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Nondestructive determination of flesh color in clingstone peaches

D.C. Slaughter [a,*], C.H. Crisosto [b], G. Tiwari [a]

[a] Department of Biological and Agricultural Engineering, University of California, One Shields Avenue, Davis, CA 95616, USA
[b] Department of Plant Sciences, University of California, One Shields Avenue, Davis, CA 95616, USA

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ABSTRACT

A nondestructive optical method, based upon visible and near infrared interactance spectroscopy, was developed for rapid determination of flesh color in clingstone peaches. Flesh color is currently used by the Californian canning peach industry as a destructive maturity index for clingstone peaches inspected at harvest and as a predictor of sensory flavor quality. Results show that skin ground color becomes uncorrelated with flesh color for skin ground color hue angles below 70°. Cultivar-specific models using nondestructive, log-transformed, interactance measurements at two wavebands in the visible region produced good predictive performance of flesh hue ($r = 0.92$), while a global model required information at five wavebands to achieve this same level of performance ($r = 0.92$ and RMSECV = 1.35° hue). The nondestructive method does not require a separate measurement of skin reflectance and is suitable for flesh color grading tasks at inspection stations prior to canning and shows good potential for on-line sorting tasks.

1. Introduction

California is the major producer of clingstone peaches in the United States, with a total estimated production of 420,000 tons in 2010 (USDA-NASS, 2010). Clingstone peaches are largely used for canning due to their superior retention of flavor and texture in the canning process. US Grade B quality is the minimum standard for all canned clingstone peaches (USDA-AMS, 1985), which requires that fruit possess reasonably good flavor and color, and should be free from defects. Californian canning peaches are inspected at harvest as part of an industry quality control program to ensure a high quality final canned product.

Several research studies have shown that flavor after canning was dependent upon the maturity and handling of the fruit prior to canning (Fuleki and Cook, 1976; Kader et al., 1982; Delwiche et al., 1987; Delwiche, 1989). Kramer and Smith (1946) observed that flesh color was the most evident and frequently the principal factor related to the characterization of quality in canned produce. Leonard et al. (1953) reported that the flesh color of fresh clingstone peaches was useful in distinguishing fruit with superior flavor from those with inferior flavor. In a consumer study of 2277 individuals in 1965 in Victoria, Australia, Czerkaskyj (1971) asked their opinions of how much they liked the color of three categories (pale yellow: Gardner color values $L = 57.8$, $a = 8.1$, and $b = 33.5$; medium orange: Gardner color values $L = 62.6$, $a = 9.3$, and $b = 37.3$; and deep orange: Gardner color values $L = 54.5$, $a = 11.9$, $b = 33.9$) of canned clingstone peaches. The pale yellow fruit was disliked by 56% of the people, while 97% liked the medium orange colored fruit and 84% liked the deep orange colored fruit, further demonstrating the importance of fruit color in consumer acceptance. In California, clingstone peaches are evaluated for maturity at harvest based upon their flesh color.

Fruit firmness is another important quality attribute in canning peaches. Clingstone peaches are easily bruised at harvest and during subsequent transport and handling if they are too soft. Additional damage may occur in pitting and peeling operations, and disintegration of the flesh may occur during thermal processing operations of soft fruit (Mitchell and Kader, 1989). It is reported that processing peaches at 'firm ripe' stage maximizes canning yields of well-colored and flavorful peaches (Crisosto et al., 2007).

The current methodology employed by the California Department of Food and Agriculture (CDFA) Shipping Point Inspection Program to access flesh color (for maturity) and firmness (for canning yield) of canning peaches utilize destructive techniques. Flesh color is determined by slicing the fruit to a depth of 6.4 mm (or 12.7 mm for extra early cultivars) from its smaller cheek, and then its flesh color is compared against the color of an industry standard colored disk used as reference standard for minimum maturity (Delwiche, 1989; Slaughter et al., 2006). Trained inspectors initially evaluate fruit firmness by touch, and any fruit considered as possibly too soft to survive the canning process without flesh damage are subjected to a destructive penetrometer flesh firmness test (Slaughter et al., 2006).

