Predicting Pitting Damage During Processing in Californian Clingstone Peaches Using Color and Firmness Measurements

C. H. Crisosto, C. Valero, D. C. Slaughter

Abstract. *Nondestructive and destructive measures of color and firmness were studied to determine the feasibility of predicting the level of damage to clingstone peaches during mechanical pitting. Nondestructive and destructive measures of firmness were equally variable when measuring the firmness at three equatorial cheek locations (coefficient of variation of about 17%), both had inverse relationships with the level of pitting damage (r^2 ranged from 0.70 to 0.83), and could classify peaches into two categories (those subject to and those not subject to pitting damage) with classification accuracies of 75.2% and 81.7%, respectively. Destructive firmness was not a good predictor of nondestructive firmness in clingstone peaches. Skin color was not a good predictor of flesh color in clingstone peaches, and flesh color was not a good predictor of potential for damage to clingstone peaches during mechanical pitting.*

Keywords. *Peach, Pitting, Firmness, Color, Nondestructive.*

Assessment of fruit quality is an important preprocessing tool in canning peaches because it can determine the suitability of individual fruit for processing and its consumer acceptance. Two important criteria in quality assessment of peaches are flesh color and flesh firmness because research has shown that they are good indices of maturity (Rood, 1957). Unfortunately, quality assessment is often a destructive and/or subjective process. For example, the current official method of quality assessment of fruit firmness for Californian clingstone peaches is based upon the tactile evaluation of the fruit when subjected to fingertip compression, and flesh color is visually evaluated by comparison with colored plastic reference standards (Delwiche, 1989).

Clingstone peaches used in canning differ from freestone peaches common to the fresh market in that their flesh tends to be firmer when ripe than freestone peaches and that their flesh adheres to the pit when ripe. After harvest, the fruit are washed and mechanically pitted. The pitting operation typically involves cutting the fruit along the suture and then application of a torque load to twist the peach halves from the pit, requiring a minimum level of tissue strength. Ideally, clingstone peaches should be canned when they are nearly at their optimal ripeness with full size and significant color and flavor but still firm enough for field and cannery handling and transport without bruising (Metheney et al., 2002). If fruit become too soft, they are easily bruised when handled and additional losses occur in pitting and peeling operations, and the flesh may disintegrate during thermal processing (Mitchell and Kader, 1989). Processing the fruit at the "firm ripe" stage maximizes canning yield of well-colored, flavorful fruit of good texture.

Considerable research has been conducted on the theory of elastic and viscoelastic behavior and strength characteristics of fruit tissue over the past 40 years (e.g. Timbers et al., 1965; Fridley et al., 1968; Hamann, 1970; Chen and Fridley, 1972; Chen and Chen, 1986; Delwiche, 1987). Several instrumental techniques have been used for fruit firmness measurement. The most common are peak force measurements based upon Magness-Taylor style cylindrical penetrometer probes with spherically shaped tips (Magness and Taylor, 1925), due to their low cost, simplicity of operation, portability, and general ability to assess fruit maturity. The main disadvantage of the penetrometer-type firmness measurement is that it is destructive. Relatively recent nondestructive firmness measurement techniques have become commercially available. Based upon high-speed impact by low mass probes, these techniques are gaining popularity because they are nondestructive and suited for online use. Reviews of fruit firmness measurement technologies can be found in Chen (1996) and in Abbott (1999).

Color has long been used in the assessment of fruit quality. In many fruits, there is a decrease in chlorophyll content of the skin that is correlated with increasing maturity, making visual assessment of fruit color an index of maturity. Because peaches are canned without skin, Californian clingstone peaches are evaluated for maturity based upon their flesh color. The current official Californian flesh color assessment

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method utilizes three colored plastic reference standards (color disks 2, 3, and 4; Delwiche, 1989). Kader et al. (1982) determined that the color of fresh flesh in clingstone peaches, as measured by the “a” value in the Gardner Rd, a, and b color system, was correlated with the color of the canned product. A description of color measurement theory and techniques and their applications to other agricultural commodities can be found in Mohsenin (1984).

