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Title:

Evaluation of a Non-destructive Impact Sensor On-line for Determination of Firmness of Peach and Apples

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Summary:

The purpose of the present study is the evaluation of the on-line non-destructive impact sensor to measure fruit firmness. This is an adaptation of a static one used in laboratory measurement of quality of fruit, and has been installed in an experimental fruit packing line that have a commercial sizer chain. This sensor measures the fruit firmness based on the acceleration-time curve supplied by an accelerometer attached to an impacting arm, working at a speed of 6-7 fruits per second. It was necessary to make an evaluation of the system, to study the variation sources and related aspects that can affect to the signal obtained, and also to quantify the operation of the system for the corrections or necessary modifications for their potential use in a commercial way, because the system presents a series of difficulties, as much from the technical point of view as from the physiology of the fruit, and all these hindrances have to be taken into account in the evaluation of the system. Ratios A/t (maximum acceleration value divided by its corresponding time), mean, and maximum slopes of the curves supplied by the accelerometer, were well correlated with the firmness data obtained in laboratory with the load-unload test. We have obtained for peach, a good separation for soft fruits with regard to the rest, an interesting fact for its on-line use for classification of firmness. Although for the time being, it is not possible the separation among the high levels of firmness. Variations in the results between different fruits, and different parts of the same fruit are obtained, mainly due to the non-uniformity of the shape between fruits, and the lack of ripeness homogeneity in each one.

Introduction

The increasing demand of quality fruit by the consumers is originating an advance in the development and application of sensors capable of measuring parameters of quality (sugar, acids, firmness, etc) on a non-destructive way. One of them is a non-destructive impact sensor to measure fruit firmness, developed initially by Chen and Ruiz-Altisent (Chen *et al.*, 1996). This sensor was used in static position in laboratory and, was also tested successfully on a 3 m length conveyor belt at California University, Davis (Chen *et al.*, 1998). Also a manual prototype has been developed recently (Chen *et al.*, 2000). Different authors have shown that this impact technique can be used to evaluate firmness of fruits successfully (Jarén *et al.*, 1992; García *et al.*, 1988; Chen *et al.*, 1993).

Ortiz-Cañavate *et al* (2000 and 2001) modified the “Chen and Ruiz-Altisent's” impact sensor (they modified a static one used in laboratory measurement of quality of fruit), and installed in the sizer of an experimental fruit packing line at the Polytechnic University of Madrid. This new on-line version it is necessary to be evaluated in their operation, with a metrology method, of the variation sources and related aspects that can affect to the sign obtained, and also to quantify the operation of the system for the corrections or necessary modifications for their potential use in a commercial way, because the system presents a series of difficulties, as much from the technical point of view as from the physiology of the fruit, and all these hindrances have to be taken into account in the evaluation of the system, to see the modifications and improvements that it would be necessary to develop for a better operation.

Materials and methods

In previous works the development of this sensor and the different elements has been described (Ortiz-Cañavate *et al*, 2000 and 2001), the following is a brief description of the system and its characteristics.

Basically the system is composed of three parts: impact sensor (installed at a conveyor), control software, and ejection system. The experimental fruit packing line have a variable speed commercial sized chain with plastic “diabolos”, with a separation of 9 cm between two plastic trays and three fruit outlets. It is important to describe now that the system is based on the working of the components by means of photoelectric cell and not with encoders, and that generates some problems.

The sensor impacts each fruit by means of a rotating arm with a semi spherical head in the rear of which a piezoelectric accelerometer is located. The firmness index is obtained from the *acceleration-time* (or deceleration in this case) curve supplied by the accelerometer with a specific software (F.A.S.T. 1.1), which allows the classification of the fruit in three levels of firmness, one for each exit. Simultaneously the data of the curve are recorded for later analysis in search for an appropriate index (examples: *maximum acceleration* (A_{max}), the *maximum slope*, the *mean slope*, the ratio *maximum acceleration / time* (A_{max}/t) of impact, etc).

In figure 1 it is shown the impact system and its operation: a) the optical sensor detects the fruit, then the electronic control circuit de-energizes the electromagnet which holds the impacting mass; b) a spring releases the impacting mass, and at the same time, a signal is sent to the PC to begin digitising the data supplied by the accelerometer (with a

CIO-DAS08 acquisition card); and c) after a brief period the electromagnet retracts the impacting mass and the system waits for the presence of a new fruit. Once the fruit is classified, a signal is sent to the micro controller of the ejection system.