* Corresponding author. Address: 2030 Bainer Hall, One Shields Avenue, Davis, CA 95616, USA. Tel.: +1 530 7520102; fax: +1 530 7522640.
E-mail address: dcslaughter@ucdavis.edu (D.C. Slaughter).

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Several objective and nondestructive methods to determine flesh firmness have been reviewed and discussed in detail (Chen and Sun, 1991; Abbott, 1999). Also, systems for nondestructive assessment of flesh firmness are commercially available for both bench-top and on-line applications. Though nondestructive methods exist for assessing fruit skin color, they are not well suited for determining flesh color as several studies have reported that the CDFA maturity or flesh color of clingstone peaches cannot be reliably determined from fruit texture or skin color (e.g., Fuleki and Cook, 1976). Therefore, it is desirable to develop a nondestructive method, which can measure flesh color in order to ensure good quality canning peaches.

Near-infrared (NIR) spectroscopic techniques have been developed for nondestructive assessment of internal quality characteristics such as soluble solids content and total solids content (Slaughter and Abbott, 2004) of fresh produce. The technique has been investigated to determine many different quality attributes of peaches, such as, soluble solids (Kawano et al., 1992; Slaughter, 1995; Peiris et al., 1998; Jiang et al., 2006; Golding et al., 2006; Ma et al., 2007; Xu et al., 2008), titrable acidity (Ying et al., 2005; Shao and He, 2006), firmness (Carlomagno et al., 2004), wooly peaches (Ortiz et al., 2001), or astringent peaches (Takano et al., 2007). Because peaches are typically canned in syrup, making soluble solids less important as compared to fresh market fruit, and because NIR prediction of titrable acidity is only robust in high acid fruits (Subedi et al., 2012), flesh color remains the maturity index of choice in canning peaches in California.

The objective of this study was to determine the feasibility of developing a rapid and nondestructive method of measuring flesh color in clingstone peaches for canning to replace the current destructive flesh color maturity index. The specific objectives were to:

(1) Characterize the relationship between skin color and flesh color in terms of hue angle, and
(2) Assess the feasibility of nondestructive determination of flesh color (as hue angle) using intact fruit interactance measurements, with or without skin reflectance information.

2. Materials and methods

A set of 617 Californian clingstone peaches (167 '*Loadel*', 150 '*Carson*', 150 '*Andross*', and 150 '*Ross*') with a range of skin color was collected over a 1 month period from mid July through mid August at canning peach inspection stations in Yuba City, CA and transported to the laboratory at UC Davis. The fruit were stored for 24 h at 5 °C and then allowed to warm to room temperature (25 °C) prior to measurement.

The skin color and reflectance spectrum of each intact fruit was measured nondestructively at the location specified by the official California Department of Food and Agriculture (CDFA) Shipping Point Inspection (SPI) procedure (the location with the greenest peel color on the center of the smaller side of the peach) using a spectrophotometer (Model Color-Guide, BYK-Gardner, Columbia, Maryland, USA). The spectrophotometer was calibrated following the manufacturer's specified method using the manufacturer's standard reference black and white calibration tiles. The spectrophotometer was set to record the abridged reflectance spectrum (every 20 nm between 400 and 700 nm) using a 20 mm diameter circular measurement aperture and a 45/0 optical geometry and to display the International commission on illumination (CIE) color values luminance (L^*), chromaticity (C^*), and hue angle (h^*) values for each fruit. The standard illuminant D65 and the 10° standard observer were used for all color measurements (peel and flesh) in the study.