Damage during mechanical pitting operations attributed to soft fruits in the processing of clingstone peaches is a significant concern in the canned peach industry. Unfortunately the current postharvest inspection methods for peach maturity and softness use subjective methods and in the case of softness, has no reference for standardization. There is a need to develop quantitative sensing methods for identifying and possibly sorting fruit according to its suitability for mechanical pitting.

The objectives for this study were:

- Determine the relationship between skin color (nondestructive) and flesh color (destructive measure) for Californian clingstone peaches.
- Determine the relationship between the traditional destructive penetrometer method of measuring fruit firmness and a nondestructive impact-type method for Californian clingstone peaches.
- Study the relationship between fruit firmness (both nondestructive impact and destructive penetrometer types) prior to processing and damage to Californian clingstone peaches during pitting.
- Study the relationship between flesh color and damage to Californian clingstone peaches during pitting.
- Determine the classification rate for using flesh color or flesh firmness of Californian clingstone peaches measured prior to processing into two categories: damaged and undamaged during pitting.

Materials and Methods

Three clingstone peach cultivars (c.v. ‘Andross,’ ’Carson,’ and ‘Ross’ in approximately equal quantities) were selected for study. Fruit were collected in 2001 and 2002 (1079 fruit in 2001 and 1309 fruit in 2002) from canning peaches received for processing in Kingsburg, California. The basic procedure was to measure the firmness and color of each fruit instrumentally before pitting. The fruit were then pitted and manually evaluated for pitting damage. Nondestructive measurements (impact firmness and skin color) were conducted prior to destructive measurements (penetrometer firmness and flesh color).

Nondestructive fruit firmness was determined using an early bench top prototype of a commercial online impact firmness measurement system (iQ™ firmness tester, model SIQ-FT, Sinclair Systems International, LLC, Fresno, Calif.). This device used a pneumatically operated impact head equipped with a piezoelectric sensor. The output was processed by proprietary software to return a measure of fruit firmness (iQ™ value called SFI in this study) as a number indexed from 0 to 100 with 0 being soft and 100 being firm. It should be noted that the manufacturer modified the impact firmness index definition by a multiplicative factor of about two between the manufacture of the prototype used in this study and subsequent models in order to improve the suitability of the system to a wide range of produce types (Howarth, 2006). Prior to each use the impact firmness tester was calibrated using an elastic calibration ball of known firmness and the operating pressure and the vacuum was adjusted to operate the pneumatic head within ±7 kPa of the manufacturer’s recommended set points. The impact firmness was measured at three equatorial positions of each intact fruit. In 2001, the average impact firmness was recorded for each fruit while in 2002 the three individual firmness measures were recorded for each fruit to allow assessment of firmness variation.

The other nondestructive measurement was skin color. In California, the maturity of canning peaches is determined by visually comparing the greenest cheek to one of the California Department of Food and Agriculture’s (CDFA) official color grading disks. To maintain compatibility with this official system, the skin color of each peach was measured on fruit collected in 2002 at the greenest cheek location using a colorimeter (model CM2002, Minolta, Ramsey, N.J.). The skin color was measured using CIE standard illuminant C with a 2-degree observer and was expressed in the CIE L*C*h* color space (CIE, 2004).

After the nondestructive measurements were complete a small section of peel was removed (to the industry standard depth of about 5 mm) on the equator of the greenest cheek at the same location of each fruit where the skin color was measured, and the flesh color was then determined using the colorimeter. Small sections of fruit were also removed at the remaining two equatorial locations where the impact firmness measurements were taken to allow penetrometer firmness measurements to be taken at the same locations. The second measure of firmness was obtained at each of the three cheek positions using a Magness-Taylor style penetrometer (UCP). This device was equipped with a manual force gage (Ametek, Hatfield, Pa.), a 7.9-mm diameter standard Magness-Taylor probe (Abbott, 1999) with a spherical tip radius of 5.16 mm, and was mounted on the standard University of California style hand-operated press (Western Industrial Supply Co., San Francisco, Calif.) to minimize loading rate variations associated with the operator.

