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Non-destructive assessment of mango firmness and ripeness using a robotic gripper

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ABSTRACT

The objective of the study was to evaluate the use of a robot gripper in the assessment of mango (cv. “Osteen”) firmness as well as to establish relationships between the non-destructive robot gripper measurements with embedded accelerometers in the fingers and the ripeness of mango fruit. Intact mango fruit was handled and manipulated by the robot gripper and the major physicochemical properties related with their ripening index were analysed. Partial least square regression models (PLS) were developed to explain these properties according to the variables extracted from the accelerometer signals. Correlation coefficients of 0.925, 0.892, 0.893 and 0.937 were obtained for the prediction of firmness, total soluble solids, flesh luminosity and the ripening index, respectively. This research showed that it is possible to assess mango firmness and ripeness during handling with a robot gripper.

Keywords: robot gripper, non-destructive, firmness, ripening index, mango

1. INTRODUCTION

Mango (*Mangifera indica L.*) is a tropical fruit with high added-value and among the most widely cultivated and consumed fruit in tropical regions. It is the fifth fruit in global consumption and third among tropical fruits, immediately behind banana and pineapple. It has been cultivated in India for more than 4000 years, but the increasing demand has stimulated production of mango and nowadays is being grown in more than 80 countries. The major producers of mango in terms of volume are India, China and Thailand (FAOSTAT, 2014). In Spain, cultivation of mango is centered in two regions, Andalucía and the Islas Canarias. Due to its good climatic adaptation, the absence of pests and the increment in inside market, Málaga region (Andalucía) has shown a significant increase during last years. Therefore, all future predictions point to an increase in the expansion of the mango market, thus extending their growing areas, productions and markets.

Mangoes are climacteric fruits, and their ripening process takes place rapidly during post-harvest time after being picked. During the ripening process, several physiological and biochemical pathways are activated simultaneously bringing changes in the fruit (Bouzayen et al., 2010), which are initiated by autocatalytic production of ethylene and increase in respiration. The changes observed generally include textural softening (Yashoda et al., 2007; Jha *et al.*, 2010), changes in colour due to the disappearance of chlorophyll and appearance of other pigments as carotenoids (Gouado et al., 2007; Zaharah et al., 2012; Rungpichayapichet et al., 2015), loss of organics acids, increase of soluble solid content, decrease of tritatable acidity and in general changes in taste, aroma and flavour (Singh et al., 2013). Accurate determination of fruit ripening stage is important to determine the packing procedure in the postharvest handling (Hahn, 2004) and to provide a consistent supply of good quality fruit (Saranwong et al., 2004). The measurement of total soluble solids, starch content, acidity, or firmness, are used as maturity index, but not always these parameters are correlated with optimal fruit quality. Among these parameters, firmness has been considered a reliable indicator of mango maturity at harvest and ripeness stages during commercial mango handling, as well as an important tool for growers, importers, retailers and consumers (Padda et al., 2011). Firmness can be measured manually by a trained person with a hand held penetrometer but this technique shows many disadvantages in terms of poor repeatability, subjectivity and is limited at certain stages of maturity (Peacock et al., 1986). The use of automated penetrometers is another alternative to measure the firmness of mango fruit but shows the disadvantage that is a destructive method which can be applied only to one sample of a fruit batch. The development of a reliable non-destructive method to assess the mango ripeness at the packing site is critical to the success of the mango industry.

Mango fruit primary packaging operations are usually done by hand. Human manipulation is able of handling mangoes with care at high speed and, at the same time, sorting the mangoes by certain quality attributes. This manual operation could spread foodborne diseases and operators can suffer musculoskeletal disorders for repetitive movements. In the automation of primary packaging lines in food industry, robotics has clear opportunities (Wilson, 2010). To achieve the objective, robot grippers need to improve their ability for handling irregular and sensitive products like mango fruit, and incorporate tactile sensing. Different solutions regarding the development of robot grippers for handling fruits and vegetables have been proposed by Blanes *et al.*, 2011. In this study, gripper finger should be adapted to the product for achieving an adequate manipulation by means of the actuation on the gripper mechanisms (Meijneke *et al.*, 2011). Some developments related to the use of this technology can be found in industrial applications (Lacquey, www.lacquey.nl). Jamming grippers have a tremendous potential in robotics (Jaeger *et al.*, 2014). By using the jamming of granular material it is possible to adapt product shapes and, at the same time, manipulate irregular products (Brown *et al.*, 2010). Despite of the developments made in the tactile sensors for robotic applications, the entry in the industrial automation is extremely low especially due to the lack of reliable and simple solutions (Girao *et al.*, 2013). Some developments can be found for vegetable grading using tactile sensing in robot grippers. Naghdy and Esmaili, 1996 use the measurement of the current of the gripper actuator. Bandyopadhyaya et al., 2014 employ piezoresistive force sensors, and Blanes et al., 2015 use accelerometers attached to the gripper fingers.

