Introducing Nondestructive Flesh Color and Firmness Sensors to the Tree Fruit Industry

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Abstract

The tree fruit industry needs sensors to measure internal fruit properties nondestructively. A prototype optical sensor based on light emitting diodes was used in this work to characterize flesh color. A commercial nondestructive impact sensor ('Sinclair Internal Quality Firmness Tester'; SIQ-FT, Sinclair Systems International, LLC, Fresno, CA) was also used to measure firmness of the samples, and its relation with the standard penetrometer was studied. Several cultivars of melting flesh peaches, nectarines, and plums were measured throughout the harvesting season in the San Joaquin Valley, California. Correlation coefficients were high for the relationship between penetrometer vs. Sinclair in all cases. Further study should be carried out in the case of the flesh color sensor.

Keywords: penetrometer, low-mass impact, colorimeter, light emitting diodes

INTRODUCTION

During the last two seasons, we have undertaken studies (Crisosto et al., 1997) using nondestructive measurements of flesh color and firmness to develop a minimum maturity index and ripening tool for tree fruit. This work is being carried out in combination with a three-year study of detailed maturity component changes for the most important commercial peach, nectarine and plum cultivars, and for the creation of ripening protocols. Based on the results of our previous work, we concluded that flesh color changes have the highest correlation with the other physical and chemical changes occurring during maturation and ripening on the tree. At the same time, fruit firmness is the best indicator of ripening changes and predictor of bruising potential, and it must be used to control ripening at the shipping and retail ends. Therefore, nondestructive devices measuring internal flesh color and firmness could be of major interest for the tree fruit industry.

MATERIALS AND METHODS

Two nondestructive sensing devices were used in this study, with the aim of finding applications for the tree fruit industry: a nondestructive firmness tester 'Sinclair Internal

Quality Firmness Tester' (SIQ-FT, Sinclair Systems International, LLC, Fresno, CA), in a bench top version (Howarth and Ioannides, 2002; Shmulevich et al., 2002) and an optical device based on light emitting diodes (LED) developed by D. Slaughter (Univ. of California, Davis).

The SIQ-FT 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 (arbitrary units), 'Sinclair firmness index' (SFI). This index is defined such that softer fruit are assigned lower index values than firmer fruit.

The optical prototype system illuminates the sample with a ring of LEDs, flashing alternately with orange and red LEDs, measuring the light transmitted through the fruit as an average response to both internally reflected lights. The measurement is done inside a black chamber and both the ring of LEDs and the sensor (in the center of the ring) are in direct contact with the skin of the fruit. The output of the system is a pair of indexes ("red-LED" and "orange-LED") related to the chlorophyll content of the flesh: the higher the indexes, the lower the chlorophyll content. A third value is registered when no LED is illuminating, the "dark value", which can be considered the system response to external light interference and internal electric noise; this value can be used to correct red-LED and orange-LED indexes in case of a noisy environment.

In this study, the sequence of measurements for each fruit of a tested cultivar were as follows. First, the SFI values were measured with the SIQ-FT at three labelled equatorial cheek positions (two cheeks and the cheek opposite the suture). The three values were averaged for data analysis (Table 1). Then, the LED optical device was used to measure the chlorophyll content on the two opposite cheeks of the fruit (Li et al., 1997). Next, the skin was removed from the same two positions, on opposite cheeks. Destructive flesh color was measured with a portable colorimeter (Minolta model CR-200, Ramsey, New Jersey) on the same two cheeks as the optical device. The CIE L* a* b* coordinates were recorded for both positions, and then hue angle was calculated and averaged for each fruit. Lastly, destructive firmness was measured on the same two labelled cheek positions as the nondestructive measurements with a 'University of California fruit firmness tester' (UCF). The UCF 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. Values corresponding to both cheeks were averaged per fruit. Finally, a database with averaged SFI, averaged UCF, averaged hue angle and red-LED and orange-LED indexes was obtained for every fruit of the studied cultivars.

