EVALUATION OF POTENTIAL MECHANICAL DAMAGE IN APPLE PACKING LINES IN THE MAIN PRODUCING REGIONS OF BRAZIL

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Abstract. Packing lines are responsible for most mechanical damage found in apples. Impacts usually occur at transference points within a line. Depending on the height difference, working speed and surface, they can cause damage that degrades quality and devalue the commercial product. The objective of this work was to evaluate seven apple packing lines located in the main producing regions of Brazil, searching for possible critical points of mechanical damage in the discharge, selection and packing processes. Additionally, the impact levels observed in the packing lines were reproduced in laboratory conditions, and the damage levels in apples were measured by the area and depth of the damaged regions. Critical points and impact magnitudes were identified using a 76mm instrumented sphere (Techmark, Inc., Lansing, MI), and an equipment developed for free fall of fruits was used to reproduce the observed conditions. Points in the packing line which resulted in acceleration values above 50 G were considered critical. Six out seven evaluated lines had high impact values between the singulator entrance and the sizer. The largest value observed was 194.8 G, which was equivalent to an 8cm fall on an unprotected metallic surface. 'Royal Gala' apples submitted to this level of impact suffered a damage of 96 mm^2 in area and 2.5 mm in depth, easily perceivable to touch and noticeable after skin removal. The use of curtains and impact absorbing materials may function as elements to reduce fruit deceleration at the transference points, decreasing the chance of mechanical damage.

Keywords. Apple, mechanical damage, instrumented sphere.

INTRODUCTION

Brazilian apple production in the 2006-07 harvest was 993 225 tons. This production is concentrated in the South of Brazil, in an area of 36 930 ha. Santa Catarina and Rio Grande do Sul are the main producing apple states (ABPM, 2008)[58].

Brazil lacks data about quality loss in apples due to mechanical damage (MD). However, as with other vegetable products, this is one of the main post-harvest problems. According to Gomila (2007), quality loss in some of the most sensible cultivars (and consequent classification into poorer categories) may reach over 50% of total production. Recent works in the Alto Valle region, Argentina, indicated that MD occurrence was the main cause of post-harvest quality loss, followed by physiological and pathological disorders (Gomila, 2007). The economic cost of MD on apples in Belgium has been estimated. The percentage of degraded apples identified during sorting, in which bruised apples were a major part, was 15% and 8% in 2000 and 2001, respectively (Knee & Miller, 2002).

MD may occur during harvest, transportation, handling and shipping, and are characterized by internal or external injuries caused by impacts, which, without breaking the skin, cause the deterioration of pulp, which acquires, gradually, a cork aspect and brownish color from oxidative enzymes activity. In addition to quality reduction, MD accelerates fruit metabolism, anticipating senescence and therefore reducing post-harvest life.

The susceptibility of apples to MD is related to intrinsic and extrinsic factors. Fruit aspects are the cultivar, firmness, turgor and maturity. However, other factors contribute to fruit damage susceptibility, such as storage period, fruit internal temperature and

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conditions of the packing line (Segatori, 2008). The severity of damage caused by impact on packing lines is a result of equipment working speed (and therefore fruit transportation speed), and height differences between transfer points. Thus, the level of impact can be reduced by eliminating or minimizing height differences between line components, line speed control, use of energy absorbing materials at impact points and synchronizing line components (Hyde & Zhang, 1992; Segatori, 2008).

As opposed to what occurs with other plant products, apple packing lines in Brazil use relatively new equipment, designed specially for apples. However, some details such absence of curtains or ramps, which act as decelerating mechanisms, as well as lack of protective materials are often observed in these lines.

The objective of this study was to evaluate seven apple packing lines, located in the main producing regions of Brazil, in order to identify points where MD occurs and propose corrective measures, as well as to relate levels of observed impact with damage occurrence on 'Royal Gala' apples.

•MATERIALS AND METHODS

Seven apple packing lines located in southern Brazil were evaluated. Lines 1 and 2, despite some structural differences were joined in a group where fruit selection and packaging were made in a single line (SL). Lines 3, 4, 5 and 6 formed a group where pre-selection and packaging were done on different lines, as separate processes (SP). Line 7 was studied separately because it does not use water in the fruit discharge step (dry discharge – DD).