The aim of this paper is to evaluate the use of a robot gripper in the assessment of firmness of mango fruit, cv. “Osteen” and to establish relationships between the non-destructive robot gripper measurements with embedded accelerometers in the fingers and the ripening index of mango fruit.

2. MATERIALS AND METHODS

2.1. Experimental procedure

A batch of 350 Mangoes (*Mangifera indica L.*, cv 'Osteen') manually harvested in Malaga (Spain) were selected showing uniform size and color and free of external blemishes or infections.

All mangoes were washed with a soap solution prepared with two drops of dishwasher with water and dried with disposable paper to completely remove water from the surface. Mangoes were individually numbered and randomly divided into 7 sets of fifty mangoes (A, B, C, D, E, F and G). All sets were stored during one day in a cold chamber (11.9 ± 0.4 ºC and 84.3 ± 1.7% RH) until gripper tests started. Thus, fruits of set A were analysed one day after reception and the remaining groups were placed in the storage chamber at 18.0 ± 2.1 ºC and 67.6 ± 3.3% RH. Every 2 days, the next set was removed from the storage chamber and fruits were analysed. From each set, all the mangoes were handled by the robotic gripper. Twenty fruits were used to evaluate the mechanical properties, the internal composition (°brix, pH and titratable acidity) and the flesh colour, and the other thirty fruits were used to evaluate the damage caused by the robotic gripper. These fruits were maintained in the storage chamber during two weeks after handling in order to detect fruit bruises.

2.2. Robotic gripper

Based on the experiences and results of previous tests (Blanes et al., 2014), a specific robot gripper was designed and manufactured for handling and the assessment of mangoes (figure 1). The gripper has parallel action and is actuated by one pneumatic cylinder. It has three fingers (A, B and C) and one suction cup located between the fingers B and C. To ensure the manipulation of mango fruits without damaging, the fingers of the robotic gripper adapt to the irregular shapes of the mangoes. The adaptability of the fingers B and C was achieved by means of their three free rotations while the adaptability of finger A is based on the use of jamming transition of its internal granular fluid. The pad of finger A is a latex membrane filled with sesame seeds. This pad is soft when its internal pressure is atmospheric or slightly positive because the sesame seeds are loose and the friction forces between them are low. On the other hand, the pad is hard when its internal pressure is negative and the sesame seeds are in contact and for hence there are friction forces between them. Every finger has at its rear side an analog accelerometer ADXL278 connected to a data acquisition USB NI-6210 device. The gripper is attached to an ABB IRB 340 FlexPicker robot. The gripper open-close operation is controlled by an electro-valve, the suction cup by a vacuum generator electrically piloted and the state soft or hard of the pad of finger A with another vacuum generator electrically piloted with blow action function. A robot program controls the gripper movements and all its devices for the good performance of the gripper.

2.3. Physicochemical analysis

In order to assess the firmness and ripeness of mango fruits, mechanical properties, internal composition, and flesh color of mangoes were analyzed. All of these analyses were performed immediately after robotic gripper measurements. A total of 140 samples were evaluated (20 fruits per set).

The mechanical properties were analyzed through a puncture test by using a universal test machine (TextureAnalyser-XT2, Stable MicroSystems (SMS) Haslemere, England). The test was performed with a punch of 6mm diameter (P/15ANAMEsignature) to a relative deformation of 30%, at a speed of 1 mm/s by triplicate. Sample dimensions were measured with calipers before the analysis and force-true stress data were estimated from the force-distance data (Dobraszczyk & Vincent, 1999). The fracture strength (F), the deformation in the fracture point (D_F), and the slope of the linear range until the fracture point, were characterized for the samples.

The internal composition was analyzed through the total soluble solids (TSS), pH and the titratable acidity (TA) of the samples. TSS content was determined by refractometry (°Brix) with a digital refractometer (set RFM330+, VWR International Eurolab S.L Barcelona, Spain) at 20°C and with a sensitivity of ±0.1 ºBrix. The analysis of TA were performed with an automatic titrator (CRISON, pH-burette 24, Barcelona, Spain) with 0.5N NaOH until a pH of 8.1 (UNE34211:1981) using 15g of crushed mango and diluting it in 60 mL of distilled water. The pH and TA was determined based on the percentage of citric acid that it was calculated using the equation 1.

$$TA\ [gcitricacid/100g\ of\ the\ sample] = \frac{(A \times B \times C/D) \times 100)}{E} \qquad (1)$$

where A is the volume of NaOH consumed in the titration (in L), B is the normality of NaOH (0.5N), C is the molecular weight of citric acid (192,1g/mol), D is the weight of the sample (15g) and E is the valence of citric acid (3).

