% respectively. On day 4, respective bruise incidences increased to 22, 39, and 72%. On day 8, 85% of fruit from all treatments showed bruises. Control samples developed small bruises on day 2, but these were related to damage from the clamshell container. Bruise area (Fig. 2b) overall mean was not significantly different, ranging from 0.427 cm^2 for 15-cm treatment to 0.591 and 0.595 cm^2 for 30-cm and 45-cm treatments, respectively (Table 1). The USDA–AMS (2004) grade standard for strawberry considers flattened, discolored bruises with a circular diameter of 1.27 cm (1/2 inch) as "damage" and 1.90 cm (3/4 inch) circular diameter as "serious damage." Circular areas calculated for these standard values correspond to bruise areas of 1.27 cm^2 and 2.85 cm^2, respectively. From this, it is possible to conclude that the bruises resulting from the three simulated drop heights in this test were only flattened areas and were not discolored, and these values were lower than the damage limits established the USDA-AMS (2004)

Firmness and Weight Loss. Fruit firmness was significantly higher for control and lower for 45-cm treatment (Table 1). Strawberry has naturally high enzymatic activity of endopolygalacturonases in the cell wall that cleaves the pectin chain leading to fruit softening (Sharma et al., 2008). On day 0, incidence of bruising was low; however, cell wall rupture in the 45-cm treatment (Fig. 4) may have intensified enzymatic activity, leading to further softening of the fruit on the following days 2 and 4. For the other impact treatments, these values became similar at days 6 and 8 when bruise incidence rose to >85%. Weight loss was lowest for the 15-cm drop fruit, and the highest loss for the 45-cm treatment (Table 1). A study of unbruised strawberry ('Florida127') by Kelly et al. (2016), reported weight loss ranging from 3.81% to 4.12% for strawberries harvested in mid-season after 9 d storage at 1.4 °C and 85% RH. Bruises did not cause significant water loss for 'Florida127' compared to unbruised berries, which may have been related to storage conditions with low temperature and elevated RH (Nunes, 2008). Low temperature reduces the respiration rate and thus cellular metabolism, retarding decay. High RH reduces water loss from fruit to the surrounding air by minimizing the difference in vapor pressure deficit; water loss reduces sheen, and increases wilting and flaccidity (Chitarra and Chitarra, 2005).

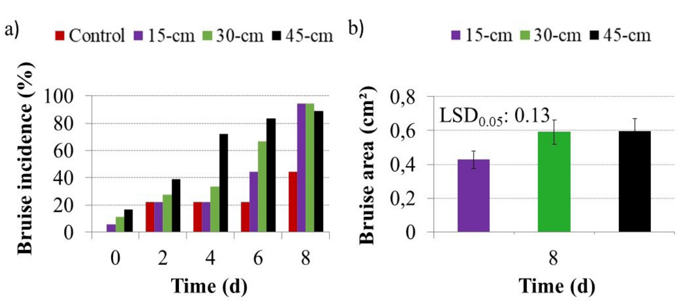

Fig.2. Bruise incidence during storge (**a**) and bruise area (cm^2) mean for treatments of 15 cm, 30 cm, or 45 cm (**b**). Vertical bars represent ± standard error (n = 54 fruits/treatment).

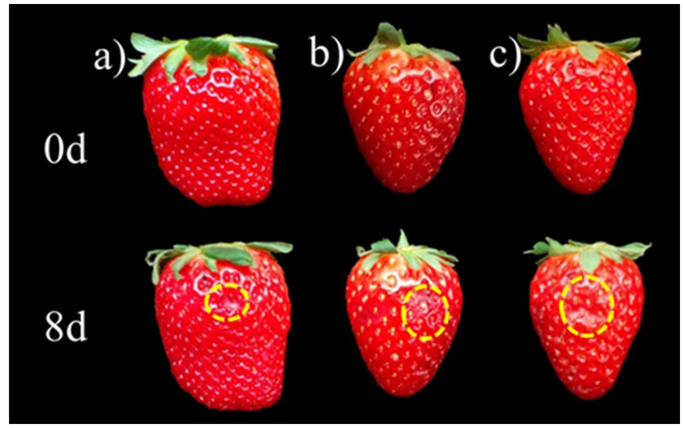

Fig. 3. Bruised strawberries from equivalent drop heights of (**a**) 15 cm, (**b**) 30 cm, and (**c**) 45 cm on day 0 and day 8 of storage at 5 °C and 90% relative humidity.