Once firmness and color measurements had been obtained, the fruit were transported to a nearby peach processing plant where a commercially available mechanical clingstone peach pitter (Atlas Pacific Engineering Co., Inc, Pueblo, Colo.) was used to pit the fruit. After pitting, the fruit were manually evaluated for damage using the following scale:

Pitting Damage Score	Damage Observed
0	None
1	Minor damage
2	Severe damage to one half of the fruit
3	Severe damage to both halves of the fruit

The data were consolidated and analyzed using the SAS statistical analysis software package. Linear regression analysis was conducted (using Proc GLM) to characterize the relationship between color and firmness measures and pitting damage. Discriminant analysis was also conducted (using Proc Discrim) to evaluate the feasibility of classifying peaches into pitting damage categories based upon color or firmness. Two classification analyses were conducted, one for applications with no tolerance to pitting damage and a second for applications with some tolerance to pitting damage. For applications with no tolerance to pitting damage, the percentage of fruit with “any” pitting damage (i.e., fruit with pitting damage scores of 1, 2, or 3) was determined for each firmness level. For applications with some tolerance to pitting damage, the percentage of fruit with “major” pitting damage (i.e., fruit with pitting damage scores of 2, or 3) was determined for each firmness level.

Results and Discussion

The mean and standard deviation of each color and firmness measurement are presented in table 1 for the three cultivars studied. Linear regression (Proc GLM, SAS) was used to investigate the relationship between skin color (a nondestructive measurement) and flesh color (a destructive measurement) because the ability to predict flesh color from a nondestructive measurement would have great practical value in canning peaches. While statistically significant (0.01 level), the level of correlation between skin color and flesh color was low. The coefficient of determination between skin color and flesh color was 0.18, 0.09, and 0.15 for L*, C*, and h*, respectively, when the data from all three cultivars was combined. When cultivar was added as a factor in the model the coefficient of determination values improved ($r^2 = 0.46$ for L*, $r^2 = 0.23$ for C*, and $r^2 = 0.35$ for h*), but were still too low to be of practical value to the industry. This indicates that skin color is an inadequate predictor of flesh color in clingstone peaches.

A plot of the relationship between the impact firmness measurement and the penetrometer firmness measurement is shown in figure 1. Although the relationship between penetrometer and impact firmness is fairly linear, there is considerable scatter in the data. A linear regression model using penetrometer firmness to predict impact firmness is statistically significant at the 0.01 level, however the coefficient of determination is only $r^2 = 0.46$ and the root mean square error of residuals is 2.1 impact firmness units, indicating low precision for predicting nondestructive impact firmness from destructive penetrometer firmness in clingstone peaches. A model with this level of imprecision will have very little practical value for producers or processors. When cultivar was added as a factor to the model there was a very small improvement ($r^2 = 0.53$, RMSE = 1.99). No improvement in performance was observed when year of harvest was added as a factor to the model.

Table 1. Color and firmness scores[a] for three clingstone peach cultivars.

	Impact Firmness Score		Penetrometer (N)		Flesh Color 2001			Flesh Color 2002			Skin Color 2002		
Cultivar[b]	2001	2002	2001	2002	L*	C*	h*	L*	C*	h*	L*	C*	h*
Andross	11.4 (3.2)	9.4 (2.9)	27.0 (11.6)	19.5 (9.3)	81.0 (1.3)	31.3 (2.2)	84.8 (3.7)	69.4 (2.5)	58.8 (4.9)	86.1 (2.3)	70.2 (2.3)	49.6 (4.0)	85.1 (4.2)
Carson	10.5 (3.0)	9.4 (2.7)	30.1 (11.8)	27.9 (10.2)	78.5 (2.2)	40.5 (6.1)	85.4 (2.7)	76.0 (4.2)	53.1 (5.4)	86.4 (3.2)	72.7 (3.9)	45.3 (4.6)	82.4 (7.1)
Ross	9.9 (1.8)	10.8 (2.9)	30.8 (9.6)	31.6 (9.0)	74.9 (2.8)	48.6 (3.0)	83.4 (3.0)	74.5 (3.7)	58.0 (4.8)	89.0 (3.9)	70.2 (6.1)	47.5 (6.0)	80.7 (11.2)

