EVALUATION OF A KIWIFRUIT NON-DESTRUCTIVE FIRMNESS SENSOR

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Abstract

Non-destructive firmness sensors have recently become available for packers and fruit handlers although they demand more information on their performance and reliability. A commercial sensor based on low mass impact has been tested on kiwifruit. Correlation between the firmness index given by the device and Magness-Taylor force was low ($r^2 = 0.594$). Classifications modeled with discriminant analysis showed that it is feasible to sort samples into two firmness groups (96 to 91%), but classification into three classes yields lower scores.

Introduction

The loss of fruit firmness is a physiological process that depends on the ripening development on the tree and postharvest storage time and conditions (Abbott, 1999; Kader, 2002). Firmness of commodities affects their final quality because it changes fruit susceptibility to mechanical damage and decay development during handling and packaging (Valero et al., 2006) and this relationship can be modeled (Barreiro et al., 1997). For the fresh market, measuring the firmness of fruit commodities during postharvest handling is becoming a key control point, as it allows the fruit handler to meet consumer demands (Bruhn, 1995), generate "ready to eat" fruit at its optimum firmness level, and it provides useful information to improve marketing, storage and shipment decisions (Crisosto and Mitchell, 2002). Development of nondestructive firmness measurements has been carried out using different principles (Chen, 1996; Abbott, 1999). For example, kiwifruit firmness has been estimated using drop impact devices (McGlone et al., 1997), near infrared spectroscopy, laser air-puff method (McGlone and Jordan, 2000), and acoustic resonance (Muramatsu et al., 1997).

From a practical commercial applications point of view, several non-destructive firmness sensing systems are being evaluated for online and bench top laboratory measurements (Aweta, 2004). The system used in this study senses the fruit response during an impact. Sinclair International Ltd. (Sinclair, 2004) developed the "Sinclair iQ® system" to measure firmness (Howarth, 2002) by tapping the fruit; it calculates an index (iQ™ firmness value) proportional to fruit firmness. This same system has been demonstrated to predict bruising susceptibility with physical properties related to firmness, and establish critical pitter thresholds for the canning industries (Metheney et al., 2002; Slaughter et al., 2006; Crisosto, et al., 2007). Other studies have been carried out to test this system on apples, melons, avocados, nectarines and mangos (Shmulevich, 2003) comparing the device with acoustic methods and other firmness tests.

The objective of this work was to compare a commercial non-destructive firmness tester ("Sinclair iQ® system") with the standard destructive firmness test on kiwifruit.

Materials and Methods

For this study, kiwifruit ('Hayward' cultivar) were evaluated for destructive and non-destructive firmness. Fruit was harvested from experimental and commercial fields in San Joaquin Valley, California, at their commercial maturity. Fruit was transported to the F. Gordon Mitchell Postharvest Laboratory at the Kearney Agricultural Center (KAC) in Parlier, California, where each fruit was labeled at three equatorial positions for firmness measurement. After harvesting each cultivar, fruits were kept at 20°C in order to measure 30 fruit per day during ripening until soft (<10.0 N), to be able to obtain a large range of firmness. The first measurement of fruit firmness was the non-destructive test, using a commercially available, fruit firmness tester, the "Sinclair iQ® system" (SiQ; Sinclair Systems International, LLC, Fresno, CA). This company has adapted its technology on labeling systems, using compressed air and expandable rubber bellows, to generate an on-line fruit firmness tester. The model used in this work was a bench top device. The pneumatically operated sensor has a head equipped with a piezo ceramic generator, which is pushed out of the bellow's end each time the device hits a fruit sample. The electronic sensor is capable of converting force to voltage. The resultant voltage signal depends upon fruit firmness. The voltage signal passed through an analog to digital converter interfaced to a personal computer and was processed by proprietary software (Sinclair iQ version PIQ01-v2.18.01) to return a measure of fruit firmness as a number indexed from 0-100, the 'iQ value' (iQ). This index is defined such that softer fruit are assigned lower index values than firmer fruit. This device was used to measure fruit firmness at the three labeled equatorial cheek locations on each fruit non-destructively. Cheek firmness, iQ values were measured for the three labeled cheek positions on each fruit. Prior to each use the SiQ system was calibrated using a rubber ball of known firmness and operating pressure was adjusted to operate the sensor head at 10 psi (+ 2 psi), following manufacturer recommendations. The reference measure of firmness, maximum force during a hand operated Magness-Taylor puncture test (Magness and Taylor, 1925) was obtained at two opposite equatorial positions on each fruit using the 'University of California fruit firmness tester' (UCF), which is a hand-driven press (Western Industrial Supply Co., San Francisco, CA) equipped with an Ametek penetrometer (Ametek, Hatfield, PA) and a 7.9 mm diameter tip. At each labeled position the skin was removed and the 7.9 mm diameter tip was inserted into the fruit flesh 5 mm. Flesh firmness measurements were expressed as Newtons (N).