Soluble Solids Content, pH and Total Titratable Acidity. During storage SSC, TTA, and the pH remained constant for all treatments. Overall mean for SSC ranged from 6.4 to 6.6 %, for TTA from 0.65% to 0.67%, for SSC/TTA ratio from 3.61 to 3.64 and for pH, 9.74 to 9.96 (Table 2). Whitaker et al. (2015) reported SSC ranges of 7.5 to 9.0 %, SSC/TTA of 9.7 to 12 and pH of 3.72 for mid-season 'Florida127' strawberry. Therefore, impact energies used in this evaluation did not affect the SSC, TTA, or the ratio (SSC/TTA) of strawberries stored for 8 days under simulated commercial conditions.

Color Assessment. All color measurements changed during storage. L* values decreased, agreeing with Nunes et al. (2006) for 3/4 color stage ripe strawberries stored for 8 days (Table 3). Hue* (i.e., red color development) and chroma* (i.e., color intensity) values decreased, agreeing also with the same author for 'Chandler' and 'Oso Grande' cultivars. 'Florida127' (stored at 1° C, 85% RH) was evaluated by Kelly et al. (2016), and the trend for hue* angle remained constant or slightly decreased to purplish-red color; they also reported different color patterns between the 2013 and 2014 harvests for L* and a*. According to Whitaker et al. (2015), the redness (a*) for freshly harvested 'Florida127' was a* = 38.9 ± 3.

Surface damage was observed as a disruption of cell walls at bruise sites, but there were no generalized dark spots that might have been related to enzymatic browning (i.e., polyphenol and

Table 1. Values for bruise area (cm²), firmness (N), weight loss (%), total anthocyanin content [mg/100g pelargonidin-3glucoside (PGN)], total ascorbic acid (mg/100g) for 'Florida127' strawberries stored for 8 days at 5 °C and 90% relative humidity after pendulum impact.

