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Impacts on Fruit from Hand- and Aided Harvests Affect Postharvest Quality of Citrus

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Fresh orange shelf life begins at harvest and the way in which harvest is conducted may influence fruit quality. Information regarding the effects of physical damage caused by impacts during citrus harvest on postharvest quality is scarce. In Brazil, manual harvest prevails but aided harvest is under trials. "Aided harvest" is performed with auxiliary machines that carry pickers, avoiding long walks and effort in handling heavy bags. However, these machines may produce fruit damage due to impacts. The goal of this study was to relate impact incidence during harvest with the subsequent quality changes during storage in 'Valencia' sweet oranges. An instrumented sphere attached to oranges in the tree and harvested among other oranges showed that impacts produced during manual and aided harvests averaged 50 and 500 G (maximum acceleration), respectively. Following the field study, oranges were subjected to 50 and 500 G impacts by dropping them different heights in the laboratory. Those treatments were compared to a control (with no impacts). Fruit were stored for 5 days at 24 °C at 85% RH and evaluated for postharvest quality. Weight loss was 2.18% for control and 2.90% for aided harvest fruit at the end of storage. Ascorbic acid content was negatively affected by aided harvest, resulting in a reduction of 15% over the control. Furthermore, control had significantly higher soluble solids content (SSC) over manual, followed by fruit that were aided harvested. Titratable acidity decreased during storage for all treatments with no differences between harvest types. This study showed that aided harvest significantly negatively affected physicochemical quality, and therefore still needs improvements in the future.

Brazil and United States are world citrus leading producers. Around 60% of global orange production is consumed fresh, and 40% is processed. Brazilian citrus GDP is U.S. $ 6.5 billion (2009), of which 64% refers to domestic market and 33% refers to export market (Neves et al., 2010). São Paulo is the main fruit producing state with 355.290 million boxes of 40.8 kg harvested in 2012 (IEA, 2013). Many direct and indirect jobs are generated by this industry, which comprises 230,000 employees, and annual payroll of U.S. $676 million (Neves et al., 2010).

Citrus harvest is almost entirely carried out by hand on Brazilian citrus farms. Although hand harvesting provides good qualitative fruit selection, labor is an important fraction of production cost, accounting for 22% of total cost for citrus orchards in São Paulo State (IEA, 2011). Considering only disbursements and excluding financial cost, overhead, and depreciation, the workforce proportion may account for up to 38% of total expenses of citrus production in Brazil (IEA, 2011). In Florida, it can reach up to 50 % of the total cost (Muraro, 2009). Furthermore, labor is becoming increasingly difficult to source due to high fluctuations as a result of competition and immigration regulations, besides requiring great physical effort by pickers (Mascarin, 2006; Spann and Danyluk, 2010).

In an attempt to improve hand harvest, some aid platforms have been developed. These auxiliary machines are designed to reduce human effort to perform harvest, providing better working conditions and speed the process (Sarig, 1993). Harvesting aid machines can increase productivity and/or reduce cost, especially when used in conjunction with packaging operations (Ferreira et al., 2008).

Even minor mechanical damages can cause permanent deleterious effects on fruit, such as changes in sensory quality, respiration rate, ethylene production, ripening and decay; thus citrus harvesting is a key operation to obtain quality fruit (Lee et al., 2004; Moretti and Sargent, 2000; Moretti et al., 2002; Pereira and Calbo, 2000). Fruit affected by impacts lose in quality and commercial value, regardless of harvest methods. Vigneault et al. (2002) defined impacts as transient movements caused by sudden acceleration or deceleration, causing large energy dissipation, triggering efforts and consequent fruit damage. Moreover, mechanical damage on citrus increases susceptibility to pathogenic infection. It also breaks skin oil glands, resulting in oleocellosis and visible scars that impair visual fruit quality (Fischer et al., 2007; Golomb et al., 1984).

To measure the magnitude of impacts in the field and during postharvest, an instrumented sphere (Techmark, Inc., Lansing, MI) was used, which consists of a plastic device containing a triaxial accelerometer used as an impact sensor. The instrumented sphere has an acceleration register and data can be stored, transferred, and analyzed in a computer, assessing impact magnitudes that fruit are subjected to during pre- and postharvest steps (Ferreira and Calbo, 2008). This instrument has been used in several crops to identify aggressive impacts to fruits and vegetables along the production chain (Ferreira et al., 2006; Miller and Wagner, 1991; Sargent et al., 1992; Valentini et al., 2009).