Impact magnitude evaluation at transfer points was made using a 76 mm impact recording device (IRD), also known as an instrumented sphere (Techmark, Inc., Lansing, USA). This equipment is being used to evaluate packing lines of potatoes (Hyde et al., 1992), onions (Bajema & Hyde, 1995), oranges (Miller & Wagner, 1991; Ferreira et al., 2006), apples (Brown et al., 1990) and tomatoes (Sargent at al., 1992; Ferreira et al., 2005). The IRD is a rigid plastic ball containing accelerometers and a microprocessor inside. It records the time of occurrence, intensity and duration of impacts which occur during a period of time and reports impact events, acceleration and velocity. The IRD was placed with the apples at the beginning of each packing line, and followed the normal flow of the line until the final step of packaging. During this time, the IRD was monitored with a video camera and a chronometer, and the time it reached each transfer point was recorded. All measurements were repeated six times, except for line 7, where only five repetitions were made. The measurement impact limits ranged from 15 to 500 G (where $G = 9.81\ m/s^2$). The values of peak acceleration (PA) at the transfer points of each line in each repetition were analyzed using the resulting graphics. The following criteria was used to identify critical points: at least 50% of the PA values between 30 and 50 G, or at least one PA value over 50 G, which, according to Gomila (2007), are considered to be of high damage potential. Additionally, a flowchart of the packing lines was used to facilitate visualization of the data.

In order to reproduce the observed acceleration values in laboratory conditions, a suction equipment (Magalhães et al., 2007) was used to assure free fall of the IRD and the fruits. Initially, the IRD was dropped from different heights (1 cm; 3 to 42 cm, with 3 cm intervals) on two surfaces: metal and synthetic rubber (8 mm, Ingeniería Prodol S/A). For each combination of height and impact surface, 15 repetitions were made. The resulting mean data were submitted to polynomial regression analysis. 'Royal Gala' apples were dropped from eight heights (2, 5, 8, 15, 18, 25, 32 and 40 cm) on the same two surfaces, in 3 replicates. After being dropped, the fruits were kept for 7 days at 24°C, simulating ambient temperature. They were then evaluated for external symptoms of MD and, after removing the skin, the damaged area (mm^2) and damage depth (mm) was measured. The data were subjected to analysis of variance, and the means compared by the Tukey test ($P<0.05$).

•RESULTS AND DISCUSSION

Evaluation of apple packing lines and identification of mechanical damage (MD) critical points.

Lines 1 and 2 (SL) have in common the discharge in water, tank and roller lift. From this step to the singulator, the lines differ (Fig. 1A).

Figure 1.

The critical point of impact is between the singulator and the sizer, where all acceleration values measured were above 30 G (ranging from 34.20 to 96.78 G), and 67% were over 50 G (Fig. 1B). According to Segatori et al. (2008), accelerations between 30 and 50 G on hard surfaces can cause commercial damage (> 50 mm^2) in sensitive cultivars. Values between 50 and 80 G are highly risky, while values under 25 G usually do not damage the fruit. The highest accelerations at this point were observed in line 1, which has a dish sizer system. According to Gomila (2007), the main problems in the singulator/sizer are inadequate working speed, excessive height difference between singulator and dishes, due to flaws in design or assembly, and unsynchronized components, which may cause severe damage by from fruit fall over the dish edges.

The remaining points in Figure 1B were critical only for one of the two lines, where four points had 100% of impacts above 30 G: (7) selection table – conveyor belt; (16) conveyor belt – rigid roller lift; (20) conveyor belt fall; (21) conveyor belt – packaging table. Except for point 20, all others had 33% of impacts above 50 G. Transfer point 21, with impacts between 39.90 and 111.17 G has a 3.5 cm fall from the conveyor belt to the packaging table. A deceleration mechanism and cushioned ramp did not avoid high impact levels, which may have occurred due to excess working speed and hardening of the rubber. Maximum impacts at points 7 and 16 were 93.88 and 74.30 G, respectively. Transfer point 7 of line 2 has a 9 cm gradient between the rigid roller selection table and the conveyor belt. The ramp, made with adequate material (Ingeniería Prodol S/A), reduces but does not eliminate the risk of MD at that point. Impacts at the transfer point from the conveyor belt to the roller lift (16) may be reduced or eliminated by increasing ramp size, in order to reduce the energy of the fruit arriving at the rollers.

