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Improvements in Citrus Packing Lines to Reduce the Mechanical Damage to Fruit

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Citrus fruits destined to the fresh market are subject to several treatments in packing lines with the aim of lengthen shelf-life, increase commercial value, and comply with the rules on marketing. During the treatments, fruits collide with each other and with components of the machines and undergo mechanical damage that can be very serious. Therefore, operators make changes to the machines in order to reduce number and intensity of impacts. This paper reports the results of a study on the impacts suffered by oranges during packing operations, carried out by using an instrumented sphere IS100. Experimental measurements were conducted in a packing house equipped with two packing lines, where they were both traditional and innovative machines (regarding the empting and the filling of the bins, the release of the fruits from the sizing machines, the transfer of the fruits between belt conveyors), specifically designed to reduce the mechanical impacts to the fruits. The results showed that the innovations were effective in reducing the intensity of the impacts, expressed in terms of acceleration. The maximum acceleration was always lower (from 47 to 83 %) with respect to the conventional machines, whereas the average number of impacts per replicate was lower in the sizing machines (−6 %) and during the emptying of the bins (−36 %), but was higher during the transfer of the oranges between belt conveyors (+33 %) and during the filling of the bins (+73 %). The increase in the average number of impacts depends from the fact that the innovative systems “accompany” the fruits towards the exit, causing a greater number of impacts of lower intensity.

1. Introduction

Bruising is the most common type of mechanical damage affecting fruits destined to the fresh consumption, downgrading quality and causing economic losses (Opara and Pathare, 2014). Bruising may occur during harvesting, transport, grading, packaging and it may be caused by impact, compression, abrasion, puncturing, or several actions combined (Van Zeebroeck et al., 2007; Li and Thomas, 2014). Today several technologies are available for bruise measurement and quality assessment, among which computer vision, near infrared spectroscopy, hyperspectral imaging, thermal imaging, X-rays, nuclear magnetic resonance imaging, optical measurement systems, acoustic methods, chemical sensing (Studman, 2001; Ruiz-Altisent et al., 2010; Yamakawa et al., 2012). Bruise susceptibility can be managed by controlling temperature, relative turgor, and strain rate (Baritelle and Hyde, 2001). The effects of fruit properties (size, mass, modulus of Young) and mechanical parameters (vibration frequency, acceleration amplitude, drop height) on impact damages can be investigated through Finite Element Method (FEM) simulations (Van Zeebroeck et al., 2006; Dintwa et al., 2008; Cerruto et al., 2015) or statistical approaches (Barreiro et al., 1997; Menesatti and Paglia, 2001; Bielza et al., 2003).
A direct measurement of impact forces, especially during pack house operations, may be carried out by means of the so called “Instrumented Spheres” (IS), a sort of “artificial fruits” which mimic physical properties and mechanical responses of fruits and vegetables during post-harvest handling. Essentially, they are data loggers subjected to the same treatments as real products, that record mechanical stresses in terms of acceleration using accelerometers as in IS100 (Zapp et al., 1990; Ragni and Berardinelli, 2001; Di Renzo et al., 2009) and PTR 100 (or PTR 200) (Van Canneyt et al., 2003), or in terms of forces using Pressure

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Measuring Sensors (PMS) as in PMS 60 (Herold et al., 1996). Some measuring devices have been miniaturised to be comparable in size with small fruits as blueberries (Berry Impact Recording Device—BIRD, Yu et al., 2011) or to be implanted inside natural fruits (Acceleration Measuring Unit—AMU, Geyer et al., 2009).

All these devices can be efficiently used in packing lines to evaluate the effect of transfer height, velocity, belt structure and padding on fruit bruising susceptibility (Ortiz-Cañavate et al., 2001; Blandini et al., 2002; Xu et al., 2015) or to assist the design of some components as decelerator elements (García-Ramos et al., 2003) or sizers (García-Ramos et al., 2004).

Aim of this work was the measurement of the mechanical stress in two packing lines for oranges by using the Instrumented Sphere IS100. The two packing lines, besides conventional machines, were also composed of innovative machines, specifically designed to reduce the mechanical impacts to the fruits.