[a] The mean value is listed first with the standard deviation below in parenthesis.
[b] The number of peaches studied were 383 and 332 ’Andross,’ 396 and 474 ’Carson,’ and 300 and 503 ’Ross’ in 2001 and 2002, respectively.

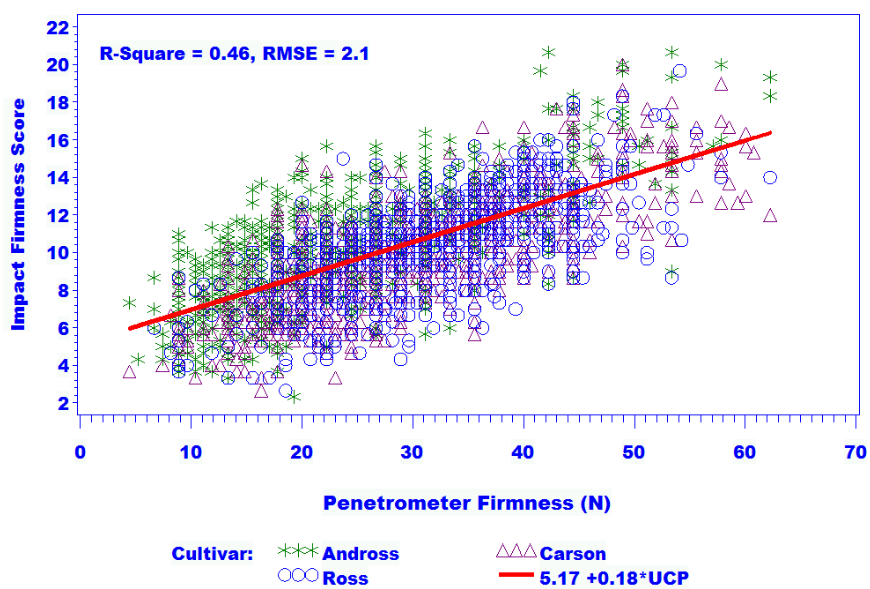

Figure 1. Relationship between impact and penetrometer (UCP) firmness measurements for three clingstone peach cultivars.

The precision of the nondestructive and destructive firmness measures was determined by calculating the coefficient of variation (CV) of firmness measurements taken in 2002 at the three equatorial locations. The average CV for the impact firmness measurement was 16.5% between the three equatorial locations while the average CV for the penetrometer firmness measurement was 17% for the same three locations. A Kruskal-Wallis one-way analysis of variance test determined that the CV values for the nondestructive impact firmness measurement were not significantly different (0.05 level) from the CV values for the destructive penetrometer firmness measurement.

Plots of the relationships between average pitting damage score (averaged across fruit with the same firmness score) and firmness indicate that firmness has an inverse relationship with pitting damage (figs. 2 and 3). Regression analysis showed that the inverse of the impact firmness score was fairly linear with average pitting damage score with a coefficient of determination of $r^2 = 0.70$ and root mean square error of residuals of 0.33 pitting damage units. No improvement in model performance was observed when cultivar was added as a factor to the model. Analysis of the inverse penetrometer firmness score with average pitting damage score showed a remarkably similar pattern to that of the

