

# COMPARISON OF INSTRUMENTAL AND MANUAL INSPECTION OF CLINGSTONE PEACHES

D. C. Slaughter, C. H. Crisosto, J. K. Hasey, J. F. Thompson

**ABSTRACT.** *The flesh color and firmness of 13,140 clingstone peaches were measured instrumentally at the cannery receiving stations and compared with the current official subjective inspection methods of the California Department of Food and Agriculture. The instruments evaluated were a nondestructive impact firmness sensor, a traditional destructive penetrometer firmness sensor, and a tristimulus color sensor. Instrumental measurements for flesh color and nondestructive firmness gave good agreement (83% across all cultivars) with the current inspection method in categorizing fruit into both mature or immature, and into firm or soft categories. The study shows that objective instrumental inspection methods hold promise as a replacement for subjective methods presently used in clingstone peach inspection at cannery receiving stations.*

**Keywords.** *Flesh firmness, Flesh color, Peach grading, Maturity, Instrumentation.*

California clingstone peaches are inspected for postharvest quality at cannery receiving stations in order to verify the suitability of fruit lots for processing and the consumer enjoyment value of the product. Two of the more important criteria in quality assessment of peaches are flesh color, for distinguishing immature from mature fruit, and flesh firmness, for distinguishing mature from over mature fruit, because research has shown that they are good indices of maturity in peaches (Rood, 1957) and suitability for processing (Metheny and Crisosto, 2002). Unfortunately, the current official inspection method employs visual assessment of fruit color and determination of fruit softness by tactile evaluation, both of which are subjective in nature and frequently result in dissatisfaction with the inspection process.

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. Early methods of assessing color involved the visual comparison of fruit skin or flesh color with spinning disks of different colored papers (Nickerson, 1946), or with Munsell or custom manufactured color-matching disks (MacGillivray, 1928;

Whipple, 1955). However, MacGillivray noted that it is critical to know the color sensitivity of the operator judging the color matching in order to have a satisfactory color evaluation. In freestone peaches, ground color, or the green-yellow colored portions of the peach skin exclusive of the red pigmented or blushed skin, is commonly used as a nondestructive index of maturity (Delwiche and Baumgardner, 1983, 1985). Because peaches are canned without skin, Californian clingstone peaches are evaluated for maturity based upon their flesh color. The current California official flesh color assessment method utilizes three colored plastic reference standards (California Department of Food and Agriculture's color disks 2, 3, and 4; Delwiche, 1989). To determine fruit maturity, an inspector makes a visual comparison of the flesh color of clingstone peaches, after removal of a 6.4-mm (or 12.7 mm for extra early cultivars) thick slice from the surface of the smallest cheek, to the color reference standard designated by the processor for that cultivar. Despite improvements in the color reference standards made in the 1980s, many individuals in the California canning peach industry are not completely satisfied with the subjective nature of the current inspection method.

Whipple (1955) observed that visual color inspection of fruits at grading stations has certain limitations (in addition to the operator sensitivity issue observed by MacGillivray, 1928). In California, grading stations typically have a roof but no walls, allowing considerable natural diffuse illumination to enter the grading area. Thus, while official standardized inspection lamps are used, graders evaluate fruit color under a varying combination of natural and artificial light. In the current California official clingstone peach inspection procedure not all fruit in the grading sample are inspected for flesh color but only those fruit suspected to be immature by the inspector are cut for flesh color/maturity classification. Thus two subjective assessments are applied in the classification of fruit into mature or immature categories, first the visual assessment of the exterior appearance of the fruit to determine which fruit should be cut, followed by the

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subjective assessment of the flesh color of those fruit actually selected for cutting.

As with many fruit inspection and sorting tasks, inspectors must make a large number of decisions on a wide range of potential defect categories while viewing a complex scene. Studman (1998) suggested that the large number of defect types that a typical fruit inspector is required to assess makes fruit grading a more challenging inspection task than the visual inspection of many manufactured products. A few studies have examined the impact of scene complexity and defect rate on inspection accuracy. Harris (1968) observed that inspection accuracy was significantly negatively correlated with complexity of the item inspected, even when an unlimited amount of inspection time was permitted. Malcolm and DeGarmo (1953) reported that the rate of defect detection decreased 3% for each additional defect type the inspector was required to detect. Broadbent (1963) and Harris (1968) report that inspection accuracy decreases as the rate of defects in the sample being inspected decreases. Purswell and Hoag (1974) observed that frequent breaks in the inspection task (e.g. 5-min breaks for every 30 min of inspection activity) allowed inspectors to maintain a sorting accuracy of 85% throughout the day as compared with a 60% sorting accuracy when breaks were less frequent (e.g. 10-min breaks for every 2 h of inspection activity). Pang (1994) observed a reduction in apple bruise detection by inspectors as their break time approached. These studies do not address the social impacts on the grader's performance such as the influence by the presence of a grower or processor in the grading area.