The transfer point from the roller lift and the conveyor belt (4) at the beginning of line 2 had 33% of impacts above 50 G. The effect of the 3.5 cm height gradient was reduced with a ramp, but the thinness of the material used and leaf accumulation may interfere with impact reduction.

Points 11, 13, 17 and 18 had fewer impacts between 30 and 50 G, but still had at least 17% of impacts above 50 G (Fig. 1B). Points 11, 13 and 17 had rubber ramps to decelerate fruits. Cushioning materials absorb part of the impact energy by deformation, increasing contact surface and decreasing fruit energy (Gomila, 2007). However, hardening, wear and rupture of the material reduce these properties, therefore they have to be constantly monitored and replaced when necessary. Transfer point 18 had a 4.5 cm height gradient, which may have contributed, along with working speed, to the occurrence of high impacts.

Figure 2.

Lines 3, 4, 5 and 6 were analyzed as a group, where pre-selection and packaging were made in separate lines (Fig. 2A and 3A). The critical point of impact in three out four pre-selection lines was the transfer between the washing body or the dryer and the singulator (Fig.2B). At this point, 67% of impacts were above 30 G, and 31% were above 50 G. Maximum impact at this point was 83.02 G. The height gradients were 7, 3 and 9 cm in lines 3, 4 and 6, respectively. Simple tasks, like monitoring and replacing protection materials used as ramps, correct positioning of curtains as deceleration mechanisms may be sufficient to reduce impact at these points. Additionally, impacts between 32.65 and 86.61 G were observed inside the dryer in line 6 (data not shown). In this component, there are no height gradients and fruits move over rotating brushes, so the registered impacts occurred between the fruits and the IRD, indicating excess fruit volume and working speed in the equipment.

The packaging step components significantly differ from one line to another. Common features are discharge in water, tank, roller lift and, at the end, the packaging table and filling of trays (Fig.3A).

Figure 3.

The transfer point between the selection table and the conveyor belt (7) from two lines had 75% of impacts above 30 G, and 100% of impacts on line 6 were over 50 G, with values between 55.42 and 62.57 G (Fig.3B). This possibly occurred due to wear of the cushioning material used on the ramp to soften the 6 cm height gradient between the components. Except for transfer point 7, all others had critical impacts in only one of the four lines. Points with 100% impacts above 30 G were: (16) roller lift – dryer; (17) dryer – conveyor belt;(20) selection table – flaps. Only points 16 and 20 had all impacts above 50 G. The transfer point roller lift – dryer (16) of line 6 had the highest impact (123.29 G). The high impact values (76.68 to 123.29 G) detected at this point are due to the large height gradient between the components and lack of cushioning material on the ramp, so fruits collide directly on a rigid metal surface. Point 20 of line 3, with maximum impact between 58.01 and 103.16 G has a 9 cm gradient between the selection table and the flaps, partially attenuated by a rubber ramp, possibly with small capacity for absorbing impact energy.

The second highest impact in the packaging step (106.46 G) occurred on line 6, at the transfer point between the selection table and the conveyor belt (18), which only had 33% of values above 50 G, but presents high risk of mechanical damage, due to a 7 cm fall directly on the table of rigid rollers without any kind of protection. Transfer points 10, 15 and 19 had at least 67% of the impact values above 30 G. Point 19 of line 3 (dryer – selection table), had 80% of impacts above 50 G, with maximum impact of 99.99 G. Points 19 and 20 of line 3 used a rubber ramp to reduce the effect of the height difference. However, the material used is probably not effective enough and should be replaced by some other with greater cushioning capacity. Points 10 and 15 of line 5 had at least 60% of impacts above 50 G, with maximum values of 77.20 and 82.50 G, respectively. At point 10, the effect if the height difference between two conveyor belts was reduced with the use of a thin rubber ramp, which, however, did not prevent the occurrence of high levels of impact. Point 15, a transfer between sizer and conveyor belt, has the fruits falling on a rotating brush, although impacts against unprotected metal surfaces are possible, which would justify the measured values.

Line 7, with no water in the fruit discharge, had high impacts in four of the nine transfer points evaluated. Points 1 and 2 (receiving and conveyor belt, respectively) had all values above 50 G, with the highest impact (194.80 G) at point 2 (transfer between conveyor belts). Singulator entrance, with a height difference of 11.5 cm, had 60% of impacts above 50 G. The high impacts observed in this line are due to the inadequate fruit discharge system (Fig.4), the large height difference between the components of the line and lack of protective materials.

