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ONLINE NON-DESTRUCTIVE AVOCADO FIRMNESS ASSESSMENT BASED ON LOW-MASS IMPACT TECHNIQUE

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SUMMARY

An online system to sort fruit according to its firmness was evaluated for avocado ("Hass" cultivar). The system was produced by Sinclair International (SIQ-FT) based on measuring non-destructively fruits' firmness using low-mass impact method. Sensory panel, parallel-plate compression, 8 mm fruit-pressure plunger and cone penetration tests followed the online non-destructive tests, testing at 5 fruit/second. The correlation between the SIQ-FT and the sensory panel and modulus of elasticity were high (R=0.866 and R=0.902 respectively). The findings demonstrated the potential of the SIQ-FT system to assess avocado quality non-destructively.

Key Words: Non-destructive, impact, Hass, firmness, avocado, quality.

INTRODUCTION

Fruits and vegetables in today's modern market must have high quality standards. Fruit texture and firmness are qualitative terms to describe internal fruit quality. Hence, fast sorting of each individual fruit and vegetable according to firmness is very important. Dynamic excitation is an acceptable method in the determination of mechanical properties for quality evaluation of fresh products. The rapid technology development opened new possibilities for non-destructive dynamic testing of agricultural products. Low-mass impact techniques sense the objects response by measuring the input signal, their analysis is simple and fast for determining local fruit properties.

The low-mass impact technique commonly used by tapping and sensing the fruit with a medium or small mass impact device. Delwiche and Sarig (1991) developed a firmness sensor of 63 g to impact the fruit. The acceleration of the mass gave a measure of the impact force, which produces the impact parameters C_1 and C_2. The first impact index was defined as $C_1 = F_p / T_p$ and the second $C_2 = F_p/T_p^2$, where F_p is the maximum force and T_p is the time from the beginning of impact until its maximum. Results indicated that these firmness indexes were sensitive to measure fruits on a wide firmness range, it was proven to be appropriate index for some fruit types. These parameters were normalized by the dropping height - h. The correlation obtained between the index C_2/h and standard compression tests were higher for peaches (R = 0.80), lower for pears (R = 0.68) and very low for Red Delicious apples (R = 0.53). Similar results were obtained by Ruiz-Altisent et al. (1993) using the index C_2 for pears, avocados and apples. Chen and Tjan (1996, 1998) introduced a new mechanical system for low-mass impact based on a swing-arm sensor. They reported good performance of the system when testing rubber balls, kiwifruit and peaches. Preliminary tests showed that the sensor could sense fruit firmness at a speed of 5 fruits / s. Ortiz-Canavate et al. (2001) adapted a modified version of the low-mass impact method for an experimental fruit packing line with an operation speed of 5 to 7 fruits / s. Golden Delicious apples and several peach varieties were tested dynamically by the system and by destructive compression and MT penetration tests. The correlation coefficients between the impact parameter C_1, when compared with force/deformation slope and MT penetration force, was quite high in peaches (0.93 and 0.87, respectively) but much lower in Golden Delicious apples (0.74 and 0.43, respectively). The authors reported that values obtained by the impact tests were very sensitive to variations in fruit form, impact location and angle. This work was repeated and extended by Homer et al. (2002) with similar results. Medium to high correlation coefficients were obtained between the impact parameters F_p, C_1, etc. and the destructive tests of nectarines and peaches; much lower correlation coefficients of 0.55 to 0.64 were obtained for Starking Delicious apples. It was observed that better performance was achieved for softer fruits. The studies reported a series of difficulties associated with the swing-arm sensor and its high sensitivity to variations in fruit position and their orientation in the conveying system.

According to the cited literature the impact techniques have given good results in the firmness evaluation of peaches, pears, apples and some tropical fruits. As mentioned by various authors, local variations in texture around the surface of fruit limit the accuracy of firmness prediction by impact testing. This is an inherent disadvantage of the method since the impact force is naturally a measure of local properties in the impact zone, rather than overall properties of the intact fruit. The research developing a low mass impact tester has been brought recently to online firmness sorting systems.