Day	Control	15-cm	30-cm	45-cm	CV[z]	LSD[y]
			Bruise area (cm²)			
0	---[x]	0.139 ± 0.00 aA[w]	0.373 ± 0.19 aA	0.285 ± 0.09 aA	35.40	0.85
4	---	0.504 ± 0.03 aA	0.479 ± 0.06 aA	0.566 ± 0.05 abA	16.40	0.17
8	---	0.639 ± 0.10 aA	0.921 ± 0.12 aA	0.934 ± 0.12 bA	26.10	0.19
Mean		0.427 ± 0.12 A	0.591 ± 0.01 B	0.595 ± 0.10 B	24.60	0.13
			Firmness (N)			
0	3.37 ± 0.12 cA	3.00 ± 0.11 cA	3.18 ± 0.11 cA	3.03 ± 0.11 cA	15.10	0.41
2	3.12 ± 0.13 cB	2.65 ± 0.10 bcA	2.74 ± 0.13 bAB	2.52 ± 0.06 bA	16.80	0.40
4	2.62 ± 0.13 bB	2.43 ± 0.08 bAB	2.45 ± 0.08 abAB	2.24 ± 0.05 aA	15.70	0.33
6	2.14 ± 0.07 aA	2.40 ± 0.07 abA	2.28 ± 0.09 aA	2.31 ± 0.06 abA	13.50	0.27
8	2.09 ± 0.05 aA	2.27 ± 0.07 aA	2.14 ± 0.08 aA	2.10 ± 0.06 aA	13.00	0.20
Mean	2.67 ± 0.33 B	2.55 ± 0.17 AB	2.56 ± 0.24 AB	2.44 ± 0.21 A	15.70	0.15
			Weight Loss (%)			
0	0	0	0	0	---	---
2	0.97 ± 0.10 aA	0.72 ± 0.03 aA	1.10 ± 0.02 aA	1.07 ± 0.14 aA	15.40	0.39
4	1.64 ± 0.18 aA	1.39 ± 0.11 aA	1.70 ± 0.07 bA	1.66 ± 0.19 abA	15.80	0.66
6	2.76 ± 0.20 bA	2.45 ± 0.19 bA	2.86 ± 0.06 cA	2.90 ± 0.35 bcA	14.40	1.03
8	3.68 ± 0.28 cA	3.34 ± 0.22 cA	3.71 ± 0.07 dA	3.90 ± 0.36 cA	12.10	1.16
Mean	1.81 ± 0.54 A	1.58 ± 0.52 AB	1.88 ± 0.52 B	1.90 ± 0.57 B	13.20	0.32
			Total Anthocyanin (mg/100 g PGN fw[v])			
0	11.52 ± 0.36 aA	11.36 ± 1.11 aA	14.55 ± 1.40 aA	10.92 ± 0.30 aA	13.20	4.17
2	14.17 ± 0.51 abA	12.96 ± 1.11 abA	15.27 ± 0.79 aA	14.45 ± 0.45 bA	9.25	3.43
4	19.79 ± 1.83 bcA	16.17 ± 0.53 bA	17.85 ± 0.97 aA	15.39 ± 0.41 bA	10.90	4.93
6	18.03 ± 0.88 bcA	16.58 ± 0.81 bA	14.86 ± 0.47 aA	15.99 ± 0.99 bA	8.60	3.68
8	17.75 ± 1.11 cA	16.47 ± 0.25 bA	15.86 ± 0.98 aA	16.70 ± 0.57 bA	8.31	3.63
Mean	16.25 ± 1.49 A	14.71 ± 1.07 A	15.68 ± 0.58 A	14.69 ± 1.01 A	11.30	1.67
			Total Ascorbic Acid [mg/100 g fw]			
0	53.70 ± 3.90 aA	59.40 ± 4.34 aA	58.45 ± 4.59 abA	56.83 ± 5.33 aA	13.90	20.70
2	61.23 ± 3.57 abA	54.90 ± 3.93 aA	63.22 ± 0.19 abA	61.47 ± 2.08 aA	8.21	12.90
4	64.70 ± 2.93 abA	61.80 ± 3.26 aA	69.51 ± 4.07 abA	63.19 ± 2.35 aA	10.60	17.90
6	53.64 ± 6.32 aA	48.70 ± 4.72 aA	53.88 ± 4.42 aA	52.26 ± 3.16 aA	7.84	10.70
8	72.95 ± 7.20 bA	62.10 ± 2.86 aA	72.26 ± 1.53 bA	69.10 ± 4.07 aA	7.41	13.40
Mean	61.24 ± 3.63 A	57.37 ± 2.53 A	63.46 ± 3.40 A	60.57 ± 2.86 A	11.20	6.60

[z]Coefficient of variation of the standard deviation to the mean of 18 fruits per treatment.

[y]Least significant differences at ($P < 0.05$).

[x]-- = Evaluation not performed.

[w]Values followed by the same capital letter in the same row and small letter in the same column are not different according to the Tukey Test ($\alpha = 0.05$). ± standard error (n = 3 replicates; 6 fruits/replicate). Transformation of data: Bruise area: $\sqrt{x}$.

[v]Fresh weight.

peroxide enzyme) (Fig. 3, Fig. 4). Enzymatic browning may occur slowly due acidic fruit pH; low storage temperature inhibits the optimal enzymatic activity (Andrade, 2013; Rupasinghe, 2008; Taranto et al., 2017).

Total Anthocyanins. Kong et al. (2003) reported that cyanidin and pelargonidin are the two most common anthocyanidins distributed in plants. In fruits and vegetables, the distribution of these compounds is 50% and 12%, respectively. TAC increased during storage but without significant differences between treatments (Table 1). Kalt et al. (1999) also observed that TAC increased in strawberry fruits stored for 8 days between 0 to 10 °C. Nunes et al. (2006) stated that fruits harvested in the 3/4 and full-red stages continued to ripen during the storage period, accompanied by increases in anthocyanin, SSC and TTA. According to Cayo et al. (2016), 'Florida127' has lower content of anthocyanins and Vitamin C when compared to other cultivars such as 'Festival', 'Radiance' and 'Winterstar'. In addition, the increase to final anthocyanin concentration is correlated with storage temperature (Cordenunsi et al., 2005).