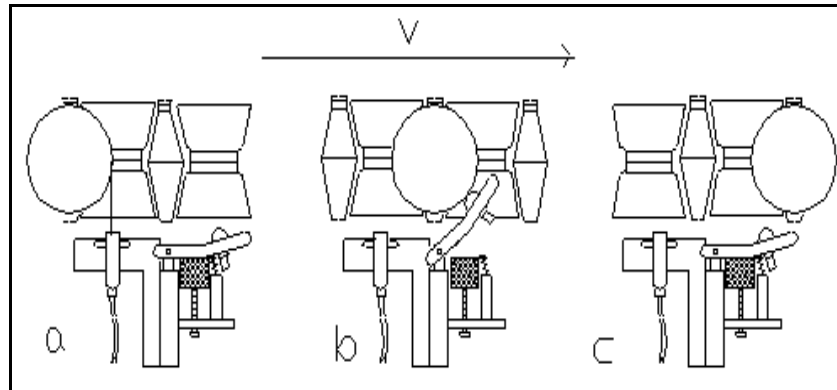


Figure 1: Phases of the operation of the impact sensor: a) detection of the fruit, b) impact and c) collection of the arm.

As it can be seen in figure 2, there are clear differences among impact curves of three materials: one hard, another intermediate, and one soft, if the maximum acceleration and the duration of the impact are compared, in this way for example the curve of a hard fruit has a maximum acceleration and an small impact duration, and on the other hand, the soft one has just the opposite. With these data obtained by the accelerometer, an index is searched that would permit classification of the impact according to the firmness of the fruit. Examples of these indexes include A_{max} , maximum slope, mean slope, ratio $A_{max}/time$, etc.

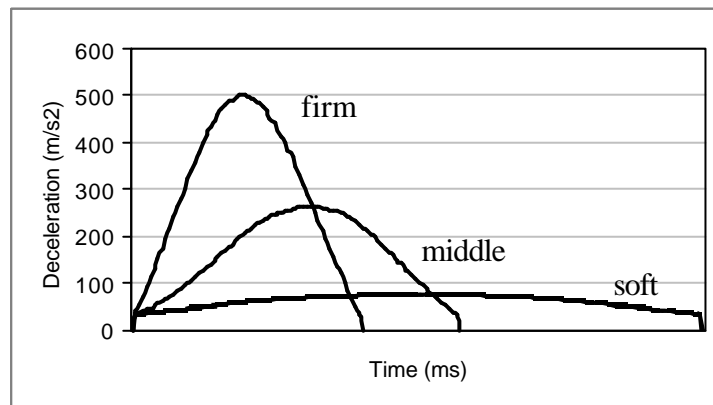


Figure 2. Representation of the different curves obtained by the accelerometer

Several preliminary tests have been carried out using different types of balls (tennis, cork and rubber balls with 100 impacts in each and velocities between 5 to 7 fruits per second and fruits in groups of 25 units at 6 fruits per second (apples (*Golden Delicious*, *Starking*), nectarines and peaches (*Gala*, *Queen Crest*, *Andros*, *Red Heaven*)), to determine the sources of variation that can affect the obtained signal: position of the photoelectric cell, effect of the position of the fruit, impact area, velocity of impact, etc. The purpose of these tests was to find the best possible measurement technique with the objective to study the sensor's characteristics and to determine the correct firmness

index for separating the fruit into different classes. (25 to 30 fruits are an appropriate size for not allowing to lapse a lot of time among the first rehearsal in the line and the last in laboratory). It should be mentioned that the great majority of tests with peaches, were made with fruit gathered directly from the field, to avoid doing tests with artificial creation of firmness ranges, like it would be to leave part of the fruit in cold, and the rest at the ambient temperature.

In parallel fruit firmness indexes have been determined in laboratory using usual methods: a) to all the fruits they were measured: the *Magness-Taylor* (MT) test and load-unload (LU) compression distance applying a force of 3 N and b) in some fruit they were measured: the same LU but with maximal forces when carrying out a compression of 2.5 mm, test of Punction with a rod of 0,5mm, and test of tube break, (with an Instron universal testing machine), and also the impact sensor in static.