Greefa Ltd. introduced an on-line non-destructive firmness detection system (Armstrong, 2001). The so-called intelligent Firmness Detector (iFD) is placed on a singulator. Firmness measurements are done via a sensor that travels with the fruit as it rotates on a singulator. According to Armstrong (2001), there are 30 sensors along each line. The sensors go round in a loop above the fruit. One sensor will drop down and attach itself to a fruit moving at the same speed as the belt speed while it takes its readings. During the sorting process, a firmness sensor takes 9 to 20 measurements around the fruit. The system currently operates at speeds of 5-7 fruit / s depending on the fruit. According to the company the patented firmness detection system has been successfully applied in practice, for apples, avocados, mangoes, peaches and kiwifruit. Unfortunately, no quantitative data that compares the online systems performance to destructive or sensory tests are yet reported. Sinclair International Ltd. has developed the Sinclair IQ™ – Firmness Tester (SIQ-FT) that is based on a low-mass impact sensor (Howarth 2002). This online system measures firmness using a sensing element on the tip of a bellow. SIQ-FT takes advantage of Sinclair's patented bellows delivery system, which is also used in fruit labelling and can be simply adapted to existing sorting lines. Medium to high correlation coefficients were obtained with penetration tests for nectarines (0.85 to 0.95), plums (0.80), avocados (0.81 to 0.84) and kiwifruit (0.83 to 0.92). The SIQ-FT online system currently operates at speeds up to 10 fruit per second and makes four independent measurements on 4 different quadrants around the fruit surface that are combined to estimate the fruit firmness. The motivation of the current work was to evaluate the performance of the online SIQ-FT system to correlate to sensory judgment of firmness as well as to mechanical destructive method used presently by researchers and industry.

METHOD AND MATERIALS

The experiment included 175 avocados ("Hass" cultivar) with a wide firmness range including a significant amount of 'hard' which were collected from a local avocado supplier. The fruits origin was Spain. All of the avocados were of approximately the same size (22), the mass ranged from 157 to 220 g (Average 186 g Standard Deviation 13 g). During the tests the fruit were kept in laboratory conditions of about 20^{0}C and 50% relative humidity.

The experimental set-up included online non-destructive systems designed to detect firmness by measuring the fruit response by a low-mass impact. The system included:

Four Sinclair IQ™ Firmness Tester (SIQ-FT) units mounted in series on a one lane sorting system by Compac™ is the online firmness sorting system (Fig. 1). The SIQ-FT is based on a sensing element placed inside the tip of Sinclair's bellow expander, which measures the impact response of the fruit (Howarth 2002). The fruits are rotated anti-clockwise by the carrier system and completed approximately a 3/4 turn while passing under the SIQ-FT. A special data acquisition and signal analysis program (by Sinclair) was employed to determine the IQ (Shmulevich et al. 2003). The air pressure set-up of the machine was 15 cm H_2O and the sensor height above the fruit was 15 to 35 mm for most fruits, depending on fruit size. The fruits were tested three times with the SIQ-FT system before and after the sensory panel test at a rate of 5 fruits / s to assess how the system compared to the sensory panel.

Prior to the test a panel of three staff were chosen. The panel attended an informal training session in which they were introduced to the score sheet, testing procedure and were given reference samples to squeeze. An avocado receiving an IQ score of 10 or less was soft - 'not firm', and an avocado receiving an IQ score of 70 or more was 'very firm'.

In addition, a TA.XT Plus Texture Analyser-Universal Testing Machine performed parallel plates compression test in order to determine the apparent elastic modulus (E) of the fruits according to the ASAE 368.3 standard. The maximum displacement was 5 mm. The test was conducted at a constant head velocity of 50 mm/min. Only one compression test was carried out on each fruit. Measurements of the radii of curvature were taken near the loading points.