After the skin color was measured, the intact fruit were placed on an interactance probe (Fig. 1) and the interactance spectrum measured nondestructively using a diode array spectrophotometer (model S2000, temperature regulated, Ocean Optics, Dunedin, Florida, USA) from 400 to 855 nm in 0.316 nm increments. Using the method of Conway et al. (1984) the diode array spectrophotometer was standardized before each measurement by measuring the reference signal from a white Polytetrafluoroethylene (i.e., Teflon®, DuPont Co.) cylindrical block, 50 mm in diameter and 22 mm thick. The interactance spectrum was measured at the same fruit location where the skin color was measured. The fruit were then cut using the CDFA official maturity slicer using the official 'single cut' method, which removed a 6.4 mm thick slice of tissue just below the peel, at the same location where the skin color was measured in order to expose the flesh. The reflectance spectrum of the flesh was determined at this spot using the same spectrophotometer used for peel reflectance measurements and the measurement was taken immediately after cutting in order to avoid flesh browning effects. The CIE L^*, C^*, h^* color values were automatically calculated by the spectrophotometer and recorded for each fruit.

Using the method of Conway et al. (1984), the standardized interactance values, I_λ, at each wavelength, λ, were processed to:

$$A_\lambda = \mathrm{Log}_{10}(1/I_\lambda) \quad (1)$$

to be similar to the use of $\mathrm{Log}_{10}(1/T_\lambda)$ for transmission measurements, T_λ, in the traditional application of the Beer–Lambert law. In order to reduce the effects of multicolinearity and due to the fact that the optical system (incorporating both slit width, fiber optics and internal lens effects) had an optical bandwidth of 5 nm, the absorbance spectra was subsampled to 5 nm spacing after application of a Savitzky–Golay quadratic smoothing operation (Savitzky and Golay, 1964; with corrections by Steinier et al., 1972). The second derivative spectra were also computed from the standardized interactance spectra using the Savitzky–Golay method. The skin and flesh reflectance spectra and color data were merged with the intact fruit interactance data.

The data were analyzed with both multiple linear regression (MLR) and partial least squares (PLSs) regression techniques using a commercial statistical software package (PROC REG and PROC PLS, respectively, SAS institute, Cary, NC, USA). In both cases, the number of terms or factors, respectively, was selected using one-out internal cross validation, and the PRESS statistic was used to determine the minimum number of independent variables (for MLR) or factors (for PLS) that produced cross-validation performance not significantly ($\alpha = 0.05$) inferior to the optimum model (for more information, please see the section on cross validation

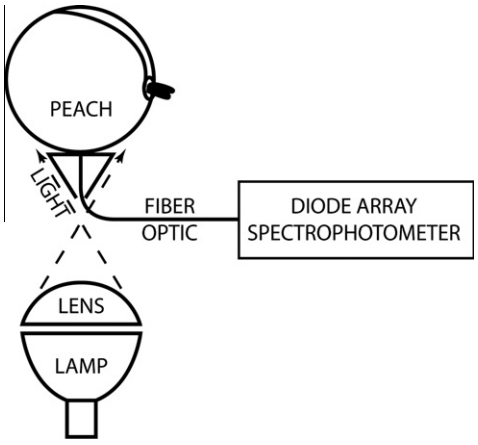

Fig. 1. Illustration of the setup used to nondestructively measure the interactance of intact peaches.

in the SAS online documentation for PROC PLS). The relationship between skin color and flesh color in terms of hue angle (h^*) was analyzed using PROC REG for both the entire set of fruit as well as the subset of fruit with skin hue angles above 70°.

3. Results and discussion

3.1. Relationship between skin and flesh color

Clingstone peaches across a wide range of maturities were included in the study. The mean flesh hue angle of the fruit was 76.2° with a standard deviation of 3.6°. The relationship between skin color hue angle and flesh color hue angle based upon diffuse reflectance is shown in Fig. 2. It is clear from this graph that the relationship between skin and flesh hue angle is non-linear and that while the flesh color changed from a greenish-yellow (hue angles above 85°) to a deep orange (hue angles below 75°) during development, the flesh hue angle did not fall below 65°, for the cultivars studied. In contrast, the skin, at the location specified by the official CDFA method, in some of the fruit with more advanced maturity developed a distinctly orange to reddish-orange colored hue with a minimum hue angle of about 33°. The linear correlation coefficient was only $r = 0.5$ (significant at the $\alpha = 0.01$ level) between the hue angles of the skin and flesh in the canning peach varieties studied, when all fruit were included in the analysis. This figure also shows that for the fruit with a skin hue angle below 70°, changes in skin color did not reflect any consistent change in flesh color. Crisosto (1994) observation that several newer peach cultivars have red peel coloration that masks the skin's 'ground' color (the nonblushed color of the skin facing the ground when the fruit is on the tree) and limits skin color as a maturity index is consistent with these results. These results also confirm the canning industry's conventional aphorism that flesh color cannot be determined by visual observation of the unpeeled fruit.