The relationship between destructive flesh color readings (Minolta colorimeter) and nondestructive light emitting diodes (LED) readings was tested for peaches (yellow cultivars: Flavorcrest, Summer Lady, O'Henry, Carson; white cultivar: Ivory Princess), nectarines (yellow cultivars: Spring Bright, Ruby Diamond, Red Diamond) and plums (Blackamber, Royal Diamond, Rosemary) including full red color peaches and nectarines, and full dark color plums. The relationship between the destructive UCF penetrometer and the nondestructive firmness sensor (SIQ-FT) measurements was also tested for many of the

important California cultivars mentioned above, including clingstone, freestone and/or melting and non-melting ones. Fruits of each cultivar were harvested twice a week during their harvesting periods, and measured the same day.

RESULTS AND DISCUSSION

Optical sensor

As flesh color was found to be of great interest in predicting peach ripeness in previous studies (Metheney et al., 2001), and the peach canning industry uses internal color to sort fruit entering the receiving area at the cannery, relations between the LED measurements on intact fruits and internal flesh color measured with the colorimeter were investigated. Correlations were very low in all cases between LED-red and hue angle (Figure 1) and LED-orange and hue angle (Figure 2). Only in the case of 'Rosemary' plums the correlation coefficient reached r=0.45 for LED-red and r=0.62 for LED-orange, but the number of samples was low.

Nonlinear models were tried, as shown in Figure 3 for 'Flavorcrest' peaches. A LED ratio was calculated dividing LED-orange by LED-red. Relations between this new index and flesh hue angle were searched for using nonlinear estimation. The best result obtained corresponded to Figure 3, with an r^2 value of 0.72. Other trials were carried out subtracting the "noise value" from the LED-red and LED-orange readings, but the results were not satisfactory.

Firmness sensor

Due to cultivar differences, the ripening process for each cultivar during the experiments varied, and thus different firmness ranges were obtained for each cultivar tested. The number of individual fruit measured for each cultivar, along with the minimum and maximum firmness values, both for destructive (UCF) and nondestructive (SFI) readings are shown in Table 1. Destructive firmness ranges varied from 13.5-126.0 N for melting flesh peaches, 36.0-135.0 N for nectarines, and 4.5-117.0 N for plums.

Correlations between UCF and SFI measurements are indicated in the last two columns of Table 1. Relationships are strong in all cases, with r-values higher than 0.70 and up to 0.93, for both cultivar data analyzed independently and fruit type (i.e. peach, nectarine, or plum) combining all cultivars as a composite set of data. Correlations where all significant at p<0.001.

Explained variance for these correlations (r^2 values) is not high for all cases (Table 1), indicating that other possible sources of variation are present in the data. When measuring with the bench top SIQ-FT, although all system parameters were kept as constant as possible, substantial influence on the reading was observed for minor changes in some parameters, such as bellow pressure, impact position (top of the fruit, or deviated location) or dirtiness of bellow's end due to peach fuzz. A detailed study of these system parameters should be carried out.

The correlations between UCF and SFI, for all cultivars grouped by fruit type (plum, peach, and nectarine) are shown in Figure 4. Several observations can be made. First, the variability obtained for firmness measurements was high enough, generating a wide firmness

range, to allow the creation of good estimative models. Nevertheless, some batches of fruits, corresponding to particular harvesting days, ripened faster than others, leaving empty areas in the correlation graphs where no firmness value was registered; this could affect some correlations extrapolating the relation between two distant groups of samples, without any information on the central part. On the other hand, it was noticed that the SIQ-FT was less sensitive to very soft fruits than to firmer ones; UCF values below 5 N resulted in a range of SFI measurements between 5–15 for nectarines and peaches, and 0-7 for plums.

CONCLUSIONS

Performance of the optical device was much worse than expected, suggesting the need for several improvements. First, a different approach in data acquisition and analysis could be made, using a spectrophotometer and the whole flesh VIS spectra to compare with LED indexes, instead of the hue angle alone. A multivariate analysis with all of the wavelengths could lead to the selection of different light emitting diodes to be installed in the device, more appropriate to measure color changes affected by the ripening process. In spite of the current limitations of the optical device, a sensor to measure internal color without damaging the fruit is still of great interest to the tree fruit industry.

Regarding the SIQ-FT, the high correlations found indicate that this system has a very good potential for application in the tree fruit industry. Extensive experimentation on these and other species should be done to enhance the firmness estimation, and a detailed metrological study should be carried out to limit the sources of variability. The on-line version of the system, currently being used in several American and European commercial facilities, also needs to be studied from a scientific point of view.