Total Ascorbic Acid. TAA content was not affected by treatment. On day zero it ranged from 53 mg/100 g to 59 mg/100 g and increased during storage, peaking at 72 mg/100 g (Table 1). According to Haffner and Vestrheim (1997), ascorbic acid content can vary from 30–70 mg/100 g depending on the strawberry cultivar. Shin et al. (2008) reported floating values, such as a slight increase at day 3, followed by a slight decrease at day 6, and an increase on day 9 at 3 °C and 95% RH. A slight increase was also observed by Andrade (2013) and Kalt et al. (1999). Cayo et al., (2016) reported a significant decrease in ascorbic acid content for seven genotypes of unbruised strawberry (including 'FL-09-127') stored at 4 °C for different periods in 2012 and 2013. A decrease also was reported in other studies as a stress effect (Cordenunsi

Table 2. Soluble solids content (%), pH, total titratable acidity (% of Citric Acid), and SSC/TTA for 'Florida127' strawberries stored for 8 days at 5 °C and 90% RH after pendulum impact.

Days	Control	15-cm	30-cm	45-cm	CV[y]	LSD[x]
			Soluble Solids Content (%)			
0	6.2 ± 0.13 Aa[z]	6.4 ± 0.46 aA	6.5 ± 0.17 aA	5.6 ± 0.35 aA	8.66	1.40
2	6.5 ± 0.18 Aa	6.2 ± 0.38 aA	6.2 ± 0.12 aA	6.3 ± 0.35 aA	7.62	1.25
4	6.8 ± 0.09 Aa	6.8 ± 0.03 aA	6.6 ± 0.23 aA	6.5 ± 0.22 aA	4.32	0.75
6	6.5 ± 0.19 Aa	6.7 ± 0.38 aA	6.8 ± 0.35 aA	6.9 ± 0.24 aA	7.75	1.36
8	6.5 ± 0.21 Aa	6.3 ± 0.24 aA	6.8 ± 0.32 aA	6.9 ± 0.58 aA	9.62	1.66
Mean	6.5 ± 0.09 A	6.5 ± 0.12 A	6.6 ± 0.11 A	6.4 ± 0.24 A	8.14	0.51
			Total Titratable Acidity (% of Citric Acid)			
0	0.68 ± 0.03 aA	0.63 ± 0.07 aA	0.65 ± 0.02 abA	0.60 ± 0.03 aA	11.07	0.19
2	0.66 ± 0.02 aA	0.66 ± 0.01 aA	0.60 ± 0.02 aA	0.62 ± 0.02 abA	4.32	0.07
4	0.67 ± 0.04 aA	0.72 ± 0.03 aA	0.72 ± 0.03 bA	0.73 ± 0.02 bA	6.81	0.13
6	0.65 ± 0.05 aA	0.62 ± 0.03 aA	0.68 ± 0.02 abA	0.68 ± 0.03 abA	8.57	0.15
8	0.70 ± 0.02 aA	0.62 ± 0.01 aA	0.68 ± 0.02 abA	0.63 ± 0.03 abA	5.06	0.09
Mean	0.67 ± 0.01 A	0.65 ± 0.02 A	0.67 ± 0.01 A	0.65 ± 0.02 A	7.83	0.05
			pH			
0	3.57 ± 0.02 aA	3.64 ± 0.02 aA	3.66 ± 0.03 aA	3.68 ± 0.03 aA	1.18	0.11
2	3.60 ± 0.02 aA	3.60 ± 0.03 aA	3.69 ± 0.02 aA	3.65 ± 0.01 aA	1.03	0.10
4	3.65 ± 0.04 aA	3.60 ± 0.00 aA	3.61 ± 0.03 aA	3.60 ± 0.01 aA	1.10	0.10
6	3.60 ± 0.04 aA	3.62 ± 0.01 aA	3.61 ± 0.02 aA	3.60 ± 0.03 aA	1.23	0.12
8	3.65 ± 0.02 aA	3.65 ± 0.02 aA	3.64 ± 0.02 aA	3.66 ± 0.01 aA	0.75	0.07
Mean	3.61 ± 0.02 A	3.62 ± 0.01 A	3.64 ± 0.02 A	3.64 ± 0.02 A	1.24	0.04
			Ratio (SSC/TTA)			
0	9.23 ± 0.31 aA	10.10 ± 0.33 aA	9.90 ± 0.21 aA	9.47 ± 0.91 aA	9.31	2.36
2	9.87 ± 0.31 aA	9.32 ± 0.76 aA	10.50 ± 0.51 aA	10.10 ± 0.41 aA	9.10	2.37
4	10.20 ± 0.44 aA	9.45 ± 0.35 aA	9.11 ± 0.62 aA	8.97 ± 0.46 aA	8.50	2.33
6	10.10 ± 0.58 aA	10.80 ± 0.39 aA	10.00 ± 0.30 aA	10.20 ± 0.45 aA	8.57	2.25
8	9.32 ± 0.10 aA	10.10 ± 0.30 aAB	10.00 ± 0.20 aAB	10.80 ± 0.41 aB	4.49	1.22
Mean	9.74 ± 0.20 A	9.96 ± 0.27 A	9.91 ± 0.22 A	9.91 ± 0.32 A	8.37	0.80