The data were reanalyzed using only those fruits with skin hue angles greater than 70°, eliminating the fruit with blush colored peels at the location specified by the official CDFA method (Fig. 3). Results show that, for fruit with skin hue angles greater than 70°, the correlation between skin and flesh hue angles improves to $r = 0.63$ (significant at the $\alpha = 0.01$ level). Rood (1957) observed negative correlations ranging from $r = -0.66$ to $r = -0.87$ between the flesh extracted total chlorophyll and sensory eating quality rating in freestone peaches, which are comparable to or a little higher in magnitude than the results in Fig. 3. These results also indicate that, even when the method is restricted to less mature fruit with skin hue angles above 70° where a linear relationship is plausible, the prediction of canning peach flesh color by measuring the skin color did not give satisfactory performance for fruit quality assessment. The data also confirmed the need in the current CDFA method to remove the skin and measure the flesh color directly, when using conventional destructive surface reflectance methods as specified in the official procedure for fruit maturity inspection in canning peaches.

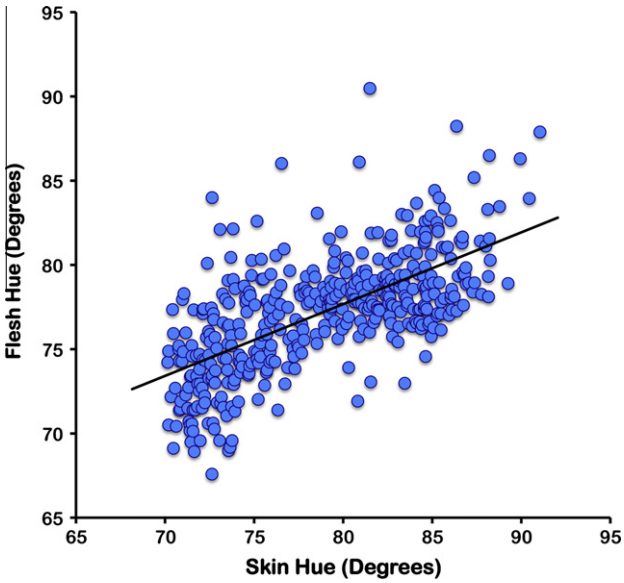

Fig. 3. Plot showing the linear relationship between skin color and flesh color for those peaches with a skin hue greater than 70°. The linear correlation coefficient between skin color and flesh color for the data shown was $r = 0.63$.

To assess the underlying optical properties of canning peaches as the fruit mature, the fruit were categorized into seven flesh hue groups spanning the range of color in the study and the mean skin and flesh reflectance spectra for each group were determined, Figs. 4 and 5, respectively. A comparison of these two figures shows that the predominant difference lies the 600–700 nm region where chlorophyll is the dominant optical absorber (Hollaender, 1956). As the fruit advance from the immature to mature stages, there is a fairly consistent increase in reflectance in the red region of the spectrum where chlorophyll absorbs light. These results are consistent with those of Sidwell et al. (1961), where they observed that the most noticeable maturation induced change was a