Figure 4.

In all lines there were high impact values on the returns, i.e. the steps leading to processing of inferior quality fruits. In these areas, there were falls without any kind of protection mechanism or deceleration of the fruit. In one point with a 6 cm fall between conveyor belts, recorded impact values were between 90.00 and 165.17 G and 16.48 and 21.25 G, corresponding to the absence or presence of a curtain, respectively.

Drop height and impact surface on the occurrence of mechanical damage to apples

The maximum acceleration values obtained from the impact of the IRD falling on a metal surface may be represented by a quadratic equation ($y = -0.1909 x^2 + 16.989 x + 72.585$), while the values corresponding to a rubber surface were best expressed by a linear equation ($y = 4.8391 x + 7.8026$). In an intermediary point of the evaluated range (15 cm), maximum impact on the rubber surface was equivalent to 28% of that observed on the metal surface, which means that the rubber absorbed 72 % of the impact energy, clearly showing its protective function (Fig.5A).

Figura 5.

Fruit evaluation indicated a 2 cm drop on a metal surface resulted in 11% of the apples with externally visible MD. The same frequency occurred in fruits submitted to a 5 cm fall, increasing to to 89% damage in fruits submitted to 8 and 15 cm fall. Drop heights from 18 cm or more resulted in 100% of fruits with externally visible damage. Apples submitted to fall on a rubber surface showed symptoms of MD only from 15 cm up, with no increase in the percentage of fruit with symptoms due to the increase in drop height (Fig.5B).

No significant effect was observed on the area and depth of MD with respect to drop height on the rubber surface, with values ranging between 0.00 and 44.58 mm^2 and 0.00 and 0.94 mm for area and depth of damage, respectively. In fruits dropped on a metal surface, there has been a gradual increase in the area and depth of the damage, reaching maximum values of 439.34 mm^2 and 7.32 mm, respectively, when released from a height of 40 cm (Fig.5C and 5D). Depending on the area, the damage to apples can be classified into three categories: light (smaller than 50 mm^2), medium (from 50 to 100 mm^2) and severe (over 100 mm^2), according to Segatori (2008).

The maximum acceleration observed in the packing lines (195 G) was equivalent, in the lab simulation experiment using the IRD, to a drop of 8 cm on a metal surface, or 39 cm on a rubber surface. In apples, the impact values obtained from an 8 cm fall on a metal surface resulted in 89% of fruits with external symptom of MD and, internally, in a damaged area of 96.29 mm^2 and depth of 2.50 mm, while a 40 cm fall on rubber (nearest height tested), resulted in 11% of fruit with external symptoms, a mean damaged area of 28.16 mm^2 and depth of 0.94 mm.

CONCLUSIONS

- Six out seven evaluated lines had high impact values between the singulator entrance and the sizer.
- The largest value observed was 194.80 G, which was equivalent to an 8 cm fall on an unprotected metallic surface.
- 'Royal Gala' apples submitted to an 8 cm fall on a metal surface suffered a damage of 96.29 mm² in area and 2.50 mm in depth, easily perceivable to touch and noticeable after skin removal.
- Measures such as discharge on water, reducing height differences between packing line components and use of decelerating elements may minimize mechanical damage and therefore reduce post-harvest losses.

ACKNOWLEDGEMENTS

The authors thank FINEP – Financiadora de Estudos e Projetos for financial support. Project INOVAMAÇÃ – INOVAÇÕES TECNOLÓGICAS PARA A MODERNIZAÇÃO DO SETOR DA MAÇÃ.