[z]Values followed by the same capital letter in the same row and small letter in the same column are not different according to the Tukey Test (α = 0.05). ± standard error (n = 3 replicates; 6 fruits / replicate)

[y]Coefficient of variation of the standard deviation to the mean of 18 fruits per treatment.

[x]Least significant differences at ($P < 0.05$).

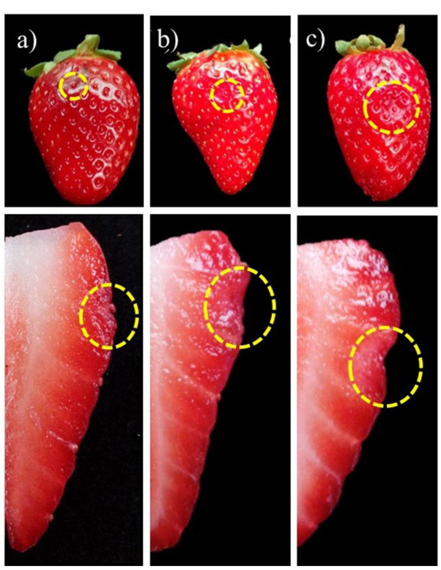

Fig. 4. Top row: external bruising induced from equivalent drop heights of (**a**) 15 cm, (**b**) 30 cm, or (**c**) 45 cm on day 8 of storage at 5 °C and 90% relative humidity. Bottom row: respective cross-sections of these same fruit.

et al., 2003; Kelly et al., 2016). According to Nunes (2006) and Cordenunsi et al. (2003), increases in ascorbic acid content during storage might be related to monosaccharide synthesis or simply a concentration effect related to water loss. These variations also may be related to the level of stress suffered by fruit, generally increasing with moderate stress while decreasing with a high stress level (Andrade, 2013; Sharma et al., 2008). Stress may be induced by changes in fruit temperature, bruises, or the interaction of both.

Conclusions

Strawberries impacted with the three energy levels of 0.036, 0.073, and 0.110 J developed bruises during 8 days of storage at 5° C. Bruise incidence was lower for the 15-cm and 30-cm impacts and higher for 45-cm impact on day 4, but by day 8 fruit from all treatments reached the same level. After 8 d storage, bruise area was lower for the 15-cm impact and higher for the 30-cm and 45-cm impacts, although none of these treatments exceeded the 1.27 cm^2 bruise area threshold set by USDA–AMS (2004) as damage. Significant differences due to impact intensity were found only for fruit firmness, weight loss and color hue* angle. Impact level caused no differences in the parameters measured for strawberry compositional quality compared to the control.

Table 3. Lightness (L*), chroma value (C*), hue angle (h*), and a* (redness) values of 'Florida127' strawberries stored for 8 days at 5 °C and 90% relative humidity after pendulum impact.