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The objective of this study was to quantify impacts during citrus hand harvest and aided harvest, and relate those impacts to physicochemical quality of stored fruit.

Materials and Methods

The trials were done in two parts, in the field for 1) impact measurement and in the lab for 2) fruit quality measurements, as follows:

1) Impact quantification on hand and aided harvests

Impact measurements in field for hand and aided harvests were conducted using the instrumented sphere (76 mm, Techmark, Inc., Lansing, MI). Maximum acceleration (MA) ($G = m \cdot s^{-2}$) was measured. Each measurement step was made twice with eight repetitions. Hand harvest impact measurements were performed by cutting an orange still attached to a tree (**A**) in the equatorial region (**B**), discarding fruit bottom half and pulp of upper half (**C**), placing the instrumented sphere in the upper empty half of the fruit, and tying it with a stretchable plastic film (**D** and **E**) (Fig. 1). Pickers were instructed to harvest the instrumented sphere like the other oranges, harvesting and putting it in picking sacks.

In aided harvest, the trials were performed with trailer-type equipment. This equipment had four movable baskets, which allocated pickers to different positions in a tree canopy. Pickers stood inside the baskets and harvested fruit while a tractor pulled the equipment along the citrus row. The baskets could move in or away from the tree canopy, according to pickers needs. Once harvested, fruit were placed in gutters located on the sides of the baskets, and moved by gravity into a temporary storage box. When the temporary storage box was filled, pickers dumped it and fruit were taken to a conveyor belt through a funnel. The conveyor belt carried the fruit to a larger reservoir, called big-bag, located at the rear of the trailer. The instrumented sphere was placed in the trees as described in Fig. 1 and the pickers were instructed to perform harvest in the same way as they would with the real fruit. The instrumented sphere went through the steps below:

- Lower baskets: gutter, temporary storage box, conveyor belt, and big-bags.
- Upper baskets: gutter, temporary storage box, funnel, conveyor belt, and big-bags.

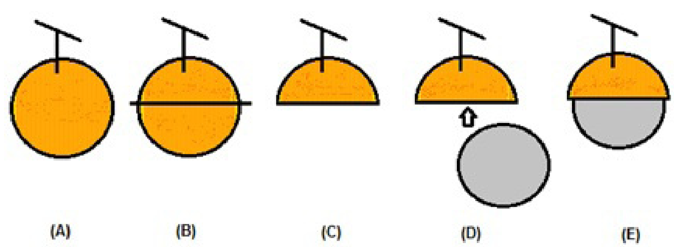

Fig. 1. Instrumented sphere prepared for harvest (Miranda et al., 2013).

2) Fruit quality analyses

'Valencia' oranges [*Citrus sinensis* (L.) Osbeck] were harvested from a commercial grove and quality analysis was performed at the Postharvest Laboratory in Embrapa Instrumentation, located in São Paulo state, Brazil. To standardize impacts, a suction device developed by Camargo et al. (2004) was applied for drop trials. The instrumented sphere was used to calibrate the drops corresponding to impacts of 50 and 500 G, and fruits were subjected to drop at those impact levels, simulating hand and aided harvest, respectively. Those treatments were compared to a control without impact. After the drop tests, fruit were stored at 24 ± 1 °C and 85% RH during 5 d. Physicochemical evaluations were performed daily using eight fruit for weight loss, soluble solids, titratable acidity, and ascorbic acid. Soluble solids content was evaluated using a digital refractometer Atago RX-5000a, according to AOAC method no. 932.12 (AOAC, 1997). Titratable acidity and ascorbic acid were determined by titration according to AOAC method no. 942.15.

Results and Discussion

Hand harvest caused lower impacts on fruit when compared to aided harvest (Table 1). In fact, all the steps during aided harvest contributed to impacts 10 times higher than during hand harvest. Impacts on fruit, pre- or postharvest is an important issue as it affects fruit quality and conservation (Ferreira et al., 2006). Based on the field results, 50 G and 500 G were selected to represent impacts during hand and aided harvest, respectively, in the follow-up laboratory experiment.