2. Materials and Methods

Citrus fruits destined to the fresh market are subject to several treatments in packing lines with the aim of improving their preservation and increasing their commercial value. During these operations, fruits collide with each other and with components of the machines in the packing lines, not always properly covered with cushioning materials. The mechanical damage to the fruits resulting from these operations can be very serious (Blandini et al., 2003) and therefore operators make changes to the machines to reduce number and intensity of impacts.

The experimental activity discussed in this paper was carried out in a citrus packing house where two packing lines were installed. They were equipped with some machines that implemented solutions capable of reducing the mechanical damage to the fruits during the packing process. The first packing line is a conventional one, where oranges, coming from the fields in plastic boxes of 20 kg capacity, are processed up to a first selection. The line feeder consists of an automatic depalletiser and a conventional box discharger (Figure 1). Then fruits undergo to the treatments of pre-selection, pre-sizing, washing (two times, the first by using horsehair rollers, the second by immersion in water), pre-drying with foam rubber rollers, drying in a hot air tunnel, manual selection and sizing by means of an optical calibrator. Due to the plant layout, connection between machines usually requires belt conveyors.

Figure 1: The conventional line feeding system (box emptying).

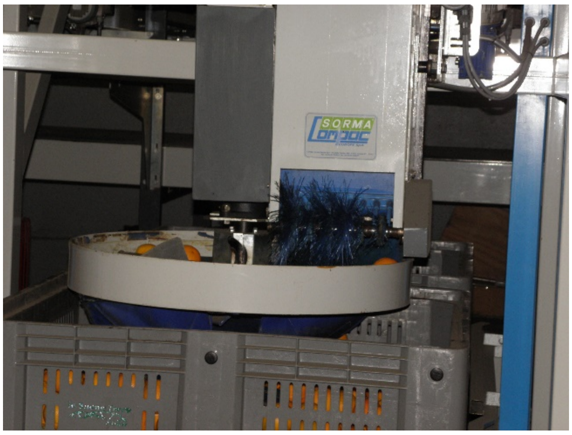

Figure 2: The innovative filling system of the containers (bins).

The calibrator sorts the oranges in accordance to the required commercial categories and conveys them in plastic containers (bins) of 200 kg capacity. To reduce the mechanical stress, the discharge of the fruits from the calibrator was improved with respect to the conventional system. In fact, the chain-belt of the sizing machine is realised with carriages that discharge the orange fruits via a lateral rotation, knocking them over strips that release the fruits on a lower transversal belt conveyor. On the contrary, in conventional sizers the chain-belt is realised by means of rollers and the fruit discharge is due to an expulsion system that projects the oranges laterally and upwards, causing high intensity impacts.

The bin filling system after sizing consists of devices able to limit the drop heights, normally installed in apple packing lines (Figure 2). In fact, it includes a small bucket-elevator that keeps constant and limited the height difference that the fruits must overcome at the output of the belt conveyor from which they come. Moreover, it discharges the fruits by means of a little transversal bristle-roller and a rotating system of strips which slow

down their velocity and distributes the oranges across all the surface of the bin, avoiding the formation of piles and reducing the impacts due to the incoming fruits. Finally, all the system moves vertically, adjusting its position in function of the filling level of the bin.
The second line is used for the final packing before shipment. It processes the fruits selected by the first line and temporarily stored in bins. The feeding of this packing line takes place by means of a dedicated dumper (Figure 3) that first closes the bin with a panel, then turns it and finally moves progressively the panel to allow the slow exit of the oranges on a belt conveyor. A transversal roller, made of soft bristles, intercepts the fruits to slow down their drop velocity and keeps them on the belt conveyor; this moves away the fruits before the arrival of the incoming ones and avoids the fruit-fruit impacts. Successively, oranges arrive on a selection bench and then on an innovative strip conveyor (Figure 4) that gently release them along the width of a lower transversal belt conveyor. Then the oranges are subject to waxing, drying with hot air, sizing with another calibrator (same model of the one installed in the first line) and packing. This may be manual on a suitable bench where operators put the oranges in cardboard or wood boxes or automatic in packing machines that make up nets of prefixed weight.