Results

In first instance, before the study of the sensor properly such, the measurements of the general operation of the line were made, to determine that the systems controllers worked correctly. The *system of exit control* when working with balls or fruit, was established correctly according to the indexes predetermined in the program, leaving correctly separate the rubber balls, tennis balls and cork. The only problem of the exit control system is that the system that controls the exit, which works by means of wait-list, can cause errors if it changes the order among the impacted fruits and those who arrive to the system of control of exits. For the correct operation, it should agree the order of the impacted fruits and the order of arrival to the exits controller. But, this order it is possible to change, due to in the exit system a photoelectric cell non-detect a fruit , or that the impact sensor doesn't impact a fruit or it impacts more than one (don't detect or detect two times or one nonexistent fruit). It is possible to solve that problem by means of the encoder employment, or with the minimization of the error possibility in the detection.

Then the *sensor* was evaluated, before that, it was examined in static the effect of the impact distance, where it was appreciated the variation from the sign when varying the impact's distance to a reference ball (figure 3).

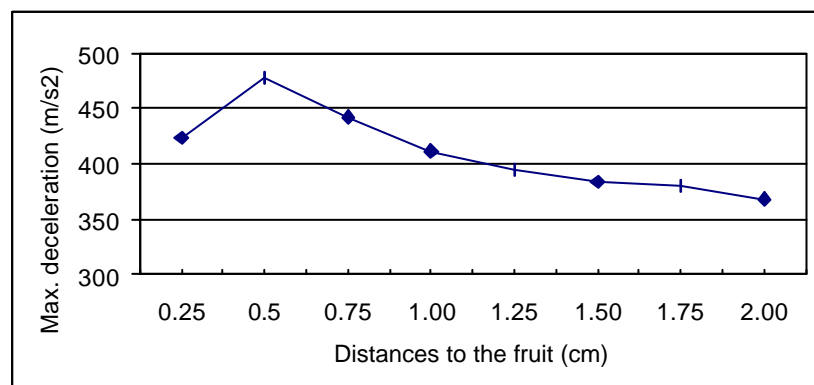


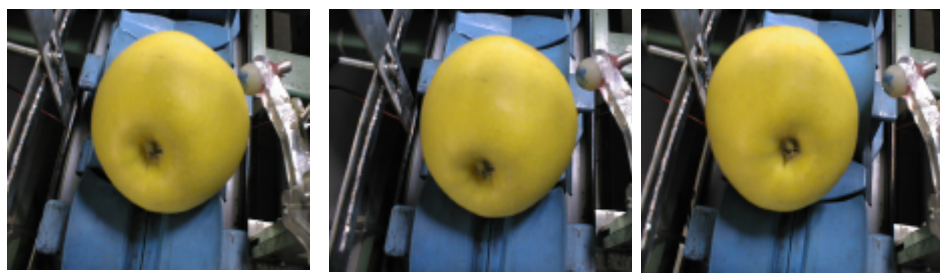
Figure 3. Deceleration variation when we change the distances to impact

When the distance is varied, the results shows that in a first moment it exists an abrupt increase of the acceleration, and then it go diminishing. The distance at about 1.5 cm is a good distance to impact, because the acceleration was not affected so much by some variations of the distance. This was possibly due to the effect of the cable, point we shall see more ahead.

When using the impact sensor statically in laboratory, it gave good results for the determination of firmness of fruits, but in the packing line, the results are more variable because the fruit and the prototype's arm are in motion. A little variation of the sensor regulations varies the impact moment, and therefore the observed values. For that reason the values obtained are very sensitive to variations in the fruit's shape, impact angle, and curvature radius of the fruit. These variations would imply an advance or retrocession in the detection of the fruit by the photoelectric cell (that would advance or set back the impact) varying accordingly the place where the fruit is impacted.

As the accelerometer is connected to the control box by means of a continuous cable, every time that the arm is working, this cable has a twist, affecting the signal according to the length of the cable in the twist area. Multiple impacts could also affect the resistance of the cable, and therefore, of the signal (because it transmits in low voltage, 10 mV/g).

In line, it is necessary to adjusted the arm to carries out a distance of approximately 15 mm (as it has been seen in figure 3), although it has been made a calibration of the sensor with a average fruit at this distance, but not all the fruits will be in the same distance and not all will be located correctly where they should be. Figure 4 shows an example of positioning of the fruit (where although it is gauged in a correct position, the fruit won't always go by that position). The test has been made when the same fruit passes in the same orientation, but in three different positions on the tray with regard to the impact sensor; there were: displaced toward inside, centred (correct position and sensor calibration position) and displaced toward out.