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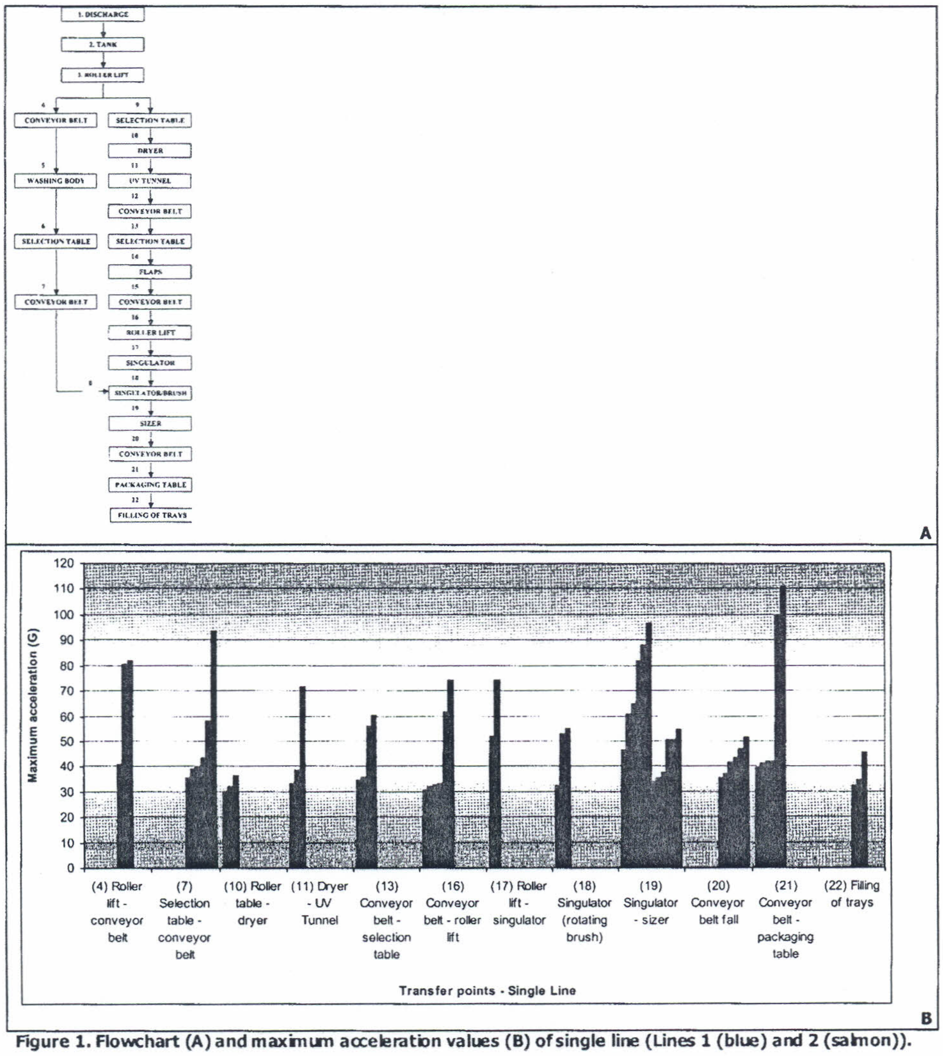

Figure 1. Flowchart (A) and maximum acceleration values (B) of single line (Lines 1 (blue) and 2 (salmon)).