The flesh color was measured using a MINOLTACM-700d spectrocolorimeter (Minolta CO. Tokyo, Japan). The reflectance spectra between 400-700 nm were measured in different points of the flesh and the colour coordinates L*, a* and b* for D65 illuminant and 10° observer in the CIELab space were obtained. Hue (h^*) and chroma (C^*) were estimated by the equations 2 and 3, respectively.

$$h^* = arctg\frac{b^*}{a^*} \quad (2)$$

$$C^* = \sqrt{{a^*}^2 + {b^*}^2} \quad (3)$$

A ripening index (RPI) was calculated, as described Vélez-Rivera et al., 2014, by equation 4.

$$\text{RPI} = \ln(100 \cdot F \cdot \frac{TA}{TSS}) \quad (4)$$

where F is firmness (Newton), TA is titratable acidity (grams citric acid equivalent/100 g sample), and TSS is total soluble solids (°Brix).

2.4. Robot operation

Previously to the physicochemical analysis, mangoes were placed manually over a cradle where the gripper picks them up. Robot moves down till locate the gripper center tool in the mango position. During 0.03 seconds the finger A pad is blown to ensure a soft behaviour before the mangoes are grasped. Then the gripper starts to close their fingers. The pad of the finger A is soft and can adapt to the mango shape during the first contact between the mango and the pad. During this first contact the fingers B and C rotate till find the parallel orientation to the shape of the mango and for hence their accelerometers are then oriented perpendicular to the mango surface. After a stabilization period of time, a negative pressure changes the pad state from soft to hard and the vacuum of the suction cup starts. The hard state was used during robot displacements and clashes for sensing the mangoes. Robot moves up the gripper and mango fruit and starts a cycle loop of five quick opening and closing clashes while the mango was maintained attached to B and C fingers due to the action of the suction cup. During the first clash the pad changed again from soft to hard, soft when was open and hard after the closing action when the pad was in contact with the mango fruit. If mangoes were grasped from the cradle the fingers adapt its orientations and shapes while mangoes keep its contact against the cradle. When the gripper is in the up position and mango is not in contact with the cradle some relative motion between mango and fingers B and C can occur. This process ensures that finger surfaces were hard and parallel to the surface of the mango. During this cycle loop deceleration signals are collected and recorded in a computer.

2.5. Robotic gripper damage

A total of 210 samples (7 sets, from A to G, of 30 mangoes fruits) were analysed in order to evaluate the possible damages onto the mango caused by the robotic gripper during handling. The samples were visually evaluated every day during the two weeks storage period using a lighter magnifying glass. After two week storage period, the inner part of each fruit was also evaluated.

2.6. Processing and data analysis

A data acquisition module USB NI-6210 collected the signals of the accelerometers ADXL278 that were attached to every finger of the robot gripper. Signals were sampled at 30 KHz, filtered with a low cut-pass at 1500 Hz and, recorded during 8 Kbs for every finger A, B and C. A LabVIEW program processed every signal to obtain 12 independent parameters. Signals were cut for analysing only the period of time where fingers were clashing against the mango (Figure 2).

These signals were used with the equation 5 to extract the independent values VA, VB and VC. Those parameters were extracted from a fixed period of time in which the fingers hit against the mango. Max A, Max B and Max C are the maximum decelerations for each finger during the contact with the mango.

$$VA = \int_{t_0}^{t_1} A^2 dt\,; \qquad VB = \int_{t_0}^{t_1} B^2 dt\,; \qquad VC = \int_{t_0}^{t_1} C^2 dt \qquad (5)$$

The deceleration severity that happens after the first contact between the finger and the fruit was calculated using the smoothed signals, as the slope of the line from the first contact till the maximum value. In the figure 2 the deceleration signal of the Finger A, in this case and mostly, had two peaks because the finger A rebounded during the impact. This peak created interferences for calculating this slope. To avoid several peaks signals were smoothed and processed to get the slope of every finger Slp A, Slp B and Slp C. With the derivative function of the signals smoothed is possible to obtained the maximum values of the line slopes; MaxSlp A, MaxSlp B and MaxSlp C, and the slope average; AvgSlp A, AvgSlp B and AvgSlp C.

The extracted parameters provided by the robot gripper and the data obtained from the physicochemical analysis were then arranged in a matrix where the rows represent the number of samples (n = 140 samples) and the columns represent the number of variables (the variables provided by the robot gripper and the variables provided by the physicochemical analysis). Partial least squares regression (PLS) was applied to the matrices to develop separate models for each physicochemical property. PLS technique is particularly useful when it is necessary to predict a set of dependent variables from a set of independent variables (Abdi, 2010). In such case, the values of one attribute (each physicochemical property analysed) of the dataset were used to represent the dependent variable and the extracted parameters from the robot gripper represented the independent variables.