If this new technology becomes commercially available, it may potentially induce major changes in the fruit industry regulation of fruit maturity and quality. Traditional destructive fruit maturity/quality measurements could be replaced by nondestructive technology. For example, nondestructive flesh color readings could be added to our current inspection programs. This objective machine measurement would help to avoid the "human error" in the California Department of Food and Agriculture (CDFA) (Inspection Service Branch) enforcement of these maturity standards.

Literature cited

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Tables

Table 1. Firmness levels found in samples: range of penetrometer readings (UCF) and of Sinclair index readings (SFI), for all cultivars tested. Correlation results between destructive (UCF) and nondestructive (SFI) measurements are shown. All correlation coefficients are significant at $p < 0.001$.

| Fruit Type	Cultivar	n	UCF (N) min-max	SFI (0-100) min-max	r	r^2
Peaches, melting flesh	**All cultivars**	**698**	**13.5-126**	**0-18**	**0.829**	**0.687**
	Flavorcrest	120	22.5-117	0-13	0.922	0.850
	Ivory Princess	41	40.5-126	2-13	0.886	0.785
	Summer Lady	150	27-99	1-16	0.847	0.718
	O'Henry	120	13.5-121.5	1-18	0.910	0.828
Nectarines	**All cultivars**	**536**	**36-135**	**1-16**	**0.913**	**0.833**
	Spring Bright	116	40.5-126	1-14	0.906	0.820
	Red Diamond	90	45-121.5	1-13	0.898	0.806
	Summer Bright	90	36-81	1-12	0.756	0.571
	Ruby Diamond	90	63-135	4-16	0.701	0.491
Plums	**All cultivars**	**536**	**4.5-117**	**0-13**	**0.843**	**0.711**
	Blackamber	165	36-99	3-13	0.821	0.674
	Royal Diamond	180	40.5-117	2-11	0.842	0.709
	Rosemary	115	4.5-67.5	0-10	0.931	0.867