For each sample evaluated, average iQ firmness value per fruit was calculated; UCF destructive firmness values were also averaged for each fruit. The relationship between iQ values for each fruit and UCF flesh firmness was analyzed using a regression analysis. The evaluation of the Sinclair bench top system to classify samples according to their firmness was studied using clustering techniques and classification models (Valero, 2004). In order to develop the classfication models, first samples have to be previously sorted according to UCF values. This was done by two methods: first, establishment of a "natural grouping" of the population (using cluster analysis); second, direct ascription to groups delimited by pre-established thresholds. The term cluster analysis (StatSoft, 2002) actually encompasses a number of different classfication algorithms to organize observed data into meaningful structures, that is, to develop taxonomies. In this work, the "k-means" algorithm was used. In general, the k-means method will produce exactly k different clusters of greatest possible distinction. The selection of samples into the cluster is computed through an algorithm that used the 'mean' of the cluster. The firmness values measured for each fruit through the UCF destructive test were used in the cluster analysis as the independent variable to pre-sort samples into k=3 clusters ('hard', 'medium' and 'soft'). This procedure is referred in the following tables as 'auto-thresholds' as the limit values between clusters are not fixed by the operator.

The second method to pre-sort samples was to set the limits between groups. Thresholds were set between clusters, according to industrial requirements. Packing houses in the San Joaquin Valley use several firmness levels to decide when a fruit is too ripe, when it should be pre-conditioned in storage or when it goes to cold chambers. Summarizing that information and our experience, the thresholds were established in a way that the final application of the SiQ device could be of help for the industry. Trials were performed with one boundary firmness level (classification of samples into two clusters 'hard' and 'soft') and two boundary levels (classification into three clusters 'hard', 'medium' and 'soft'). Thresholds were selected following industry standards (Crisosto et al., 1999; Crisosto and Mitchell, 2002), but also a variation in the thresholds was studied on purpose, to search for different sensibility of the non-destructive system across the firmness range.

Once the samples were pre-sorted and the clusters were established, discriminant function analysis was applied. It is often used to determine which variables discriminate between two or more naturally occurring groups. In this case, the only discriminant variable (sometimes called 'dependent' or 'classifier') used was SiQ, trying to match UCF pre-sorting. The percentage of correctly classfied samples was used as an indicator of a reliable model. As a result of the analysis, a 'discriminant model' is obtained, formed by functions (one mathematical function per cluster), which can be used by an automatic process to perform the classification.

Results and Discussion

Correlation between iQ non-destructive and destructive penetrometer values was significant (Fig. 1), but with a relatively low relationship ($r^2 = 0.594$). Therefore, this 59% of linear relationship account between the two measurement methods is not enough for the modeling of a direct prediction equation of destructive firmness based on non-destructive SiQ readings.

The classification of samples in three classes (Table 1) resulted in a percentage of correctly classified fruits between 65% and 71% for kiwifruit depending on the firmness thresholds. The clustering technique applied before discrimination analysis resulted in worse classification scores than setting the threshold manually based on industrial criteria, despite the fact that the clustering method provided the most equal distribution of samples into the clusters. The best results in this three classes distribution were achieved for the 22.3 - 44.5 N threshold, even if the middle groups had a significantly lower partial score (17%). Therefore, classification of kiwifruit with this non-destructive device into three firmness classes is not accurate enough for an industrial application. Classfication of samples into two groups achieved better results (Table 2), ranging from 79% to 97% in kiwifruit, depending on the threshold between 'soft' and 'hard'. The device seems to segregate scores lower for very soft thresholds than for harder ones. The SiQ device seems to be industrially applicable for segregation of two firmness clusters, with an acceptable error in the classification.

In other work, different factorial design experiments were conducted searching for sources of error that could be affecting the low performance in the firmness estimation of this non-destructive sensor. Unpublished results indicated that parameters such as the distance from the impacting sensor head on the fruit, the displacement of the real impact from the theoretical impact point at the top-center of the fruit, the working pressure of the pump controlling the sensor head, and the time since the unit was powered on significantly affect the reliability of the measurements. Enhancements in the system design should be done to avoid variations in firmness estimation due to these parameters before commercial application (Valero, 2008; unpublished data).