The sample data (140 samples) was separated randomly into two groups, one group (105 samples) was used to develop the calibration models and the other group composed by the remaining samples of the population (35 mangoes) was used to prediction set. Performance of the models was evaluated using the standard error of calibration (SEC), the standard error of cross-validation (SECV), the root-mean-square error of calibration (RMSEC), the root-mean square error of cross-validation (RMSECV), the correlation coefficient (r), and the numbers of the latent variables required (#LV). The number of latent variables was determined using the minimum value of predicted residual error sum of squares (PRESSs) (Esquerre et al., 2009; Talens et al., 2013). When the number of latent factors in the model increased, the value of PRESS decreased until its lowest value corresponding to the ideal number of latent factors. Leave-one-out cross-validation method was used to validate the calibration models.

2.7. Statistical analysis

Analysis of variance (ANOVA) was conducted to determine significant differences in the physicochemical and robot gripper analysis using the software

Statgraphics Plus for Windows 5.1 (Manugistics Corp., Rockville, Md.). The PLS multivariate analysis was conducted using The Unscrambler v9.7 (CAMO Software AS, OSLO, Norway)

3. RESULTS AND DISCUSSION

3.1. Physicochemical analysis

The physicochemical characteristics (mechanical properties, total soluble solids, pH, tritatable acidity and flesh colour) of mangoes during the storage period are presented in Table 1. As expected, during the ripening process a textural alteration (loss of firmness) of mango samples was observed. The fracture strength and the slope of the linear range until the fracture point decreased whereas the deformation in the fracture point increased during the storage period. These changes may be due to an increase in the enzymatic activity on the fruit that provokes changes in the structural integrity of the cell wall and middle lamella as was described previously by Yashoda et al., 2007. During fruit softening, cell walls were modified by solubilisation, de-esterification, and de-polymerization, accompanied by an extensive loss of neutral sugars and galacturonic acid (Singh et al., 2013). Other internal compositional changes were observed during the storage time. Total soluble solids and pH increase, whereas tritatable acidity decreases (table 1). Generally, soluble solid content in mango range from 7.0 to 17.4 °Brix, depending on the variety, the production place and maturity stage (Lucena *et al*., 2007). For 'Osteen' variety the mature stage where the fruit attains the stage of maximum consumer acceptability is reached when the mangoes has around 14-15 ºBrix (Vilela *et al.,* 2013). The mango fruit tested in the present experiment range from 5.85 to 19.50 ºBrix.

According to these values, A set samples are unripe mangoes, G set samples are over-ripe samples, whereas B, C, D, E and F set samples are intermediate-ripe mangoes.

The pH and the tritatable acidity of the mango tested in the present experiment range from 3.35 to 6.62 and from 0.97 to 0.07, respectively. Similar values were observed by Yashoda et al., 2007 working with Alphonso variety. The increase in pH and the decrease in the tritatable acidity during the ripening process can be explained by the cell metabolization of volatile organic acids and non-volatile constituents.

Regarding colour measurements, a clear tendency was observed in the changes of flesh colour of the mangoes during the ripening process. Among the three elements of flesh colour evaluated: luminosity, hue and chroma; the luminosity seems to be the best parameter to assess the maturity of mangoes.

In general, the physicochemical analysis showed that the best parameters to assess the maturity of “Osteen” mangoes are the firmness, the soluble solid content and the flesh colour. These results agree with the studies done by Padda et al., 2011 where described that the best tools to assess changes in mangoes during ripening process are the penetrometer, followed by flesh colour and total soluble solids content. In fact, these parameters are used in the mango packing-lines to assess ripeness stage (Brecht, 2010).

3.2. Robot gripper analysis

The robot gripper was capable of grasping 100% of the mangoes from sets A to F without any damage. In the case of the extremely over-ripe mangoes from the set G, 10% of the fruits were severely damaged during the robot handling.

Table 2 shows the range (minimum and maximum values), mean and standard deviation of the extracted parameters provided by the robot gripper analysis. All the parameters were measured along the x axis because no clear correlation was found between the sample hardness and acceleration measured along the y axis. The same effect was previously observed by Blanes et al., 2015 working with eggplants.

During the robot gripper analysis it was observed that gripper fingers suffered the most violent deceleration when the ripening stage of mango was low whereas deceleration decreased when the ripening stage of mango was high. The best parameters that showed this behaviour were Max A, Max B, Max C and MaxSlp A, MaxSlp B, MaxSlp C. Figure 3 shows median plots with 95% confidence intervals of average of maximum deceleration parameters during the contact between fingers and fruits (figure 3A), and average of deceleration severity parameters after this contact (figure 3B) during the storage period of samples where clearly this behaviour was observed.