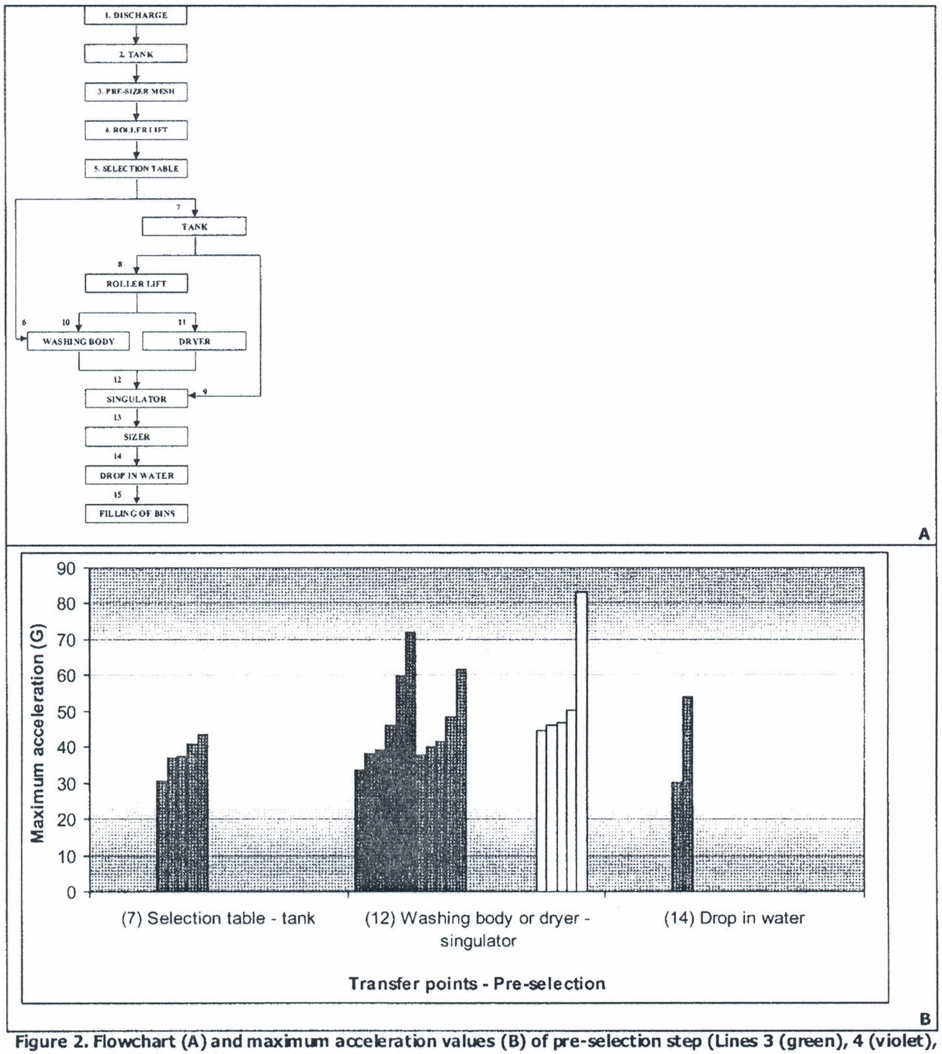

Figure 2. Flowchart (A) and maximum acceleration values (B) of pre-selection step (Lines 3 (green), 4 (violet), 5 (pink) and 6 (yellow)).

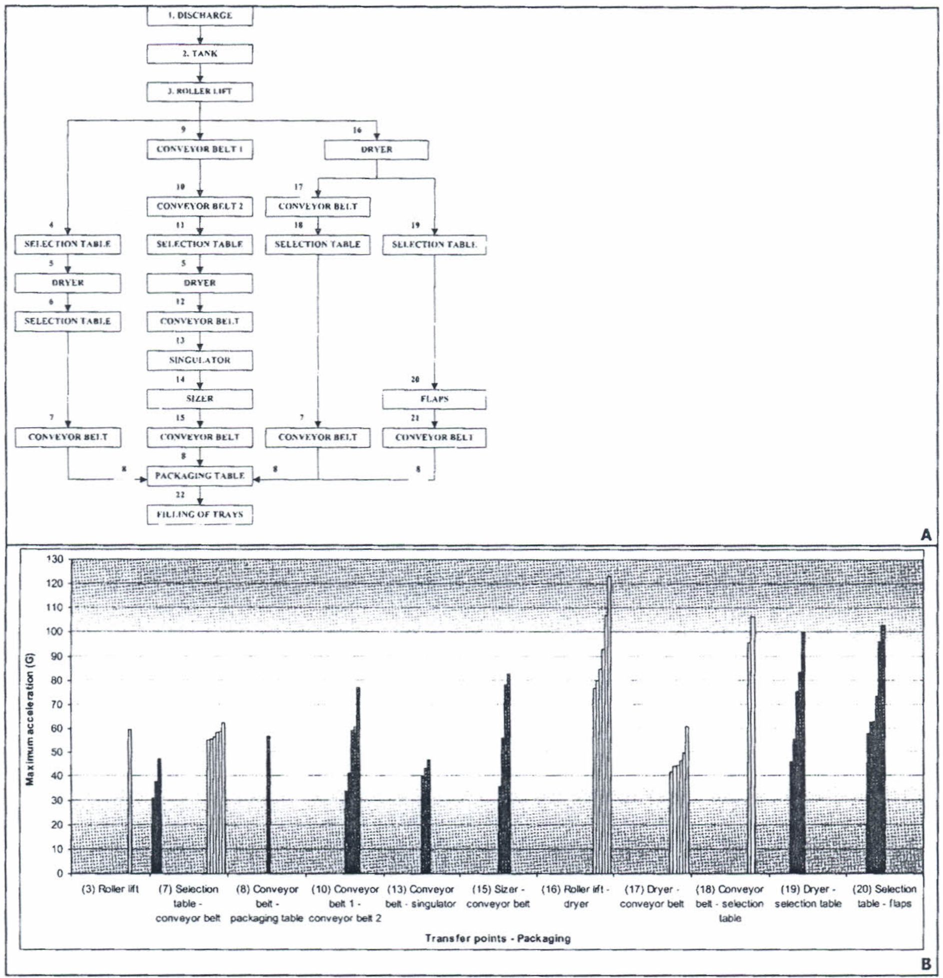

Figure 3. Flowchart (A) and maximum acceleration values (B) of packaging step (Lines 3 (green), 4 (violet), 5 (pink) and 6 (yellow)).