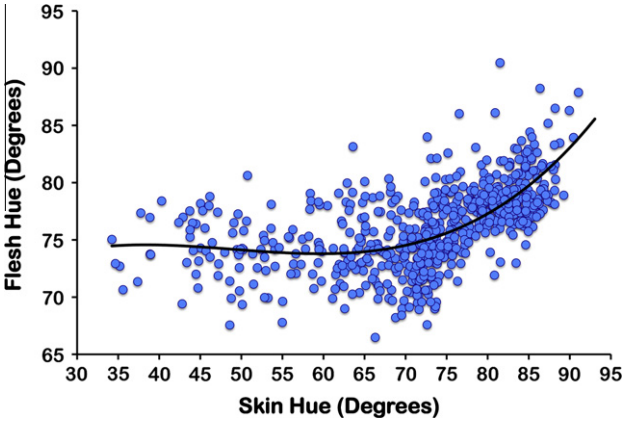

Fig. 2. Plot showing the non-linear relationship between skin color and flesh color for four clingstone peach cultivars. The linear correlation coefficient between skin color and flesh color was $r = 0.5$.

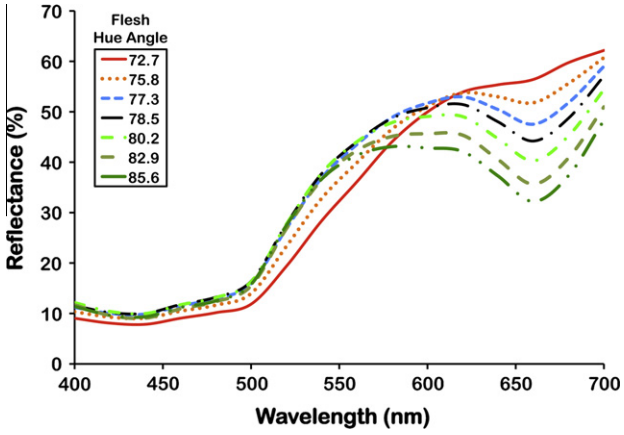

Fig. 4. Plot showing the change in the mean diffuse reflectance spectra of the skin for subsets of peaches with similar flesh hue angles (in degrees).

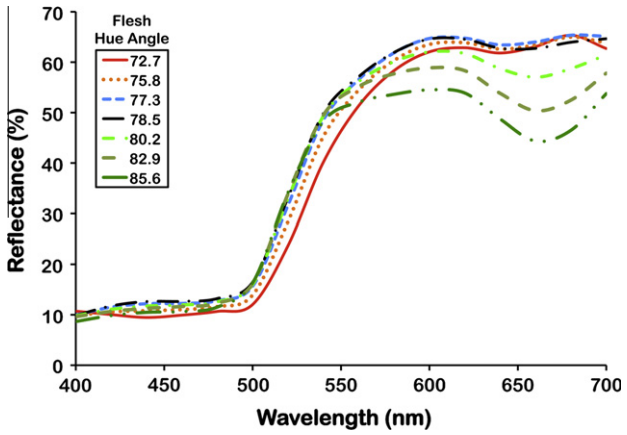

Fig. 5. Plot showing the change in the mean diffuse reflectance spectra of the flesh for subsets of peaches with similar flesh hue angles (in degrees).

decrease in absorbance in a narrow band at 675 nm in whole fruit transmission measurements on the freestone, fresh market peach '*Elberta*'. They also found that early harvest fruit were more optically dense than the 6 OD range of the novel instrument used (Birth and Norris, 1958). Rood (1957) observed that chlorophyll content of the flesh was not as strong a predictor of eating quality in freestone peaches as was skin 'ground' color, which the current study has shown in Fig. 2 to be problematic in clingstone peaches.

Careful comparison of Figs. 4 and 5 shows that while there is a systematic increase in the mean skin reflectance at about 675 nm with decreasing flesh hue angle, the general level of reflectance in the mean flesh spectra are quite similar for fruit with flesh hue angles about 79° and below. The overall reflectance values are higher in the flesh than they are in the skin at wavelengths between 500 and 700 nm as are the slope of the reflectance curves between 500 and 550 nm. These differences between skin and flesh reflectance appear to show why chlorophyll-dominated optical indexes are not good predictors of flesh hue angle.