	Average	Desv. Std.	Average	Desv. Std.	Average	Desv. Std.
A_{\max} (m/s ²)	1300.58	16.48	929.41	50.55	713.90	116.35
T.to impact (ms)	59.69	4.26	67.62	2.72	79.87	9.95

Figure 4 Effect from the distance to impact, average for 10 impacts in the same fruit in three positions, very near the impact sensor, centred and very far from the sensor (note: T.to impact it is the impact arm swinging time until the beginning of the contact with the fruit)

Graphically it can be seen in figure 5, where the curve is smoothed in higher values of acceleration (over 1000 m/s²) due to the saturation of the accelerometer signal. For that reason, there is a small Desv. std in the impacts of 1300 m/s² in figure 4. Under normal

conditions, the variations of the impactor swinging time, T , can go from 2 to 20 ms when compared three impacts at each fruit. This is caused by the decrease measured in static, as well as now in dynamic, in that the impact arm as the fruit is in movement and when changing the time that happens, it changes the impacted zone.

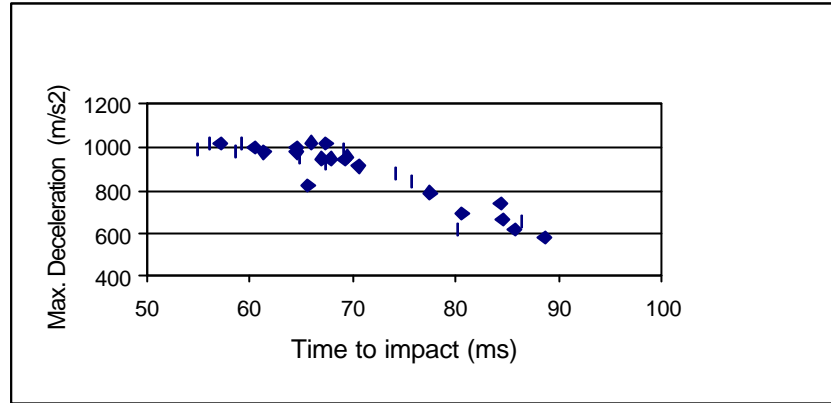


Figure 5: Graph of the variations of acceleration with regard to the time for impact

Similar situation happens when the fruit is in different orientations, although there is also variation of the firmness in different parts of the fruit.

It was found that one of the most important parameters that affect the signal of the sensor, was the impact arm swing time (the time lapse between the moment of the arm begins to move and the moment of the initial contact with the fruit). When comparing this time with the data of the three repetitions, it is usually associated to the lowest accelerations a longer time to impact and for the opposite, the highest acceleration is usually associated to shorter times. This variation is usually associated to the orientation of the fruit, positioning of the fruit on the tray, etc. Because the trays are of a standard type, the fruit is not located every time at a similar distance from the impact.

We should remember that the test was made on a conveyor that consists of a chain, commonly used in commercial packing lines, on which the sensor has been mounted. In order to correct this problem of varying fruit position, some modifications, such as using a guide or redesigning the trays, should be made so that the fruit surface will always locate at the same position on the tray at the time of impact.

Tests carried out with apples and peaches, had given good results when fruits of regular form and similar size were tested, and the results improved when the firmness range of the fruits was broader.

When being presented a wide range of firmness, a curve is obtained as the example of figure 6, where the graph relationship maximum MT Forces with maximum acceleration (means valued of three impacts at each one) of the sensor impact in peaches (in this case *Queencrest*), being observed a good discrimination in low ranges of firmness, but a flat tendency in firm fruits, hindering fruit separations in ranges of 20 and 40 N like we want to be carried out in this graph. There is a good separation of soft fruit and the others (firm), in this cases there is 95% of the fruit was well classified (43 good and 2 bad).

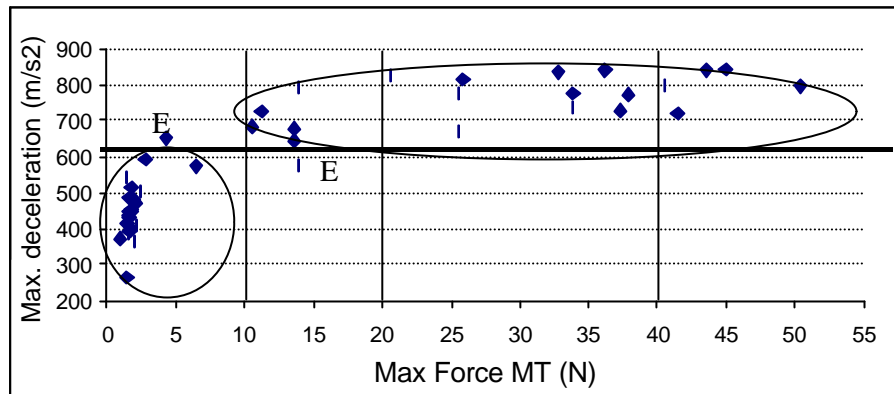


Figure 6 Example test with 45 Queencrest peaches.