Different harvest methods can influence fruit quality and physical injuries incidence, which in turn, can affect fruit storability. In this study, the impacts that oranges were subjected to increased weight loss up to 54% during postharvest storage, and resulted in significant changes, mainly in simulated aided harvest (Table 2). Maintaining fruit water content is directly correlated

Table 1. Maximum accelerations ($G = m \cdot s^{-2}$) during hand- and aided harvests.

	Repetitions								Avg	All steps avg
Hand harvest	46.8	61.9	58.9	56.4	50.7	67.4	45.1	68.6	55.3	55.3
Aided harvest (low baskets)										
Gutter	166.3	91.9	172.9	292.5	148.2	112.9	183.3	125.4	161.7	
Temporary storage box	169.6	40.6	138.7	222.3	202.7	162.7	183.3	65.8	148.2	
Conveyor belt	57.3	93.8	101.7	196.2	169.2	185.7	70.3	45.8	115.0	
Big-bags	103.8	79.3	59.9	168.1	153.5	103.4	70.0	63.8	100.2	525.1
Aided harvest (upper baskets)										
Gutter	160.6	123.2	65.1	90.4	135.1	165.2	175.9	160.1	134.5	
Temporary storage box	160.6	197.5	145.9	137.2	79.4	76.3	89.2	91.2	122.2	
Funnel	69.4	194.2	220.9	81.5	79.8	98.9	114.4	166.1	128.2	
Conveyor belt	126.0	139.6	136.2	118.2	80.1	101.6	79.7	146.2	116.0	
Big-bags	109.8	73.5	90.4	79.7	67.8	79.2	55.3	74.0	78.7	579.4

Table 2. Physicochemical quality of 'Valencia' oranges submitted to maximum acceleration of 50 G and 500 G, simulating hand- and aided harvest impacts, respectively.

	Wt loss (G)	SSC (°Brix)	TA (g·100 mL^{-1})	Ascorbic acid (mg·100 mL^{-1})	TSS/TA ratio
Control	0.95 c	12.50 a	0.69 a	51.23 a	18.31 a
Hand harvest (50 G)	1.10 b	10.96 b	0.60 b	45.06 b	18.48 a
Aided harvest (500 G)	1.46 a	10.05 c	0.60 b	43.27 c	16.98 b

*Significant at 5% probability level ($P < 0.05$).

with texture and nutritional value, in addition to affecting fruit appearance (Kader, 2002). Similar results were observed in tangerines 'Rainha' subjected to impacts by fruit fall from different heights (Montero et al., 2009).

In the same way, soluble solids content decreased in damaged fruits, even in hand harvested fruit, which are subjected to low impacts (Table 2). Impacts usually do not cause external symptoms immediately observable, but their effect causes internal injuries (Moretti et al., 1998; Quintana and Paull, 1993). An increase in fruit metabolism from damage could explain the reduction in soluble solids content, as sugars are being used as a source of energy (Sanches et al., 2008). Reduction in soluble solids content was also observed in tangerines and limes subjected to mechanical damage (Durigan et al., 2005; Montero et al., 2009). Soluble solids are related to quality, indicative of fruit maturity and fruit flavor as well as an important attribute in future to be used as criteria for productions payments in Brazil (Neves et al., 2010).

Impacts may also result in enhanced respiration, thus accelerating acid oxidation (Montero et al., 2009). In this study, damages induced a reduction of 15% in total titratable acidity during storage for both impact treatments as compared to control, independently of intensity (Table 2). SSC/TA ratio was similar in control and hand harvest treatments (Table 2), although this had occurred because of a concomitant decrease in SSC and TA in hand harvested fruit, and it was not related to the quality maintenance as in the control fruit.

Mechanical injuries such as bruising, surface abrasions, and cuts can accelerate loss of ascorbic acid in fruits. Impacts on oranges were responsible for the decrease in ascorbic acid content in this study (Table 2), demonstrating high sensitivity to this type of damage. In limes, negative effects caused by impacts were also observed, leading to reduction of AA total content (Durigan et al., 2005). As nutritional quality is an important issue, it is recommended to avoid damages as much as possible. Postharvest losses can be substantial, especially in nutritional quality, and could increase without proper management to minimize physical damages during harvesting, independently by hand or by machines (Kader, 2002).

Conclusions

Aided harvest showed important behavior differences in postharvest fruit quality, which was negatively affected in all evaluated parameters. Therefore, in order to maintain citrus postharvest quality, aided harvest still needs improvements.

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