Figure 3: The innovative line feeding system (bin emptying).

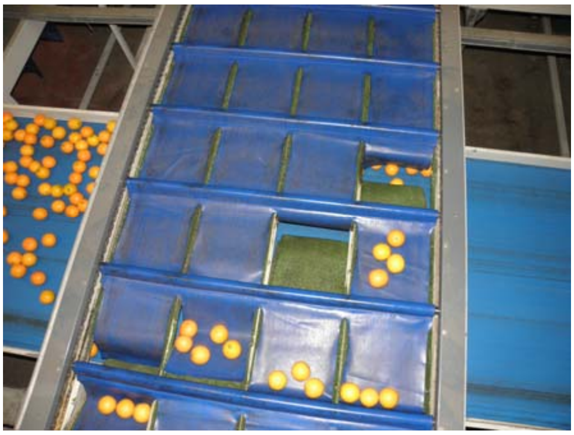

Figure 4: The innovative strip conveyor.

The mechanical bruising to which the fruits are subject during the packing process in the two lines was evaluated by using the IS100 Instrumented Sphere. It is a spherical device in thermoplastic material with diameter of 89 mm and mass of 290 g (similar to an orange and able to tolerate the same process of the fruits), containing inside it a triaxial accelerometer, a microprocessor, a memory and a battery. The IS, once inserted into the packing line together with the fruits, records number, acceleration and duration of each impact caused by the process higher than a prefixed threshold; an internal clock allows to locate the impacts in the packing line by comparing the internal time with the moment of transit of the IS100 in each section of the line. A dedicated piece of software provides for its initialisation and the analysis of the recorded data.
Measurements were replicated three times in each packing line, and the threshold was set equal to 10 *g* (1 *g* = 9.81 m/s^2), so to do not saturate the internal memory of the IS100 before the end of the process. Data were analysed in such a way to point out the performance of the “innovative” machines with respect to the “conventional” ones, also measured by the authors in other packing lines for oranges (Blandini et al., 2002; Blandini et al., 2005).

3. Results and discussion

Figure 5 reports the correlation between maximum acceleration and mean number of impacts in the two packing lines. Data referring to the innovative machines are enlightened in red. From it emerges that Line 2 pays closer attention than Line 1 in reducing the impacts, both in terms of maximum acceleration and mean number of impacts per operation. In fact, the maximum acceleration in Line 1 was 270 *g* (during the emptying of the boxes for line feeding) and in Line 2 was 227 *g* (due to a drop at the end of an elevator). The highest number of impacts per replicate was 19.7 in Line 1 (during singling, before sizing) and 10.0 in Line 2 (during waxing and during the emptying of fruit bins). The analysis of impacts produced by conventional machines confirmed the results obtained in previous studies in similar packing lines (Blandini et al., 2002; Blandini et al., 2005). Small differences were due to the state of the cushioning material, differences in height between successive machines, differences in connection between successive machines, mainly due to different plant layouts imposed by the space availability.