The vertical lines are theoretical separations at 10, 20 and 40N (the separations are pre-established by commercial approaches, not are natural separations of the sample), and the thick horizontal line it be the elected value of acceleration to separate two groups, under and over 10 N. Circumferences are correct separations in the two groups, and “E” classification errors

It is also observed that in the case of fruit with similar firmness, between 20-40 N for example, the correlations diminish, and it is not possible a good separation of the fruits.

At a speed of 5 to 7 fruits per second the relationship variables: *ratio A/t* (maximum acceleration value divided by its corresponding time), *mean* and *maximum slopes* of the curves supplied by the accelerometer, were the best correlated with the firmness data obtained in laboratory with the *load-unload* test. Due mostly to that the impact and LU are superficial measurement in the fruit.

At the following table there are appraised some of the data that have been obtained.

Summary of some obtained results

Fruit	MT range (N)	Better correlations (R) between impact and laboratory parameters	Separation in two groups Well/bad classified	Firmness of separation
Nectarinas	0.75-33.43	0.88	23/1	10N
Nectarinas	0.89-33.0	0.74	20/4	10N
Peaches	1.92-38.62	0.9	17/1	10N
Peaches	1.71-42	0.92	22/2	10N
Peaches	1.97-34.54	0.9	22/2	10N
Peaches	1.65-54.11		22/1	10N
Peaches	6.44-45.33	0.82	18/4	10N
Peaches	6.65-41.40	0.79	22/0	10N
Peaches	7.0-49.41	0.75	19/4	10N
Peaches	1.0-46	0.85	43/2	10N
Apples starking	9.5-30.5	0.55	24/3	20N
Apples starking	10-25	0.64	23/7	17N
Apples starking	11.08-29.14	0.63	26/3	17N

It has not been observed damages in fruits after the impact of the sensor, and also it has not been observed that there was influence in the presence or absence of "fluff" in peaches. What would not be quantified is the effect of accumulation of wax in the head from the sensor when impacting fruit after the wax, but in the event of accumulating the wax in the head, there should go affecting progressively to the obtained answer

Conclusions

- We have obtained for peaches, a good separation for soft fruits with regard to the rest, an interesting fact for its on-line use for classification of firmness.
- The variations in the impact arm swinging time, affect the performance of the sensor and we should continue working to minimizing this variation.
- Variations in the results between different fruits, and different parts of the same fruit are obtained, mainly due to the non-uniformity of the shape between fruits, and the lack of ripeness homogeneity in each one, because: a) Variability of force/deformation properties in different areas of the same fruit, b) Variability in the lateral position of fruits, which affects the distance of impact. c) or variations in the time of provoked impact, for detection differed on the part of the photoelectric cell, or for the effect of the twist of the cable.
- It is necessary to find a method to position the fruit well, at the detect moment and to eliminate the twist of the cable. Possibly by means of encoders and ceramic badges at the two last respectively

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Evaluation of a Non-destructive Impact Sensor On-line for Determination of Firmness of Peach and Apples

(02-PH-026)

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Purpose

The purpose of this research was the evaluation of the on-line prototype of a non-destructive impact sensor to measure fruit firmness, which has been installed in an experimental fruit packing line working at a speed of 7 fruits per second, described at previously papers (Ortiz-Cañavate *et al*, 2000 and 2001). This is an adaptation of a static sensor used in laboratory measurement of quality of fruit. This impact sensor measures the fruit firmness based on the acceleration-time curve supplied by an accelerometer attached to an impacting arm. The system presents a series of difficulties, as much from the technical point of view as from the physiology of the fruit, and all these hindrances have to be taken into account in the evaluation of the system.