The strength of the fruit tissue was determined by three destructive means: a 60^{0} conical indenter plunger, with a maximum diameter of 6.35 mm, was used to penetrate through the flesh, 10 mm into the tissue, the maximum force was recorded. Two penetrations on 2 different sides of the fruit were performed. An 8 mm diameter cylindrical fruit-pressure plunger, usually used in industry, was used after peeling the fruit skin, to penetrate 8 mm into the fruit. Two penetrations close to the cone penetrations location were performed by using the loading machine (MT) as well as 4 penetrations around the fruit by hand penetrometer using a drill stand. (Pen).

RESULTS AND DISCUSSION

A typical signal for various firmness fruits is given in Fig. 2. The firm avocado will give a higher peak amplitude and lower time duration comparing to the less firm fruit. It was thought that during squeezing by panellists, the avocados would be softened. The IQ value of the avocados before and after squeezing were compared using a paired t-test. There was no significant difference between the groups at 95% confidence and the means differed by 1 IQ unit.

In general, PCA (Principal component analysis) between all the measurement techniques show that all techniques measured a similar attribute of firmness, with slight differences between elastic properties and yield properties. The data obtained from the SIQ-FT non-destructive system was correlated to the destructive methods using Pearson linear correlation. The results presented in Table 1 and the values are significant at the 0.05 level. Very high correlation was observed between the two destructive methods E and MT (R=0.935). The impact method correlates highly to the destructive elasticity modulus, sensory panellists and cone penetration (R=0.902, 0.866 and 0.828 respectively) than to the MT (R=0.666). The relationship between the SIQ-FT and the destructive tests is not linear and changes during the ripening process as demonstrated in Figures 3 and 4. Better relationships can be found between the modulus of elasticity, the sensory panel and SIQ-FT Firmness tests.

CONCLUSIONS

The general conclusions can be drawn from the study as following**:**

- In this study, the SIQ-FT correlated strongly to elastic modulus and a sensory panels judgement of firmness.
- Poor correlation found between SIQ-FT and the 8 mm diameter fruit-pressure plunger com monly use in industry, which is a yield texture measurement.
- The SIQ-FT relationship to panel judged external firmness shows that SIQ-FT can be used as efficiently as sorting avocados by hand in a pack-house environment.
- There is further need to investigate the higher end of the IQ scale for avocados investigate the high scattering of data in this region.
- Invetsigating different avocado varieties and grading fruit at a faster rate is recommended.

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Table 1: Pearson linear correlation between the destructive and non-destructive tested avocadoes

	MT	Cone	E	Pen	Panel	IQ
MT	1	0.935	0.809	0.854	0.591	0.666
Cone		1	0.918	0.920	0.724	0.828
E			1	0.886	0.801	0.902
Pen				1	0.703	0.785
Panel					1	0.866
IQ						1

Figure 1: The online SIQ-FT sorting firmness system.

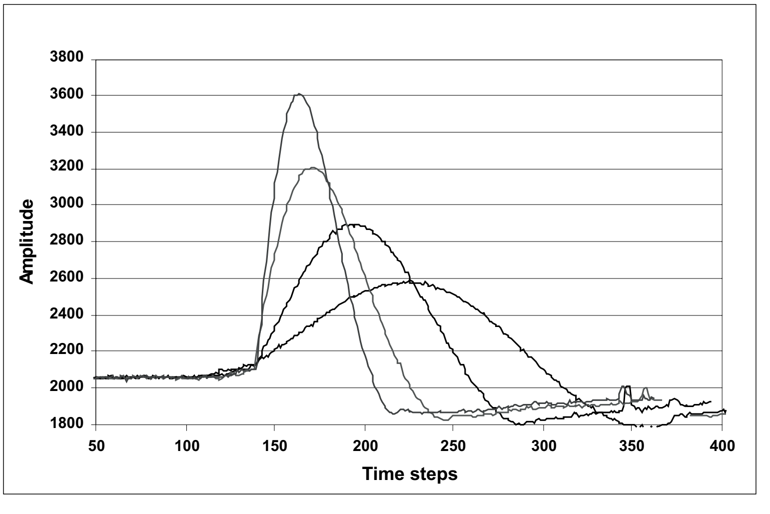

Figure 2: Typical signal from the SIQ-FT device.