3.3. Correlation between robot gripper measurements and mango physicochemical characteristics

In order to see if the robot gripper can assess the mango firmness and ripeness partial least square regression models (PLS) were developed to explain the physicochemical characteristics according to the variables extracted from the accelerometer signals. The sample data (140 samples) was separated randomly into two groups, one group (105 samples) was used to develop the calibration models and the other group composed by the remaining samples of the population (35 mangoes) was used as prediction set. Table 3 shows the standard error of calibration (SEC), the standard error of cross-validation (SECV), the root-mean-square error of calibration (RMSEC), the root-mean-square error of cross-validation (RMSECV), the correlation coefficient (r), and the numbers of the latent variables required (#LV) for firmness (slope of the linear range until the fracture point), soluble solid content, and flesh luminosity. The results indicated that the PLS models for these parameters exhibited low values of SEC, SECV, RMSEC and RMSECV, and high values of r, indicating good performance of the models.

When the models were used to predict the new 35 samples of mango, predictions were also high. The best results were obtained for the mango firmness. The correlation coefficient between robot gripper values and the slope of the linear range until the fracture point was 0.925, with a standard error of prediction of 2.524 N/mm, root-mean-square error of prediction of 2.517 and a BIAS of -0.380 N/mm. This result indicates that there are good relationships between robot gripper measurements and mango firmness.

In the case of total soluble solids, the correlation coefficient between robot gripper values and TSS was 0.892, with a standard error of prediction of 1.579 ºBrix, the root-mean-square error of prediction of 1.574 ºBrix and the systematic difference between predicted and measured values (BIAS) of -0.228 ºBrix. For flesh luminosity, the correlation coefficient between robot gripper values and flesh luminosity was 0.893, with a standard error of prediction of 23.187, root-mean-square error of prediction of 3.166 and a BIAS of 0.396.

The scatter plots of figure 4 shows the efficiency of the PLS models for predicting firmness (figure 4a), soluble solid content (figure 4b) and flesh luminosity (figure 4c). In all figures, the ordinate and abscissa axes represent the predicted and measured fitted values of the appropriate parameters, respectively. The correlation between the measured and predicted values for each parameter showed a good prediction performance.

The most essential physical and chemical properties of mangoes linked with the sensory perception of the ripeness of the fruits can be described by the ripening index (RPI). This RPI combined the values of firmness, titratable acidity and total soluble solids. Figure 5a shows the median plot with 95% confidence intervals of the RPI during the storage of the samples. Similarly to the results observed by Vélez-Rivera et al., 2014 working with "Manila" mango the RPI values decrease during the storage. Three ripeness phases were identified based on the RPI parameter: unripe mangoes (A set samples), intermediate-ripe mangoes (B, C, D, E and F set samples) and over-ripe mangoes (G set samples). A PLS model was developed to explain the RPI according to the variables extracted from the robot gripper. The correlation of calibration between the variables extracted from the accelerometer signals and the RPI was 0.887, with SEC and RMSEC of 0.617 and 0.614 respectively. When the model was used to predict the new mango samples, it showed a better correlation coefficient (0.937), with a standard error of prediction of 0.517, root-mean-square error of prediction of 0.518 and a BIAS of -0.089. Figure 5b shows the good prediction performance of the PLS model for RPI.

4. CONCLUSIONS

The physicochemical analysis showed that best parameters to assess the ripeness of cv "Osteen" mangoes are firmness, soluble solid content, and flesh luminosity. These variables are the parameters used in the mango packaging -

lines to assess fruit ripeness and to take decisions according to their values. The prediction models, developed by partial least square regression, have the potential to estimate the described parameters and also the ripening index of the samples based on the information obtained from the robot gripper accelerometers. This research showed that it is possible to assess the firmness and ripeness of mango fruits using a non-destructive technique during robot handling operation with a robot gripper.

5. ACKNOWLEGMENTS

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Figure 1
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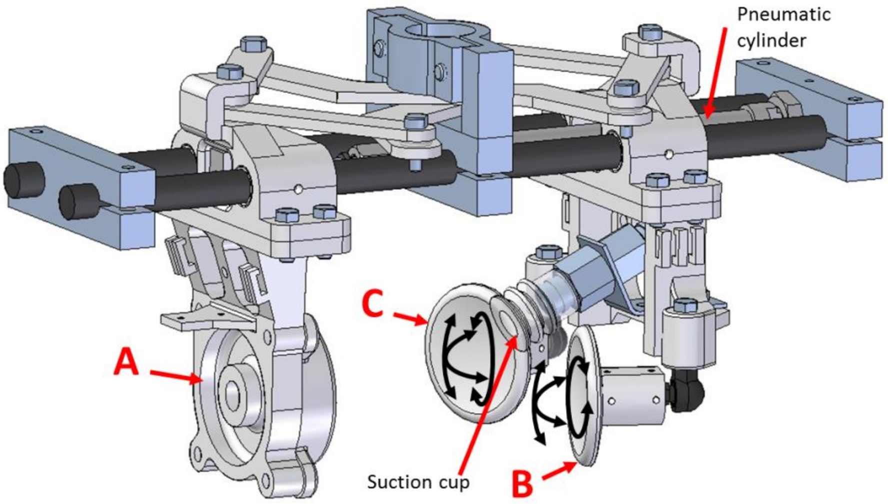