Method

After adapting the non-destructive impact sensor into a packing line, several tests have been carried out using different types of balls and fruits (mainly apples and peaches) to determine the sources of variation that can affect the obtained signal and the search for appropriate firmness indexes. During the tests, several parameters were changed: position of the photoelectric cell, effect of the position of the fruit, impact area, work velocity, etc, to achieve the best possible measurements and calibration. In parallel, the fruit firmness indexes have been determined in laboratory using traditional methods (Magness-Taylor (MT), load-unload (LU) with a compression of 2,5 mm and also applying a force of 3 N).

Figure 1 shows the impact system and its operation.

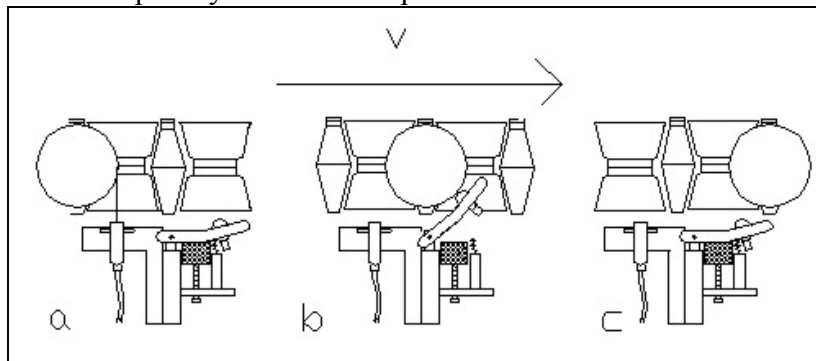


Figure 1: Phases of the operation of the impact sensor: a) detection of the fruit, b) impact and c) collection of the arm.

Results and conclusions

Variations in the results between different fruits, and different parts of the same fruit are obtained, mainly due to the non-uniformity of the shape between fruits, and the lack of ripeness homogeneity in each one:

- 1.- Variability of force/deformation properties in different areas of the same fruit, and
- 2.- Variability in the lateral position of fruits, which affects the distance of impact.

This last point is one of the most important parameters that affect the answer of the sensor; because, a commercial conveyor is used, and the fruit is not located every time at similar distance of the impact sensor, problem could be solved by means of some changes in the line.

The following graph (figure 2), shows a relationship of MT max. forces with maximum acceleration of the impact sensor in *Queencrest* peaches (mean value of three impacts at each one). As can be seen, a good separation of firmness for soft fruit is achieved. with 95% and the fruit was well classified at two groups (43 good and 2 bad).

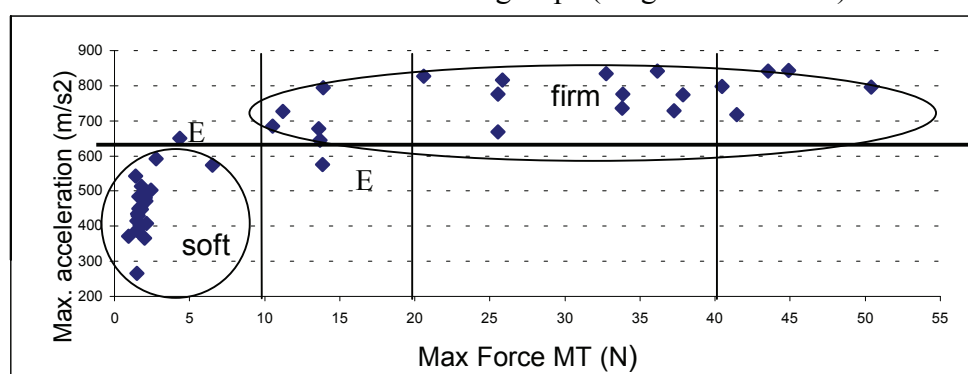


Figure 2.) Example test with 45 *Queencrest* peaches.

The vertical lines are theoretical separations at 10, 20 and 40N, and the thick horizontal line is the elected value of acceleration to separate two groups, under and over 10 N. Circumferences are correct separations in the two groups “soft and firm”. "E "are classification errors.

It is also observed that in the case of fruit with similar firmness, between 20-40 N for example, the correlations diminish, and it is not possible a good separation of the fruits. At the following table there are appraised some of the data that have been obtained.

Summary of the best results			
	<i>Firmness range MT (N)</i>	<i>Correlation R</i>	<i>Good classified at two groups %</i>
<i>Nectarines</i>	0.9-33	0.84	90
<i>Peaches</i>	2-45	0.90	92
<i>Apples</i>	10-30	0.60	75

Note: Complete information of all the results and justifications, in the paper

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