Conclusions

A bench top version of a commercial fruit firmness sensor has been successfully tested on kiwifruit. Correlation between the reference destructive test (Magness-Taylor maximum force during penetration) and the index value given by the non-destructive device resulted in $r^2 = 0.49$ for kiwifruit.

The direct approach to relate non-destructive value and fruit physiological-ripeness stage was accomplished by using discrimination analysis. Discrimination analysis functions were created to sort samples into two groups and three groups. In the case of three-group sorting models, the range was from a score of 65% of well classified fruit to 71% in kiwifruit. In the case of a dichotomist classification, performance was higher: 67 to 97% for kiwifruit.

Adaptation of these sensors to commercial operations should be pursued by studying the direct relationship between non-destructive sensors with fruit important physiological stages rather than the direct relationship between the destructive and non-destructive sensors. In addition, engineering improvements of this sensor should be carried out prior to commercial use.

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Table 1. Results of classification into three classes: samples were sorted in three clusters according to their firmness level (UCF) using iQ as predicting variable. Figures correspond to percentage of correctly classified samples (overall score for each model and partial percentage for each cluster), and the number of individuals per cluster is expressed in brackets.

Resultados de la clasificación en tres clases: muestras fueron segregadas en tres clusters de acuerdo a su firmeza usando iQ como valor de la predicción. Figura muestra los porcentajes de nuestras clasificadas correctamente (valor total para cada modelo y porcentaje parcial por cada cluster), y el numero de individuos por cluster es expresado dentro del paréntesis.

Type of fruit	*Thresholds (N) between 'soft', 'medium' and 'hard' clusters*	*Percentage of well classified fruits (and number of samples)*			
		model average	*'soft' cluster*	*'medium' cluster*	*'hard' cluster*
Kiwifruit					
	13.4- 44.5	**66%** (536)	25% (142)	86% (303)	62% (91)
	17.8- 35.6	**65%** (536)	73% (222)	55% (209)	69% (105)
	22.3- 44.5	**71%** (536)	93% (325)	17% (120)	66% (91)
	Auto-thresholds	**65%** (536)	59% (222)	61% (92)	73% (222)

Table 2. Results of classification into two classes: samples were sorted in two clusters according to their firmness level (UCF) using iQ as predicting variable. Figures correspond to percentage of correctly classified samples (overall score for each model and partial percentage for each cluster), and the number of individuals per cluster is expressed in brackets.

Resultados de la clasificación en dos clases: muestras fueron segregadas en dos clusters de acuerdo a su firmeza usando iQ como valor de la predicción. Figura muestra los porcentajes de nuestras clasificadas correctamente (valor total para cada modelo y porcentaje parcial por cada cluster), y el numero de individuos por cluster es expresado dentro del paréntesis.

Type of fruit	*Thresholds (N) between 'soft' and 'hard' clusters*	*Percentage of well classified fruits (and number of samples)*		
		model average	*'soft' cluster*	*'hard' cluster*
Kiwifruit				
	17.8	**76%** (536)	71% (222)	79% (314)
	22.3	**81%** (536)	90% (325)	66% (211)
	26.7	**87%** (536)	96% (389)	62% (147)
	35.6	**90%** (536)	96% (431)	65% (105)
	44.5	**91%** (536)	97% (445)	62% (91)
	53.5	**90%** (536)	96% (454)	56% (82)
	62.4	**93%** (536)	97% (485)	59% (51)
	71.3	**97%** (536)	98% (519)	59% (17)

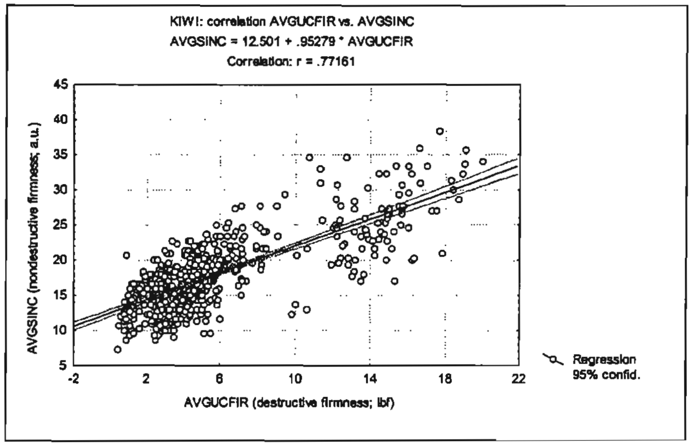

Figure 1. Correlation between non-destructive measurement and penetrometer readings for kiwifruit.

Correlación entre valores no-destructivos y destructivos.

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