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Figure 2
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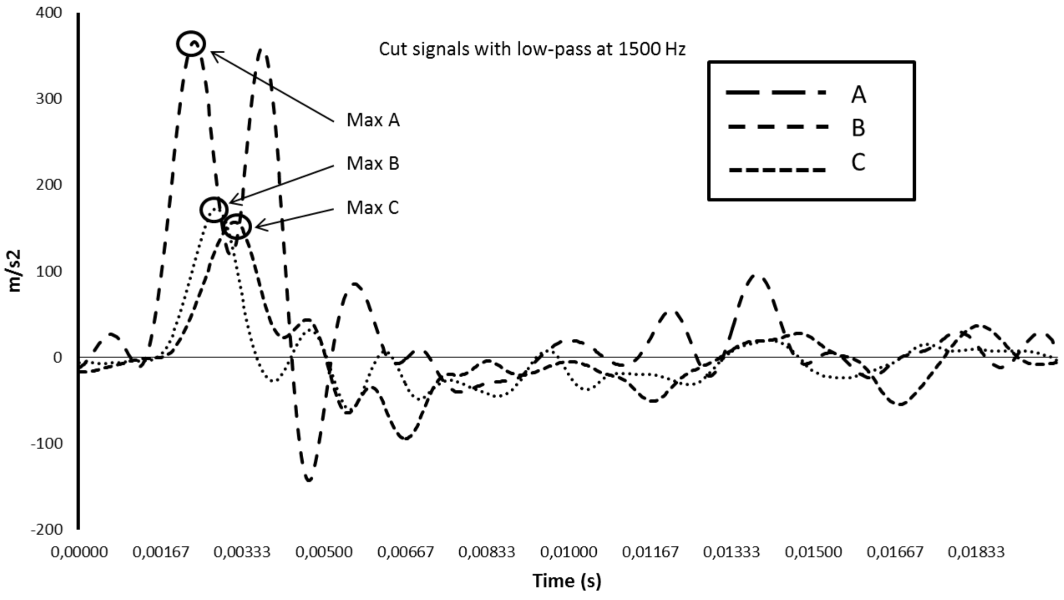

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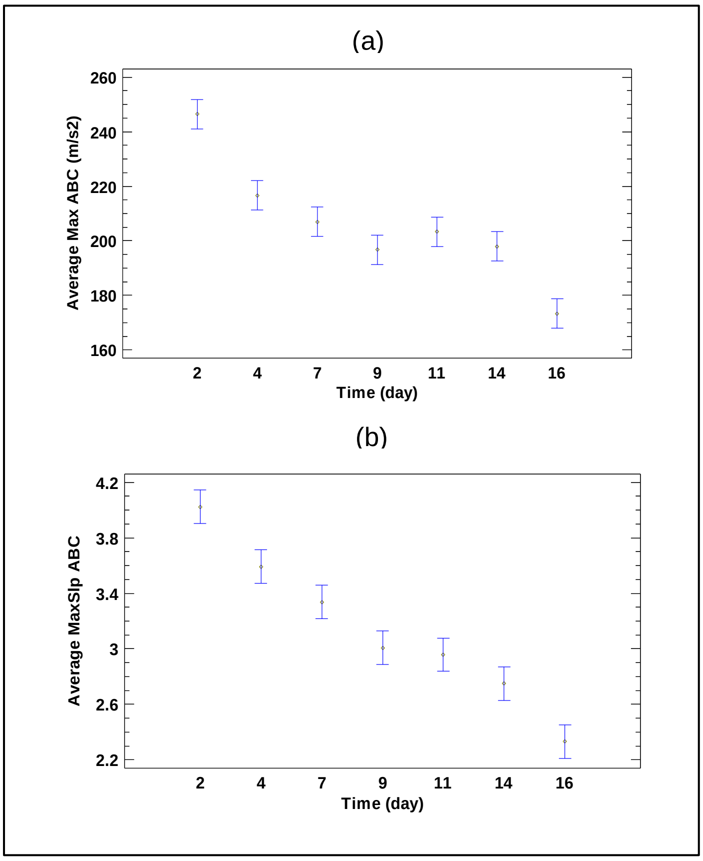