While the optical characteristics of fruits across the visible spectrum have been documented in many research studies of fruit maturity (e.g. Bittner and Norris, 1968) full spectrum instruments have not been adopted at grading stations due to cost and complexity or because the instrumentation was not suited to operation in the uncontrolled environment of a grading station. Beginning in the 1950s, "abridged" spectrophotometers were introduced in Californian tomato grading stations (Whipple, 1955) to evaluate fruit color using a simple ratio of green to red reflectance. With the development of standardized tristimulus color measurements (CIE, 2005) many researchers have evaluated the potential of colorimeter-based measurements in assessing fruit maturity. 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). The development of light emitting diode (LED) based color instruments has allowed the development of more robust systems that are better suited for the uncontrolled environment of the grading station (Jones and Slaughter, 1996). LED-based color instruments typically have more stable illumination and require less frequent recalibration than systems with tungsten-halogen or xenon flash lamps.

Instrumented methods of assessing fruit firmness have been available for many years, with the most common being the measurement of the peak force to penetrate the flesh using Magness-Taylor style cylindrical penetrometer probes with spherically shaped tips (Magness and Taylor, 1925). Often the viscoelastic characteristics of fruit tissues are ignored making this technique sensitive to loading rate, and instru-

ment configurations that control loading rate tend to give more consistent measurements (Abbott, 1999). A recent review of commercial penetrometer-type firmness instruments was conducted by Kupferman and Dasgupta (2001). While destructive, the Magness-Taylor style penetrometer measurement is in widespread use because of its low-cost, simplicity of operation, portability, and general ability to assess fruit maturity.

A number of research studies have been conducted on the development of nondestructive methods of assessing fruit firmness. These methods generally measure elastic or viscoelastic properties of the skin and flesh rather than the flesh failure properties measured by a penetrometer. Recent reviews of several fruit firmness measurement technologies have been published by Chen (1996) and Abbott (1999). Delwiche et al. (1987) studied the measurement of impact forces for peaches striking a rigid surface as a means of sensing fruit firmness that would be suitable for on-line inspection tasks. They found that impact force characteristics, related to the ratio of peak impact force to the elapsed time (or elapsed time squared) between initial contact and the time at which the maximum impact force occurred, were significantly ( $\alpha = 0.01$ ) correlated with fruit elastic modulus (ASAE Standards, 2003) and penetrometer firmness. Correlation values for three fresh market peach cultivars over two growing seasons between impact characteristics and elastic modulus and between impact characteristics and penetrometer firmness ranged from  $r = 0.82$  to  $r = 0.93$  and  $r = 0.75$  to  $r = 0.84$ , respectively. They also observed that the correlation between penetrometer firmness and elastic modulus was  $r = 0.88$  for 120 'Redglobe' peaches harvested in 1984. In a subsequent study of on-line measurement of impact force characteristics of peaches and pears using a research prototype sorting system, Delwiche et al. (1989) reported that correlations between impact characteristics and elastic modulus and between impact characteristics and penetrometer firmness ranged from  $r = 0.81$  to  $r = -0.90$  and  $r = 0.78$  to  $r = 0.84$ , respectively. They also observed that the correlation between penetrometer firmness and elastic modulus was  $r = 0.90$  for 90 fresh market peaches. Hung et al. (1999) studied the performance of a laser air-puff firmness sensor for nondestructive measurement of firmness in three fresh market peach cultivars over two seasons. This technique measures the surface deformation of the fruit when impinged by a brief puff of air. They reported that coefficient of determination values between nondestructive air-puff firmness and penetrometer firmness ranged from  $r^2 = 0.36$  to  $r^2 = 0.77$  depending upon cultivar and the number of seasons of data from which the model was developed. Recently, commercial online systems using impact techniques have become available for firmness measurements.

The subjectivity in fruit quality inspection can be eliminated by using instrumented assessment methods that provide a quantitative quality score for each quality attribute. Furthermore, instruments do not suffer from fatigue or distractions that may affect human inspectors associated with the monotony of fruit inspection tasks.