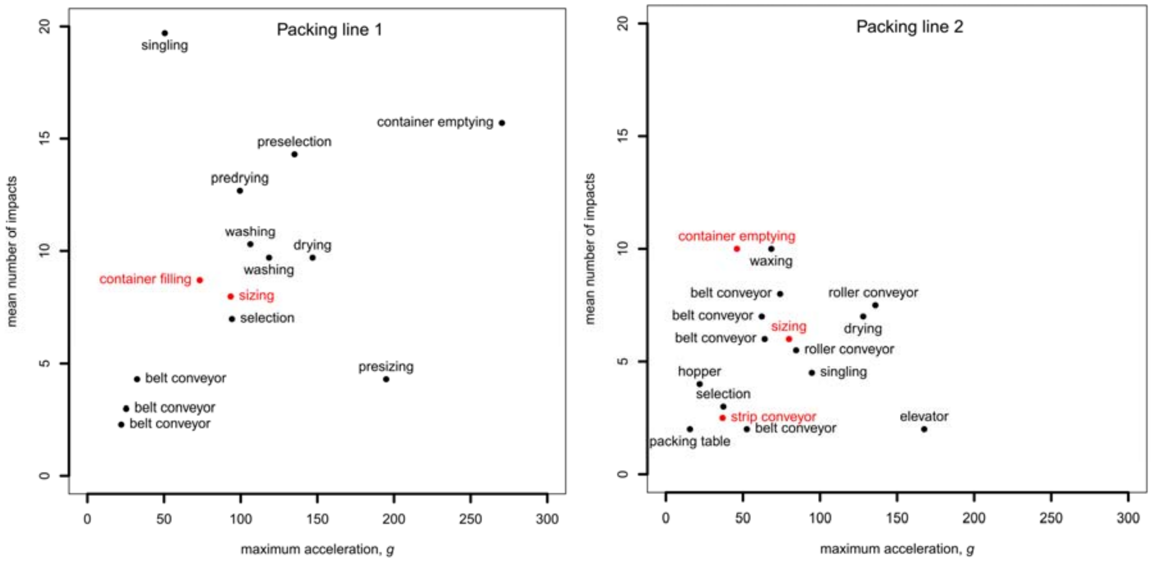

Figure 5: Correlation between maximum acceleration and mean number of impacts in the two packing lines (innovative machines are enlightened in red).

The comparison between “conventional” and “innovative” machines in terms of maximum acceleration, mean number of impacts and variability of raw data (Figure 6), pointed out a considerable reduction in mechanical stress produced by the latter with respect to the former. Data on the conventional machines for sizing, container filling and belt conveyors have been measured in other packing lines for oranges (Blandini et al., 2005).

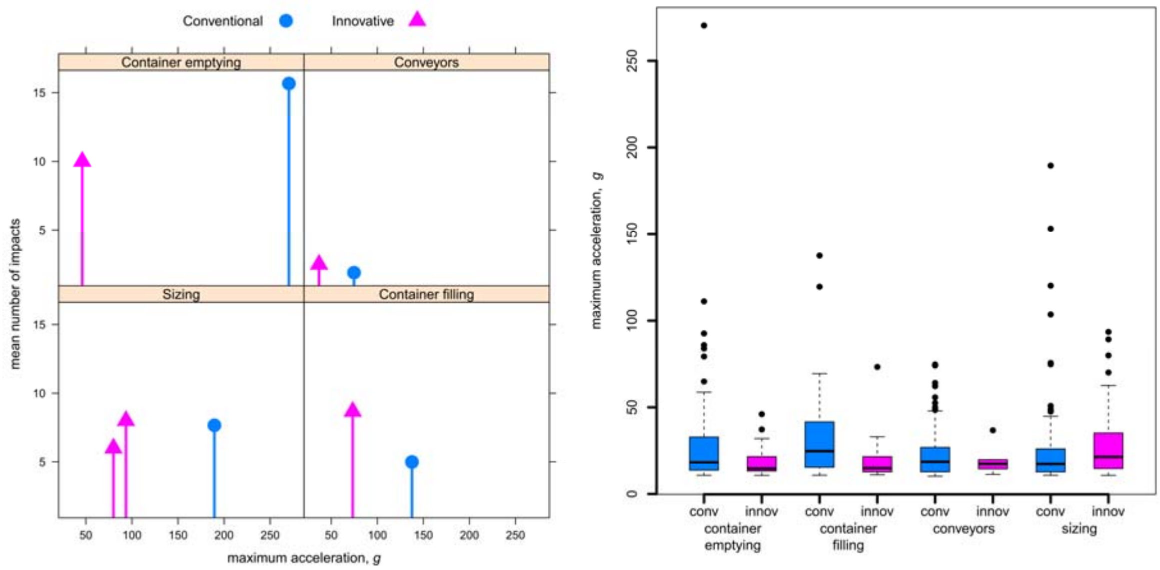

Figure 6: Comparison between conventional and innovative machines.