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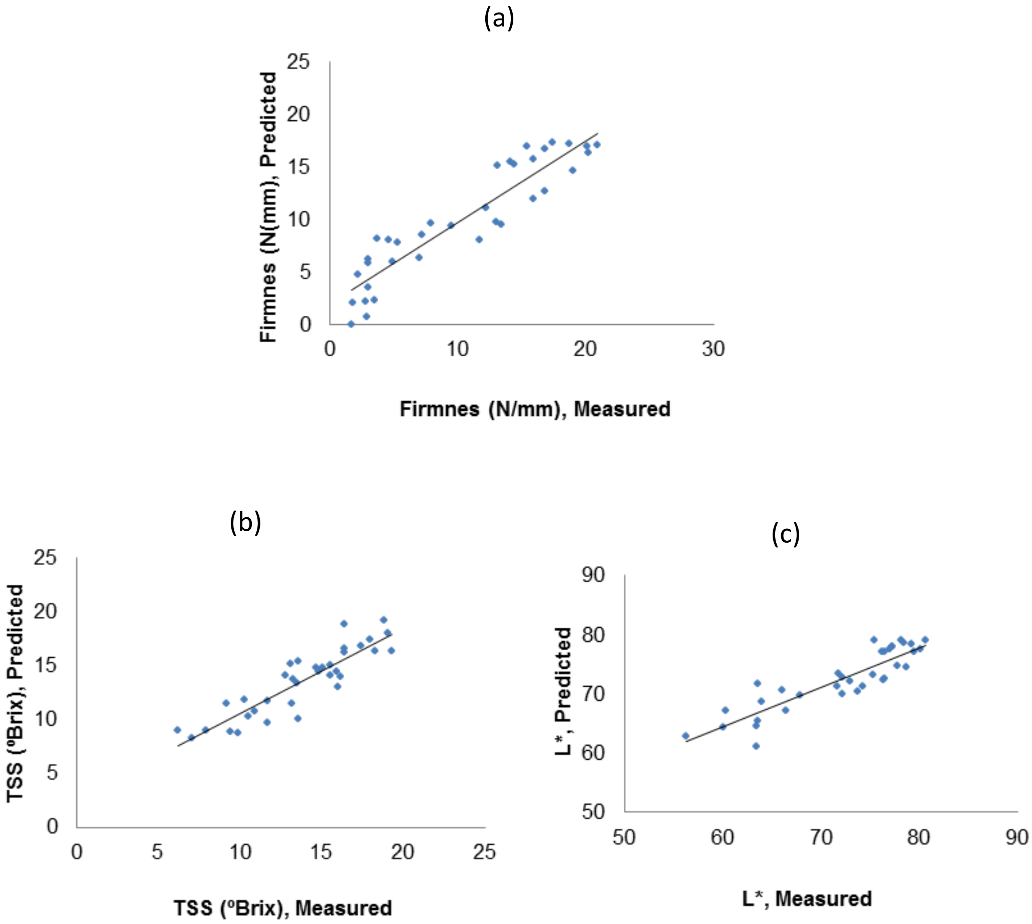

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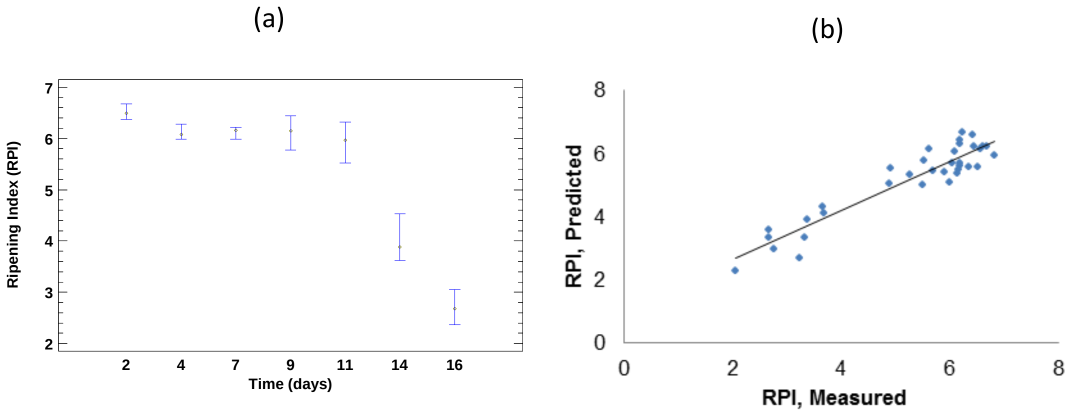

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Table Captions

Table 1.Physicochemical characteristics of Mangoes during the storage period

Table 2.Range, mean and standard deviation of the 12 extracted parameters provided by the robot gripper analysis for the mangoes studied

Table 3. Results of the PLS models for the prediction of soluble solid content, firmness and flesh luminosity in mango samples (n = 105 samples)