## OBJECTIVES

The goal of this project was to study the feasibility of using objective instrumented methods of assessing flesh color and flesh firmness at Californian clingstone peach inspection stations. Specifically, this project:

- Characterized the flesh color and firmness differences between Californian clingstone peaches classified into California Department of Food and Agriculture (CDFA) firmness and maturity categories.
- Developed and evaluated stochastic classification methods for: -- Firmness (destructive and nondestructive) as measured with an instrument to determine the amount of fruit CDFA classified as firm and soft using the current manual inspection process. -- Maturity as measured with a LED-based colorimeter to determine the amount of fruit CDFA classified as mature and immature (green) using the current visual inspection process of peach flesh using plastic color standards.
- Determined the relationship between destructive penetrometer firmness and nondestructive impact firmness as measured with a commercial firmness instrument.

## MATERIALS AND METHODS

The general procedure was to obtain samples of 30 fruit each from delivered commercial loads of clingstone peach cultivars. The flesh firmness and flesh color of each peach was measured instrumentally. In addition, the official flesh color grade (mature or immature) was determined for each peach and all the soft fruit were identified. The flesh color and firmness of 13,140 peaches were evaluated in 2004. Twenty-four cultivars were studied ('Andross,' 'Arakelian,' 'Bowen,' 'Carolyn,' 'Carson,' 'Corona,' 'Dee-six,' 'Dr. Davis,' 'Evans,' 'Everts,' 'Goodwin,' 'Halford,' 'Hesse,' 'Klamt,' 'Late Ross,' 'Loadel,' 'Monaco,' 'Riegels,' 'Rizzi,' 'Ross,' 'Stanislaus,' 'Starn,' 'Sullivan,' and 'Tuolumne'). The 30 peaches in each sample were selected to represent the range of color and firmness in the bin being sampled as part of the official inspection process for the load. Instrumental fruit firmness was measured at four equatorial positions for each fruit using both destructive and nondestructive methods. Flesh color was measured at the greenest equatorial location on the smallest cheek of each fruit using an LED colorimeter. The peaches were classified into firmness and flesh color categories: peaches of acceptable firmness or soft, and peaches being immature (green) or of an acceptable color (maturity level) using the official California Department of Food and Agriculture (CDFA) Shipping Point Inspection (SPI) procedure. The fruit was not graded for worm, brown rot, or split pits. All measurements were made indoors, in an office adjacent to the inspection station.

A LED-based colorimeter (BYK-Gardner model Color-Guide), a universal testing machine equipped with a Magness-Taylor style penetrometer probe (Guss Fruit Texture Analyzer, FTA GS-14, with 7.9-mm diameter probe), an impact-type firmness instrument (Sinclair IQ interim bench top model SIQFT-B of 2004), and a data logging computer system were setup at two Californian clingstone peach inspection stations during the entire 2004 season in order to collect information on early, mid, and late season fruit across a wide range of cultivars and geographic regions. Inspectors had been trained by the SPI inspection agency as to the standard clingstone peach grading procedure. All CDFA SPI inspectors must pass a color vision test (Pseudo-Isochromatic Color Perception Test, Richmond Products Inc., Albuquerque, N.M.) as a condition of their employment.

At the beginning and end of each day of testing, the calibration of the colorimeter was checked using the manufacturer-supplied green reference standard and verification method built into the instrument. According to the manufacturer's calibration verification method, the colorimeters were quite stable and did not require recalibration during the 2-month season. Each colorimeter was set to automatically record the CIE L\*, C\*, h\* values (CIE, 2005) for each fruit. The standard illuminant D65 and the 10-degree standard observer were used for all measurements in this study. In addition, the color of each of the California Department of Food and Agriculture's (CDFA) canning peach grading disks (No. 2, 3, and 4) was measured using the colorimeter at the beginning of each day, however only the No. 2 color disk was used by the industry in 2004. The CIE L\*, C\*, h\* values of two disks used in this study were quite similar. Once a week the calibration of the FTA's load cell was checked using a standard reference mass and the load cell recalibrated as needed according to the manufacturer's instructions. Minor adjustments to the load cell calibration were required once during the 2-month season. The impact-type firmness tester was adjusted according to the method described in the operator's manual as needed. Typically minor adjustments to the pressure and vacuum levels of the impact-type firmness tester were required on a weekly basis.

A representative sample of 30 peaches was collected from the same bin(s) selected for official inspection by CDFA SPI Services. The fruit selected for this study did not contain any fruit that was: broken apart, contained imbedded foreign material, or that contained conspicuous discoloration, rot, or mildew along the equator. No fruit cut by the official inspector was used in this study. Each fruit was labeled along the shoulder near the stem end of the fruit using a permanent marker for identification during the measurement process. The letter 'A' was placed on the shoulder above the region on the smaller cheek with the greenest skin color, and the remaining letters 'B,' 'C,' and 'D' were placed in alphabetical order in a clockwise direction approximately 90 degrees apart.