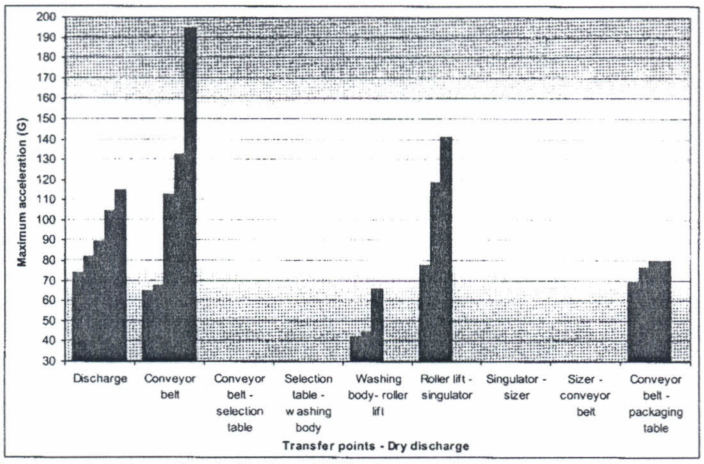

Figure 4. Maximum acceleration values in the Lines 7 (dry discharge).

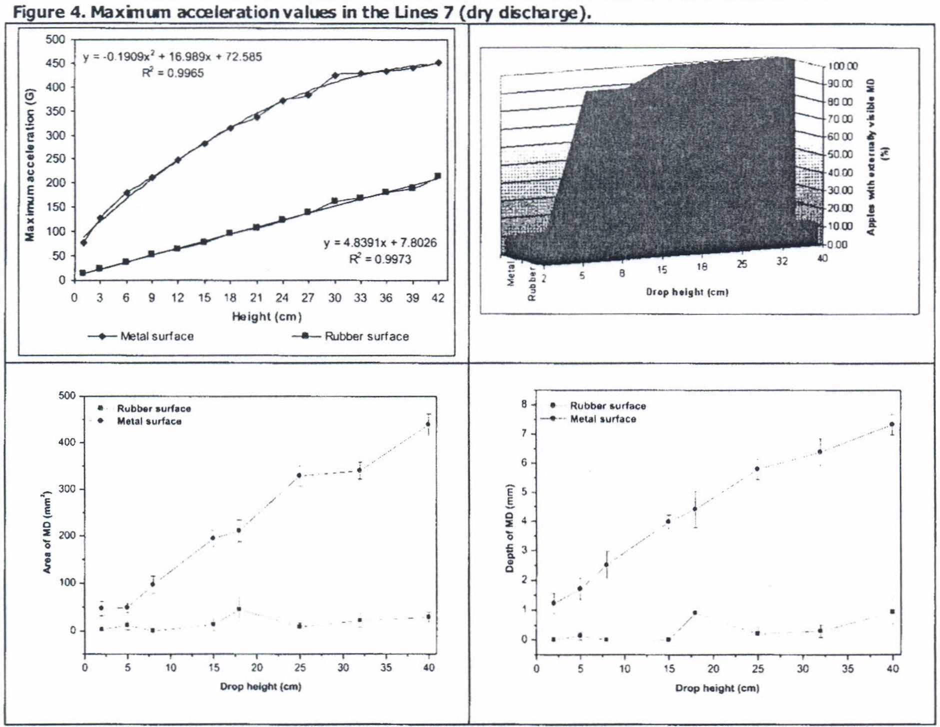

Figure 5. Maximum acceleration values from IRD (A) and occurrence of MD to apples (B: externally visible MD; C: area of MD; D: depth of MD).

Frutic Chile 2009

Proceedings of the
8th Fruit, Nut and Vegetable Production Engineering Symposium

January 5-9, 2009
Concepción, Octava Región Del Bío Bío, Chile

Published by
Progap - INIA's National Precision Agriculture Program
Avenida Vicente Méndez 515, Chillán, Chile