Table 1
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Table 1.Physicochemical characteristics of Mangoes during the storage period

Physicochemical Characteristic	Set A	Set B	Set C	Set D	Set E	Set F	Set G
Mechanical Properties							
F (N)	105 ± 8[a]	97 ± 19[a,b]	100 ± 30[a,b]	90 ± 25[b,c]	77 ± 25[c]	40 ± 17[d]	24 ± 6[e]
D_F	7 ± 3[a]	7 ± 1[a]	8 ± 1[a,b]	9 ± 1[b]	10 ± 1[c]	10 ± 2[c]	10 ± 2[c]
Slope (N/mm)	18 ± 2[a]	15 ± 4[b]	14 ± 5[b]	11 ± 4[c]	8 ± 4[d]	4 ± 2[e]	2 ± 1[e]
Internal Composition							
TSS (º Brix)	8 ± 1[a]	12 ± 2[b]	12 ± 3[b,c]	14 ± 2[c,d]	15 ± 2[d,e]	16 ± 2[e]	18 ± 1[f]
pH	4.10 ± 0.13[a]	4.09 ± 0.23[a]	4.04 ± 0.17[a]	3.71 ± 0.21[b]	3.68 ± 0.15[b]	4.89 ± 0.60[c]	5.70 ± 0.40[d]
Titratable acidity (g/100g)	0.49 ± 0.09[a]	0.55 ± 0.13[a]	0.50 ± 0.09[a]	0.67 ± 0.11[b]	0.67 ± 0.15[b]	0.26 ± 0.12[c]	0.12 ± 0.03[d]
Internal Color							
L*	79 ± 1[a]	76 ± 4[b]	76 ± 5[b]	75 ± 4[b]	73 ± 3[c]	67 ± 3[d]	64 ± 3[e]
C*	49 ± 4[a]	53 ± 4[b]	48 ± 6[a]	49 ± 6[a]	53 ± 5[b]	58 ± 3[c]	61 ± 3[c]
h*	83 ± 2[a]	79 ± 3[b,c]	80 ± 3[b]	81 ± 3[b]	78 ± 3[c]	75 ± 2[d]	74 ± 1[d]

Values are mean ± SD
[a–f] Different superscripts in the same row indicate significant difference among sets ($p < 0.05$).

Table 2
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Table 2.Range, mean and standard deviation of the 12 extracted parameters provided by the robot gripper analysis for the mangoes studied

Parameters	Minimum value	Maximum value	Mean	Sdev
VA (m^2/s^2)	95.76	260.27	173.09	30.52
VB (m^2/s^2)	14.45	45.49	27.69	6.79
VC (m^2/s^2)	10.97	87.61	45.10	11.55
Max A (m/s^2)	205.36	441.58	330.73	41.34
Max B (m/s^2)	74.19	198.41	132.37	26.82
Max C (m/s^2)	64.76	236.35	154.72	29.18
MaxSlp A	2.12	6.98	4.71	1.03
MaxSlp B	1.00	3.38	2.22	0.45
MaxSlp C	-0.24	3.86	2.50	0.76
AvgSlop A	1.15	2.98	2.34	0.31
AvgSlop B	0.30	1.14	0.79	0.17
AvgSlop C	0.42	2.27	1.16	0.28

Table 3

Table 3. Results of the PLS models for the prediction of soluble solid content, firmness and flesh luminosity in mango samples (n = 105 samples)

	#N	#LV	Calibration			Cross Validation		
Parameter			r	SEC	RMSEC	r	SECV	RMSECV
Firmness	12	4	0.918	2.457	2.446	0.904	2.656	2.644
Soluble solid content	12	3	0.859	1.795	1.786	0.834	1.936	1.927
Flesh Luminosity	12	3	0.874	2.94	2.930	0.853	3.170	3.156

#N: total number robot gripper parameters, #LV: number of latent variables, SEC: standard error of calibration, SECV: standard error of cross-validation, RMSEC: root-mean-square error of calibration, RMSECV: root-mean-square error of cross-validation, r: correlation coefficient.

ABSTRACT

The objective of the study was to evaluate the use of a robot gripper in the assessment of mango (cv. “Osteen”) firmness as well as to establish relationships between the non-destructive robot gripper measurements with embedded accelerometers in the fingers and the ripeness of mango fruit. Intact mango fruit was handled and manipulated by the robot gripper and the major physicochemical properties related with their ripening index were analysed. Partial least square regression models (PLS) were developed to explain these properties according to the variables extracted from the accelerometer signals. Correlation coefficients of 0.925, 0.892, 0.893 and 0.937 were obtained for the prediction of firmness, total soluble solids, flesh luminosity and the ripening index, respectively. This research showed that it is possible to assess mango firmness and ripeness during handling with a robot gripper.