3.2. Nondestructive flesh color prediction

A preliminary study was conducted to compare the performance of both spectral preprocessing methods as well as discrete waveband (i.e., fewer than 10 wavebands) multiple linear regression (MLR) and full-spectrum PLS-based model building methods for use in this study. These preliminary analyses indicated that the MLR method, based upon the log transform shown in Eq. (1) and the RSQUARE selection method in PROC REG (SAS Institute Inc., 2009), which determines all possible subset regressions up to a specified model size, gave the best model performance for predicting flesh hue angle. The result regarding the use of A_λ rather than I_λ is similar to those of Conway et al. who found that like $\mathrm{Log}_{10}(1/R_\lambda)$, where R_λ is the diffuse reflectance, the $\mathrm{Log}_{10}(1/I_\lambda)$ transform of the interactance spectra improved the linearity of the model relationship to chemical constituents in biological materials. Use of the second derivative spectra, or using PLS regression methods in this study produced inferior model performance and so the MLR method applied to the A_λ preprocessed spectral values was used for all models.

Multiple linear regression models were developed to predict the flesh hue angle using both the nondestructively measured intact fruit interactance spectra and the skin reflectance spectra. Thus a total of 108 variables were available to the MLR method for model development. Separate models were developed for each cultivar as well as a combined "global" model for all cultivars (Table 1). In each case, inclusion of any skin reflectance variables in the model did not improve the performance, while in contrast, exclusion of all interactance variables significantly degraded the flesh hue prediction. Thus, to simplify the final measurement method, only the log transformed interactance variables, A_λ, acquired nondestructively using the method shown in Fig. 1 were included in the final models selected. The number of model terms was set to the minimum number of terms (i.e. the simplest model) that produced a PRESS for one-out cross validation that was not significantly different ($\alpha = 0.05$) from the minimum PRESS for models containing up to 25 terms. In general, all nondestructive interactance models gave good flesh hue angle prediction performance with correlations of $r = 0.92$ or greater and RMSECV values of 1.41° (hue angle) or less.

There were substantial cultivar differences in the number of model terms selected by the one-out cross validation criterion. The final models for both '*Loadel*' and '*Ross*' cultivars contained two A_λ terms while the models for both '*Andross*' and '*Carson*' cultivars contained four terms. When restricted models with two A_λ terms were applied to the both '*Andross*' and '*Carson*' cultivars, the models' performance were similar to that of the two term models for both '*Loadel*' and '*Ross*'. All optimized two term models utilized wavebands in the 530–675 nm region with parameters of opposite signs, but with varying gap spacings and varying levels of symmetry between the model parameter magnitudes. Upon combining the cultivars to form a global model, a two term model had reduced performance with a correlation of $r = 0.87$ between predicted and actual hue angle with a gradual increase in performance to $r = 0.92$ when the final five term model shown in Table 1 was obtained.

Examination of the nondestructive interactance model parameters showed that the MLR method essentially created a customized 1st or 2nd derivative-like treatment of the data. For example, the MLR prediction model for '*Ross*' shown in Eq. (2) has model parameters for the $A_{560\ \mathrm{nm}}$ and $A_{545\ \mathrm{nm}}$ terms with nearly identical magnitudes, but opposite signs. Thus Eq. (2) is essentially a 1st derivative between 560 nm and 545 nm with a gap spacing of 15 nm. The model form for '*Loadel*' also showed a similar sign pattern, however the magnitude of the parameter for the 575 nm term was about 25% higher than that of the 545 nm term. The five term MLR prediction model for all cultivars shown in Eq. (3) can be viewed as approximating a 2nd derivative term centered at 560 nm with a 10 nm gap plus a 1st derivative term between 695 nm and 710 nm with a 15 nm gap. The magnitudes of the

Table 1
Multiple linear regression models for nondestructive flesh hue angle prediction.

Cultivar	Wavelengths in interactance model					r	RMSECV[a]
	λ_1 (nm)	λ_2 (nm)	λ_3 (nm)	λ_4 (nm)	λ_5 (nm)		
'*Andross*'	545	560	600	690		0.96	1.04
'*Carson*'	550	560	580	640		0.96	1.12
'*Loadel*'	545	575				0.92	1.41
'*Ross*'	545	560				0.92	1.10
Combined	550	560	570	695	710	0.92	1.35

[a] Root mean standard error of cross-validation.