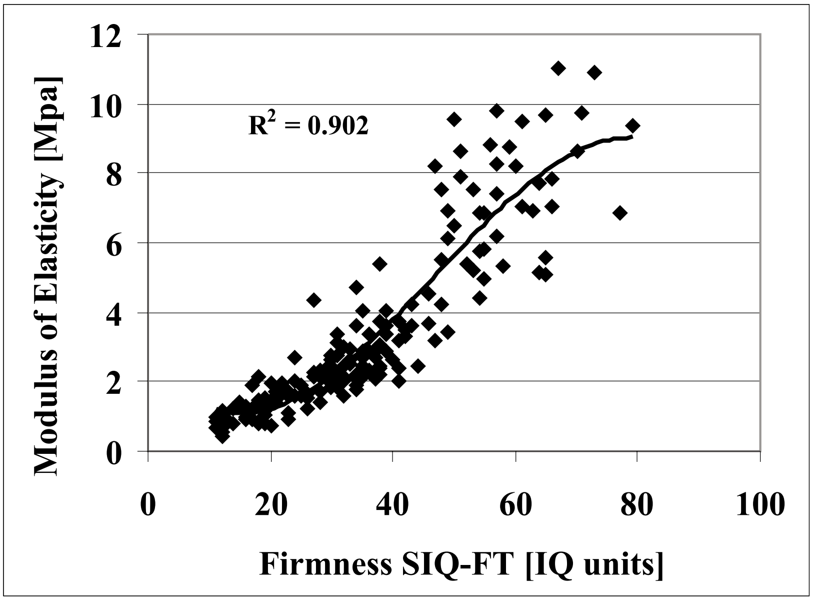

Figure 3: Online firmness measurements by SIQ-FT system vs. Modulus of Elasticity from Parallel Plate tests for 175 "Hass" Avocados.

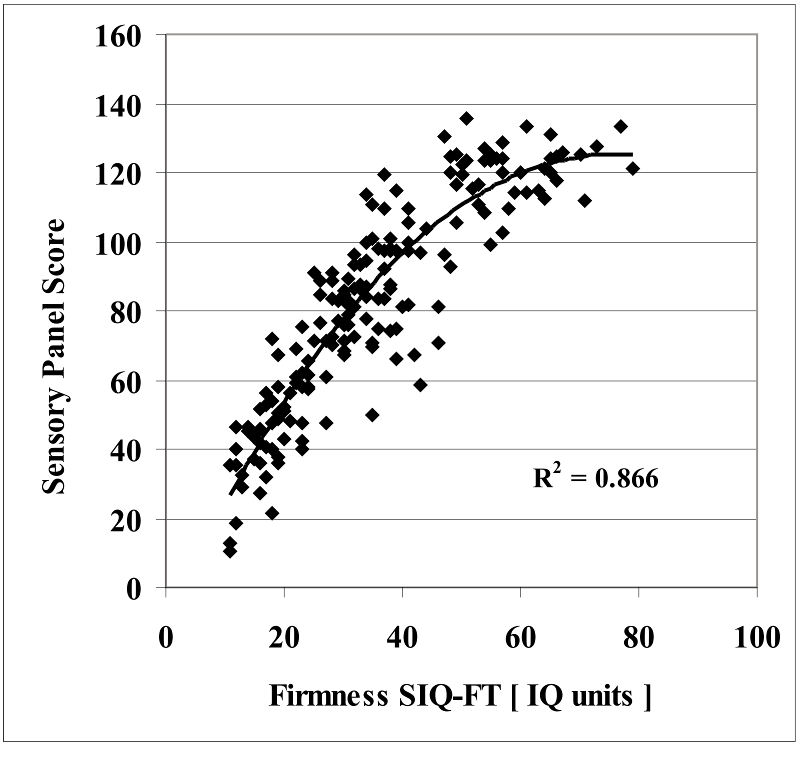

Figure 4: Online firmness measurements by SIQ-FT system vs. Sensory panel for 175 "Hass" Avocados.