Figures
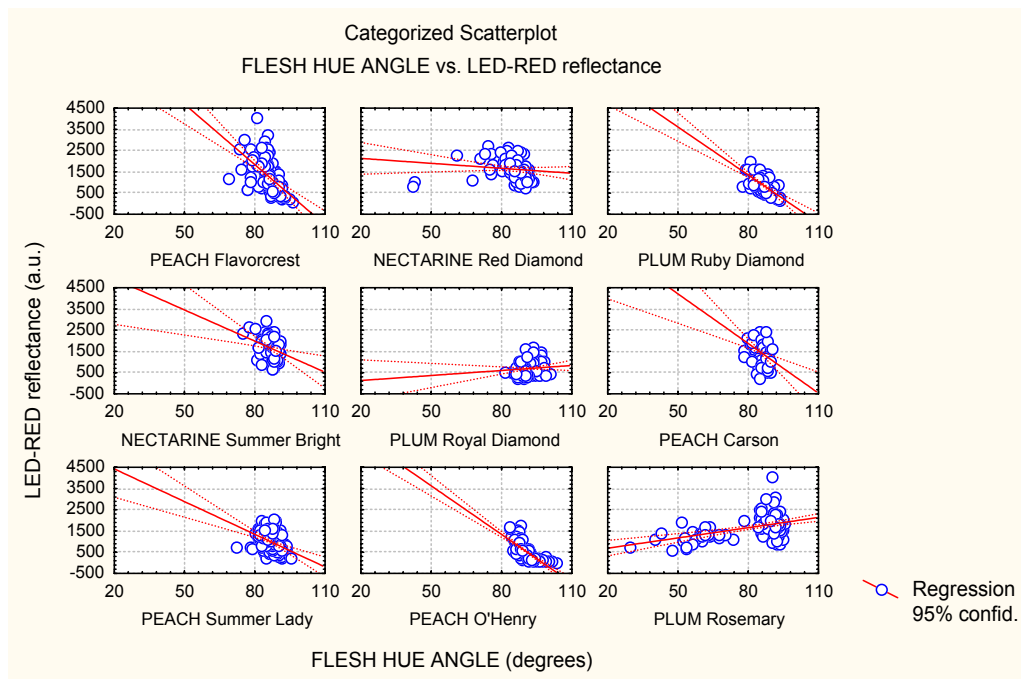
Figure 1. Correlations between nondestructive LED-red index optical measurements and flesh color measured with a colorimeter, after removing the skin. Each scatter plot corresponds to one cultivar. Correlations are significant at p<0.05.
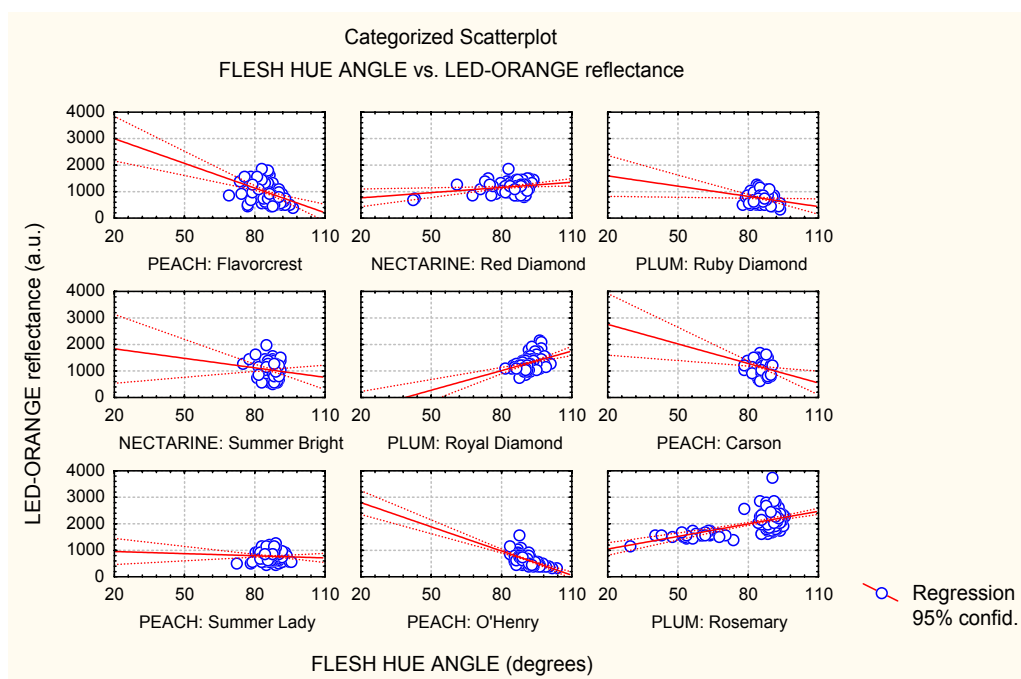
Figure 2. Correlations between nondestructive LED-orange index (arbitrary units) optical measurements and flesh color measured with a colorimeter, after removing the skin. Each scatter plot corresponds to one cultivar. Correlations are significant at $p<0.05$.

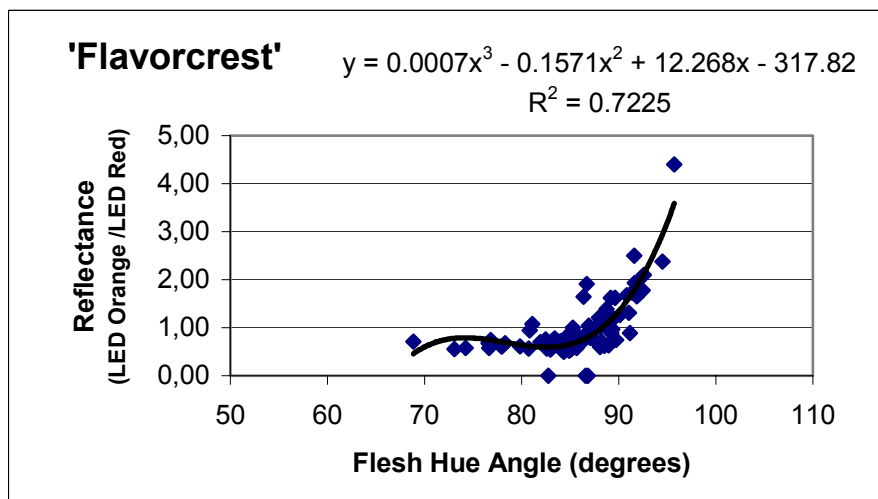'Flavorcrest' $y = 0.0007x^3 - 0.1571x^2 + 12.268x - 317.82$
$R^2 = 0.7225$