The innovative bin emptying system (Figure 3), due to the panel that closes the bins at the top when they are overturned and the handling system that carries out a progressive unloading of the fruits, provided a reduction in the maximum acceleration of 83 % (from 270 to 46 *g*, Figure 6) with respect to the conventional system (Figure 1). This result was also due both to the overturning of the fruits over a belt conveyor rather than over

metallic chutes, and the presence of the transversal bristle-roller which slows down the falling speed of the fruits. The number of impacts per replicate was also reduced from 15.7 to 10.0 (−36 %, Figure 6), due to the quick moving away of the fruits with the belt conveyor, so that they were not impacted by the incoming ones.
The innovative bin filling system also caused a considerable reduction in the level of acceleration compared to the traditional packing in boxes of 20 kg capacity. In fact, the maximum acceleration decreased from 138 to 73 *g* (−47 %, Figure 6). This reduction with the innovative machine is due to its working principle, aimed at minimising the drop heights, at slowing down the fruit velocity and then at reducing the intensity of the impacts. All considered, the innovative system "accompanies" the fruits inside the bins, lowering the intensity of impacts, but inevitably increasing the average number of impacts per replicate (from 5.0 to 8.7, +73 %). The higher number of impacts, however, is characterised by a lower value of the average acceleration (reduction from 40 to 19 *g*, −52 %) (consider that when the IS100 drops on steel padded with 12 mm of polyurethane foam from a height of 40 mm, it records average acceleration values of 12 *g*; 28 *g* from height of 80 mm).
Similar reductions in maximum acceleration (−51 % and −58 % in the two lines, Figure 6) with respect to the conventional system were measured during the discharge of the fruits by the two calibrators. Average acceleration and average number of impacts per replicate were similar in conventional and innovative system. The reduction in maximum acceleration was due both to the improvements in the connection system between the plane of the chain-belt and the belt conveyor underneath by means of strips and to the new fruit discharge system at the programmed exit by means of lateral rotation rather than projection. Maximum and average acceleration values were 80 and 30 *g* in the first packing line and 94 and 31 *g* in the second one. On the contrary, in conventional calibrators with fruit discharge realised via the expulsion system, impacts were characterised by maximum acceleration values of about 190 *g* (Blandini et al., 2005).
Finally, with respect to the conventional system realised by means of a free drop, the strip conveyor (Figure 4) proved to be effective in reducing the mechanical stress to the fruits during their transfer to a belt conveyor underneath. In fact, the comparison between the two systems (Figure 6) showed a reduction in the maximum acceleration values of about 51 % (from 75 to 37 *g*). Like the innovative filling machine, the strip conveyor caused an increase in the average number of impacts per replicate (from 1.9 to 2.5, +33 %), but a reduction in the average acceleration value (from 26 to 20 *g*, −24 %). When comparing the strip conveyor with the other belt conveyors in packing lines 1 and 2, it was measured a reduction in acceleration values of about 50 % (from 74 to 37 *g*), in the average acceleration value of about 11 % (from 22.4 to 19.9 *g*), and in the average number of impacts per replicate of about 43 % (from 4.4 to 2.5).

4. Conclusions and perspectives

The present study, although it may be improved with further experimental measurements, showed the validity of the solutions proposed for the reduction of the mechanical bruise affecting oranges during packing operations in packing lines. On average, the four operations under study (emptying and the filling of the bins, release of the fruits from the sizing machines, transfer of the fruits between belt conveyors) showed, compared to conventional systems, a reduction in the maximum acceleration of 65 % (from 270 to 93 *g*) and in the average acceleration of 24 % (from 31 to 24 *g*). However, the average number of impacts per replicate increased from 6.3 to 7.2, mainly due to the new bin filling system: the machine was designed in such a way to prefer the reduction of the level of acceleration (−47 % of maximum acceleration and −52 % of mean acceleration). However, accompanying the oranges from the input towards the exit, it inevitably caused an increase in the number of impacts due to the complexity of the handling system.
All considered, it can be said that bruise reduction in fruits is more topical than ever and one has to hope for a continued interest from researchers and manufacturers to find new and more efficient solutions.

Acknowledgments

The authors equally contributed to the present study.

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