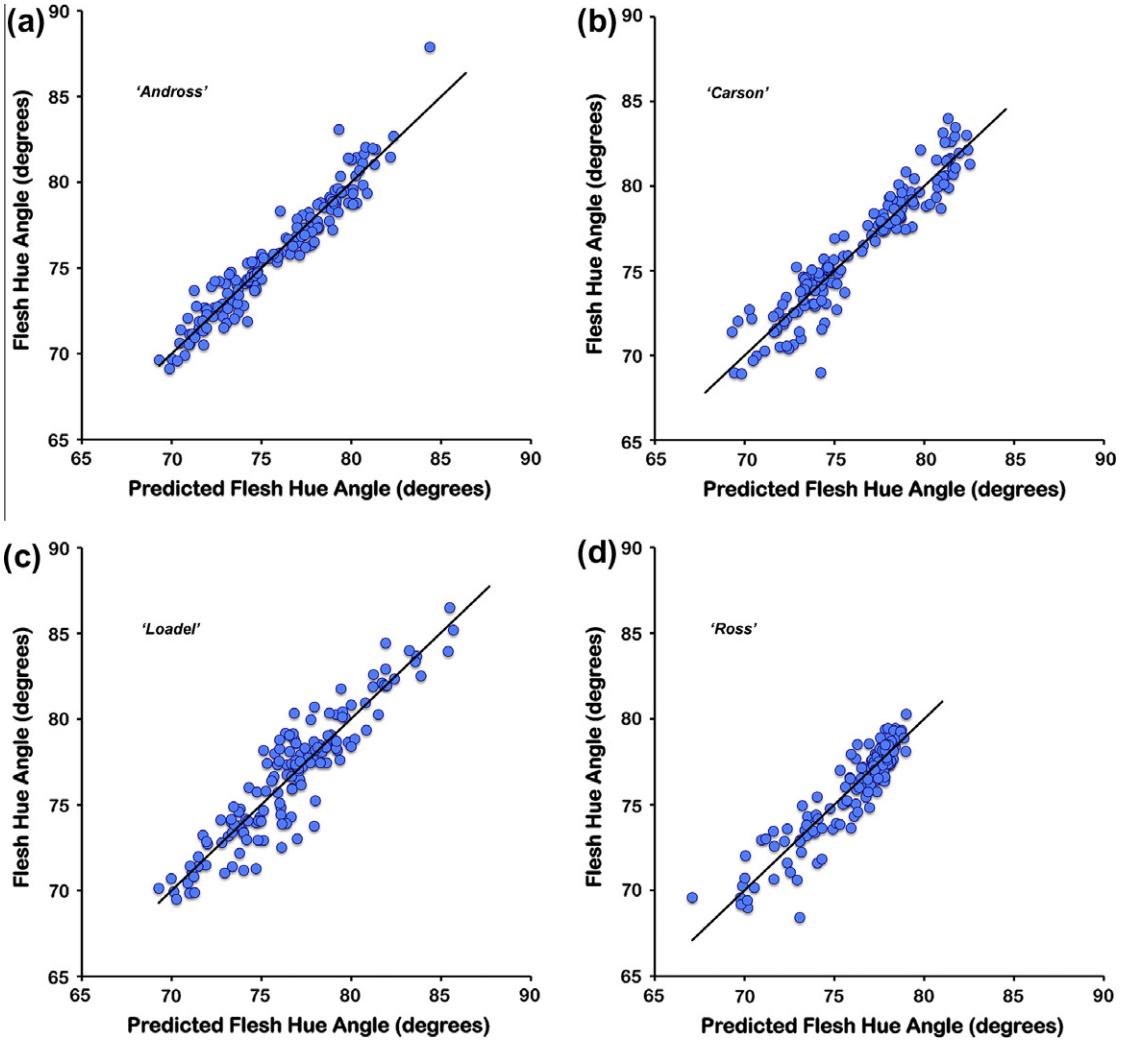

Fig. 6. Panel showing the cultivar specific relationships between the actual flesh color and the predicted flesh color for each of the four peach cultivars using the instrumental setup in Fig. 1. The linear correlation coefficients for each relationship were: $r = 0.96$ for '*Andross*', $r = 0.96$ for '*Carson*', $r = 0.92$ for '*Loadel*', and $r = 0.92$ for '*Ross*'.