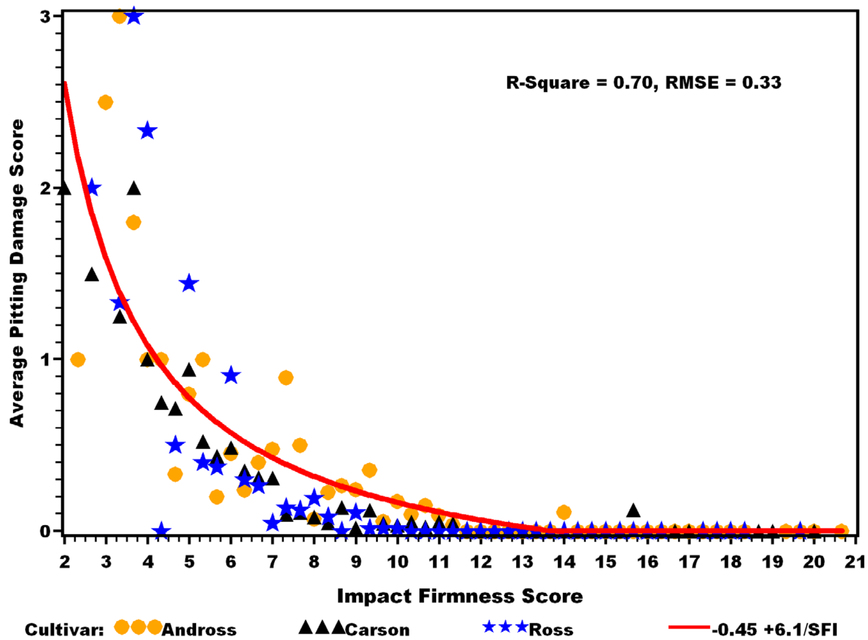

Figure 2. Relationship between average pitting damage score and impact firmness score (SFI) for three clingstone cultivars.

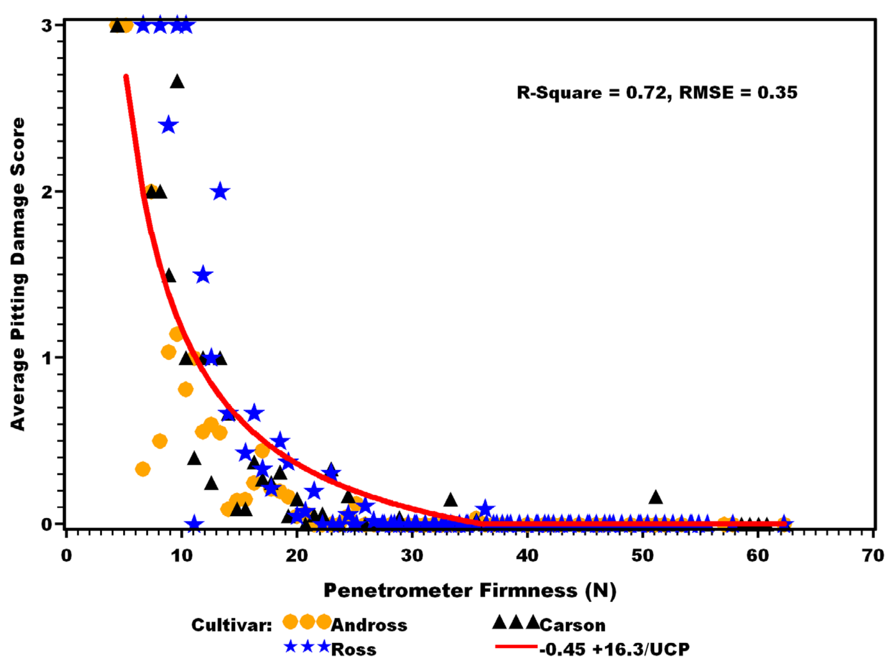

Figure 3. Relationship between average pitting damage score and penetrometer firmness score (UCP) for three clingstone cultivars.

impact firmness despite the fact that impact and penetrometer firmness do not predict one another well. The inverse of the penetrometer firmness score was fairly linear with average pitting damage score with a coefficient of determination of $r^2 = 0.72$ and root mean square error of residuals of 0.35 pitting damage units. When cultivar was added as a factor to the inverse penetrometer model there was a very small but statistically significant (0.01 level) improvement ($r^2 = 0.74$, RMSE = 0.34).