Figure 3. Nonlinear estimation model between LED ratio (orange/red values) and flesh color, for 'Flavorcrest' peach samples.
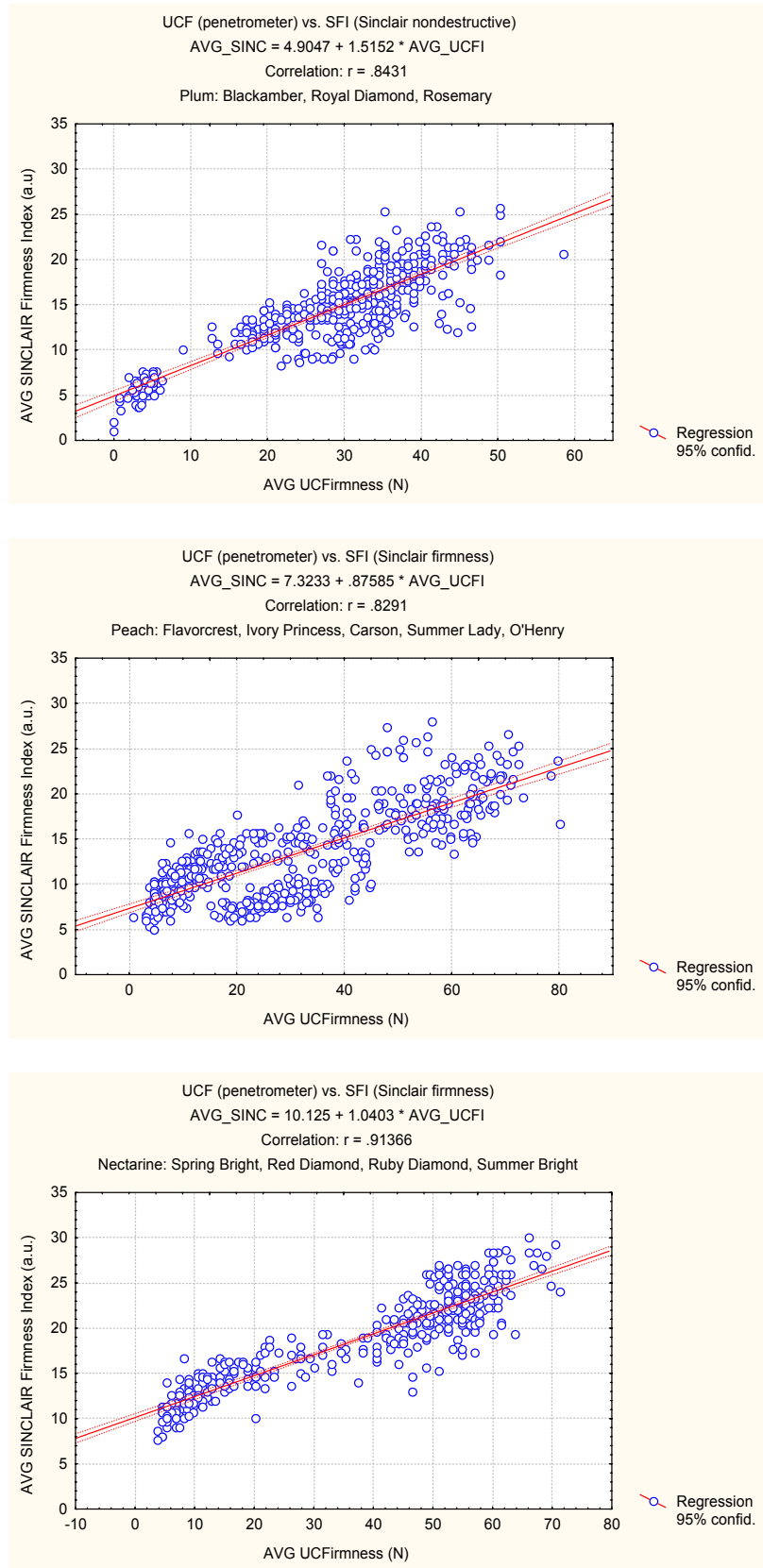
Figure 4. Correlation between destructive firmness measurement (UCF penetrometer) and
   nondestructive Sinclair firmness index (SFI) for plum (upper panel), peach (middle panel)
   and nectarine (lower panel) cultivars.