Days	Control	15-cm	30-cm	45-cm	CV[y]	LSD[x]
			Lightness (L*)			
0	38.95 ± 0.56 bA[z]	38.93 ± 0.58 aA	38.56 ± 0.74 aA	38.40 ± 0.77 aA	2.99	3.02
2	37.66 ± 0.42 abA	37.94 ± 0.70 aA	37.99 ± 1.58 aA	38.60 ± 1.03 aA	4.67	4.65
4	36.96 ± 0.56 abA	37.67 ± 0.87 aA	36.38 ± 0.68 aA	38.35 ± 1.22 aA	4.04	3.95
6	36.78 ± 0.66 abA	36.75 ± 0.35 aA	37.09 ± 0.37 aA	37.53 ± 0.74 aA	2.86	2.76
8	35.57 ± 0.34 aA	36.95 ± 0.42 aA	36.51 ± 1.18 aA	37.13 ± 0.30 aA	3.16	3.02
Mean	37.18 ± 0.36 A	37.65 ± 0.30 A	37.31 ± 0.43 A	38.00 ± 0.35 A	3.35	1.22
			a*			
0	40.16 ± 0.54 bA	39.02 ± 0.68 aA	39.52 ± 0.69 bA	38.94 ± 0.33 bA	2.54	2.62
2	37.42 ± 0.35 aA	37.54 ± 0.60 aA	38.38 ± 0.26 abA	37.03 ± 0.30 abA	1.84	1.81
4	37.37 ± 0.50 aAB	38.26 ± 0.07 aB	36.71 ± 0.26 aA	37.89 ± 0.32 abAB	1.51	1.48
6	37.38 ± 0.78 aA	37.80 ± 0.25 aA	38.16 ± 0.42 abA	36.18 ± 0.55 aA	2.38	2.32
8	36.62 ± 0.67 aA	37.53 ± 0.81 aA	36.18 ± 0.99 aA	36.90 ± 0.54 aA	3.63	4.49
Mean	37.79 ± 0.61 A	38.03 ± 0.28 A	37.79 ± 0.60 A	37.39 ± 0.47 A	2.63	0.96
			Chroma (C*)			
0	48.68 ± 0.44 bA	47.5 ± 0.53 aA	47.62 ± 0.48 aA	47.16 ± 0.65 bA	2.81	3.51
2	44.15 ± 0.47 aA	44.9 ± 0.18 aA	46.17 ± 0.69 aA	44.16 ± 0.57 abA	2.74	3.21
4	43.39 ± 0.53 aA	45.6 ± 0.50 aA	43.13 ± 0.91 aA	45.69 ± 0.75 abA	3.63	4.22
6	43.11 ± 1.15 aA	44.3 ± 1.37 aA	44.98 ± 0.31 aA	43.32 ± 0.50 aA	3.12	3.57
8	41.98 ± 0.87 aA	44.4 ± 0.85 aA	42.44 ± 1.03 aA	43.08 ± 1.73 aA	5.14	5.77
Mean	44.26 ± 1.16 A	45.3 ± 0.59 A	44.87 ± 0.95 A	44.68 ± 0.77 A	3.65	1.58
			Hue Angle (h*)			
0	33.80 ± 0.41 cA	34.20 ± 0.56 aA	33.30 ± 1.28 aA	33.74 ± 0.97 aA	4.47	3.94
2	31.59 ± 0.43 bcA	32.53 ± 1.38 aA	33.26 ± 2.07 aA	32.48 ± 0.78 aA	7.06	5.99
4	30.00 ± 0.79 abA	32.01 ± 1.32 aA	30.74 ± 1.49 aA	33.29 ± 1.65 aA	7.42	6.11
6	29.13 ± 0.47 abA	30.83 ± 0.32 aAB	31.38 ± 0.82 aAB	32.43 ± 0.32 aB	2.93	2.37
8	28.45 ± 0.66 aA	31.67 ± 1.72 aA	30.96 ± 0.88 aA	30.45 ± 0.58 aA	6.04	4.80
Mean	30.59 ± 0.96 A	32.25 ± 0.56 AB	31.93 ± 0.56 AB	32.48 ± 0.56 B	5.58	1.72

[z]Values followed by the same capital letter in the same row and small letter in the same column are not different according to the Tukey Test ($\alpha = 0.05$). ± standard error (n = 3 replicates; 6 fruits/replicate).
[y]Coefficient of variation of the standard deviation to the mean of 18 fruits per treatment.
[x]Least significant differences at ($P < 0.05$).

While the 15-cm treatment resulted in the smallest bruise area, there were no other significant differences for the other analyses conducted.

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