Neither skin color nor flesh color predicted average pitting damage score well. Color models using L*, C*, or h* values separately or in combination were evaluated using linear regression. The best models involved flesh L* and h* values, and while statistically significant (0.01 level) the coefficient of determination was very low $r^2 = 0.06$. While color is used as an index of maturity by CDFA inspectors, it does not appear to be of value in predicting damage to peaches during pitting.

To characterize the distribution in pitting damage at different firmness levels, the percent of fruit with any damage (pitting damage scores of 1, 2, or 3) and major damage were determined for each level of firmness and their relationships to firmness level were analyzed. The basic form of the relationships was similar, so only the plots between fruit with any pitting damage and firmness level are shown (figs. 4 and 5). As with pitting damage score, the percent of fruit that was damaged during pitting had an inverse relationship with firmness. The coefficient of determination between inverse impact firmness, inverse penetrometer firmness, and the percent of fruit damaged during pitting was $r^2 = 0.83$, (RMSE = 11%) and $r^2 = 0.73$, (RMSE = 14%), respectively. When cultivar was added as a factor to either of these firmness models it was statistically significant (0.05 level) but of no practical value as the RMSE value did not change.

A Bayesian classifier (Proc Discrim, SAS) was used to evaluate the classification accuracy of the two firmness methods for separating fruit into damaged (pitting damage scores of 1, 2, or 3) and undamaged (pitting damage score of 0) categories during pitting. Using impact firmness score, a Bayesian classifier was 76.4% correct in predicting which peaches would not experience pitting damage and 73.9% correct in predicting which peaches would experience any damage during pitting. A Bayesian classifier developed using the penetrometer firmness score was 82.5% correct in predicting which peaches would not experience pitting damage and 80.5% correct in predicting which peaches would experience any damage during pitting. The improved performance of the penetrometer classifier may be due to the fact that tissue failure during penetration of the Magness-Taylor probe may be better related to the tissue failure mechanism that occurs when the torque load is applied in the pitter. Being nondestructive, impact firmness measurements are suited for real-time online sensing of potential pitting damage, however the classification levels indicate that future research and development is needed to increase the performance of this technique for predicting which peaches would experience some damage during pitting.

Conclusions

Nondestructive (impact type) and destructive (penetrometer type) firmness measurements show good potential as quantitative methods of predicting the level of damage to Californian clingstone peaches during mechanical pitting. Both impact firmness and penetrometer firmness have inverse relationships to average pitting damage score or the percent of fruit damaged during pitting (r^2 values ranging from 0.70 to 0.83). Impact firmness and penetrometer firmness have similar levels of precision (about 17% coefficient of variation between three equatorial measurements on a fruit) in measuring the firmness of individual fruit. Firmness measured by a penetrometer, although destructive, had a slightly higher classification rate in sorting peaches into damaged and undamaged categories due to mechanical