model parameters vary from ~5% to ~10% from the true 1st and 2nd derivative parameters and helps explain why the MLR method based upon the individual A_{λ} values was superior to methods which imposed symmetric model parameters used in traditional derivative preprocessing techniques. The advantage of this cross-validated model selection method was that the derivative order and gap spacings did not need to be predetermined, allowing a greater degree of optimization while minimizing the number of model terms.

$$\text{Predicted flesh hue angle for '}Ross\text{'} = 82.65 + 16.52 * A_{560\,\text{nm}} - 16.55 * A_{545\,\text{nm}} \quad (2)$$

$$\text{Predicted flesh hue angle} = 77.08 - [55.73 * A_{570\,\text{nm}} - 101.64 * A_{560\,\text{nm}} + 49.85 * A_{550\,\text{nm}}] - [19.27 * A_{710\,\text{nm}} - 20.49 * A_{695\,\text{nm}}] \quad (3)$$

Plots of the actual versus predicted flesh hue angles are shown in Fig. 6 for each of the four cultivars and in Fig. 7 for all cultivars combined. The selected nondestructive interactance models showed good linearity across the range of flesh hue angles studied. The results showed that the nondestructive interactance measurement technique shown in Fig. 1 has good potential as a nondestructive predictor of flesh hue angle in clingstone peaches. One

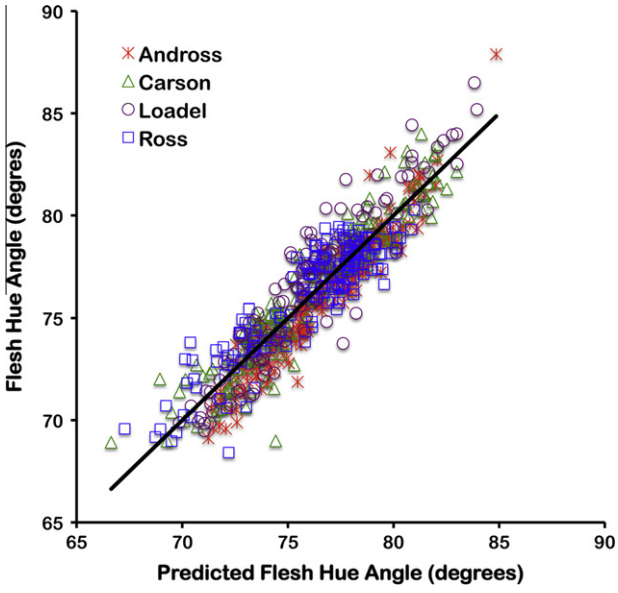

Fig. 7. Plot showing the relationship between the actual flesh color and the predicted flesh color of a global model for the four peach cultivars combined. The linear correlation coefficient for this relationship was $r = 0.92$.

advantage of this method is that the optical configuration is similar to that used in existing commercial on-line NIR internal quality sorting systems for soluble solids content available for fresh market produce. The main change required would be to expand the wavelength region to include visible wavebands. When combined with existing on-line nondestructive impact-type firmness sensing techniques, it appears that on-line nondestructive sensing of both flesh firmness and color are feasible.

4. Conclusion

The feasibility of measuring the flesh color of clingstone peaches using a nondestructive interactance measurement without cutting the skin was demonstrated. This nondestructive optical method predicted the flesh color with a RMSECV (root mean square error of cross-validation) of 1.35° (hue angle) across four peach cultivars used in commercial canning in California. Because it is nondestructive and a rapid optical technique, this method of measuring flesh color is well suited for online use. If combined with online firmness measurement technology, the potential exists for high-speed inspection and sorting of clingstone peaches for flesh color and firmness quality characteristics.

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