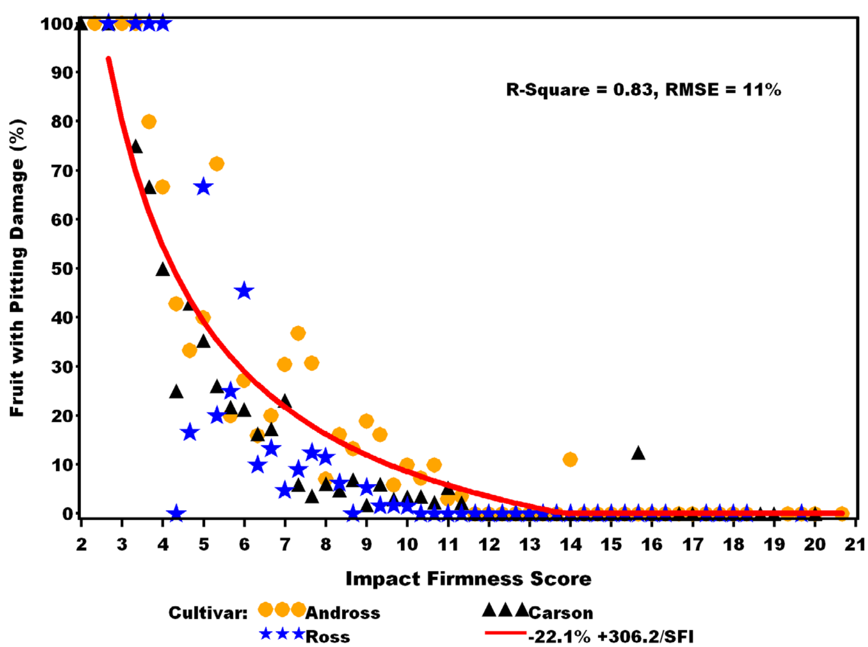

Figure 4. Relationship between the percent of fruit with any pitting damage and impact firmness score (SFI) for three clingstone cultivars.

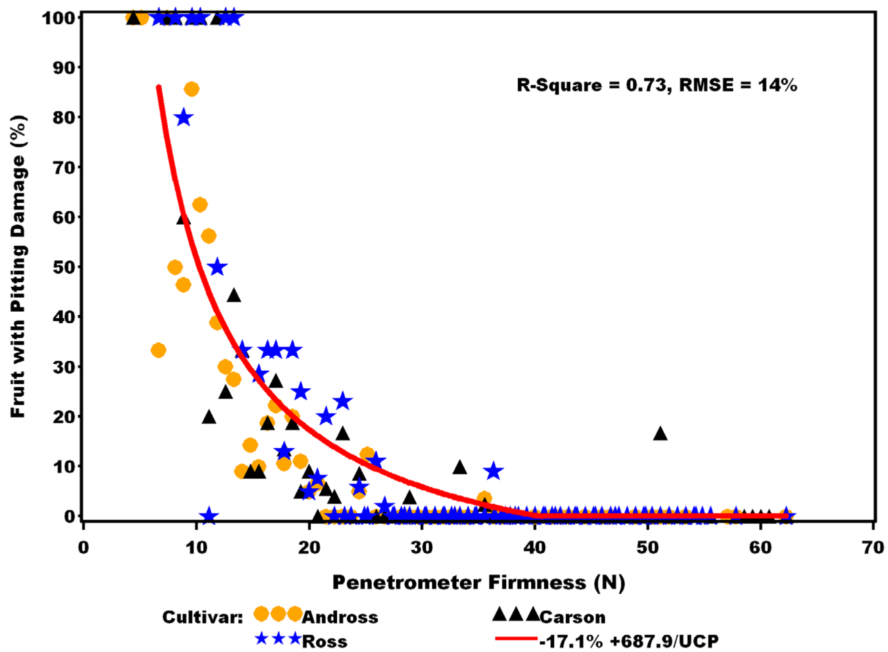

Figure 5. Relationship between the percent of fruit with any pitting damage and penetrometer firmness score (UCP) for three clingstone cultivars.

pitting than the nondestructive impact method, 18.3% total error rate and 24.6% total error rate respectively.

Skin color in clingstone peaches is not a good predictor of flesh color. When corrected for cultivar the coefficient of determination ranged from $r^2 = 0.46$ for L* to $r^2 = 0.23$ for C*, and models for three cultivars ('Andross,' 'Carson,' and 'Ross') combined had degraded performance ($r^2 = 0.18$ for L* to $r^2 = 0.09$ for C*). Although commonly used as a measure of maturity, flesh color in clingstone peaches is not a good predictor of damage level during mechanical pitting, with the coefficient of determination for the best model a very low $r^2 = 0.06$.

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