After labeling the fruit, the nondestructive firmness was measured using the impact-type firmness tester. The firmness was measured at the four labeled equatorial cheek locations on each fruit starting with fruit 1 at position 'A' and proceeding in alphabetical order (B, then C, then D). The fruit was tapped once at each of the four locations and all four readings were recorded. The height of the fruit support was adjusted for each fruit so that the tip of the impacter was about 25 mm above the top of the fruit as specified by the manufacturer's operation instructions.

After the nondestructive firmness measurements had been completed, the flesh color of each fruit was evaluated individually with both the CDFA color chip and the colorimeter. The fruit were cut using the CDFA official maturity slicer using the official 'single cut' (removal of a 6.4-mm thick slice) or 'double cut' (removal of a 12.7-mm thick slice) method as specified by the processor for each cultivar. The cut was made at the greenest equatorial location 'A' on the smaller cheek. The flesh color of the fruit was determined immediately after cutting in order to prevent browning. The official grading color chip was used by the inspector to determine if the fruit was mature or immature using the official visual method (i.e., if the color of the flesh

was greener than the color chip it was immature otherwise it was mature). Then the flesh color was measured using the colorimeter placing the measurement window against the cut flesh with the edge of the window at the edge of the cut where the color chip was placed.

After all the flesh color measurements had been completed, the second measure of firmness was obtained using the penetrometer. A knife was used to remove approximately 160-mm<sup>2</sup> section of skin from the three remaining equatorial locations (B, C, and D). The penetrometer was equipped with a standard 7.9-mm diameter Magness-Taylor tip and was programmed to insert the probe 5 mm into the fruit flesh at a speed of 5 mm/s. These parameters were the same as those used by Metheny and Crisosto (2002) and allowed comparison with their results. The penetrometer firmness was measured at each of the four equatorial positions.

## RESULTS AND DISCUSSION

### FLESH COLOR AND FIRMNESS CHARACTERISTICS OF CLINGSTONE PEACHES

In general, there was good agreement between the human inspectors' grading assessments and the instrumented measurements. The mean and standard deviation of each of the two firmness measures and the three flesh color parameters were determined for fruit graded soft and for fruit of acceptable firmness (called firm peaches in this study; table 1). The average firmness scores for the soft peaches were about half that of the firm peaches. The flesh of soft peaches were also, on average, darker, and had higher chroma (more saturated) and had lower hue values (more orange or red) than firm peaches. However, there was considerable overlap in flesh color values between soft and firm peaches.

The mean and standard deviation of each of the three firmness measures and the three flesh color parameters were determined for fruit graded immature ("greener" than the #2 color disk by visual inspection) and for fruit of acceptable flesh color (called mature peaches in this study; table 2). The difference in firmness values between the immature and mature peaches was not as great as it was between the soft and firm peaches. On average, immature peaches were firmer than mature peaches, but with considerable overlap in firmness values between the two populations. The average lightness scores for the flesh of immature and mature peaches were quite similar (unlike the firm and soft peaches). The difference in flesh chroma between mature and immature peaches was similar to the difference observed for soft and firm peaches with mature peaches being, on average, more saturated, but with considerable overlap. There was, on average, a 5-degree difference in hue angle between the mature and immature fruit, with the flesh of mature peaches being more orange or red than immature peaches. The LED-based colorimeter used in this study did not require recalibration during the 2-month harvest season. The long-term stability of LED-based color measurements is an advantage in a grading station environment where robust instrumentation that is simple to operate is desirable.

### INSTRUMENTAL CLASSIFICATION OF PEACHES FOR FIRMNESS AND MATURITY GRADES

The ability of the two firmness measures and the three flesh color parameters to classify peaches into soft and firm categories as well as mature and immature categories as determined by human inspection was investigated. Stochastic Bayesian classifiers were developed in SAS using Proc Discrim to assess the ability of each of the measures in sorting soft fruit from firm fruit and immature fruit from mature fruit. Of the six parameters, hue angle gave the best classification

**Table 1. Summary of flesh color and firmness values for firm and soft peaches.**

	Firm Peaches <sup>[a]</sup>				Soft Peaches <sup>[b]</sup>			
	Mean <sup>[c]</sup>	Std. Dev.	Min	Max	Mean <sup>[c]</sup>	Std. Dev.	Min	Max
Impact firmness score	22.8	5.1	4.5	43.7	13.5	4.6	4.6	28.0
Penetrometer firmness (N)	26.7	8.9	5.8	64.1	15.1	5.3	3.6	37.8
L*	69.7	3.0	48.9	79.7	66.2	4.4	49.2	75.9
C*	61.7	5.1	16.2	83.0	63.9	5.5	45.8	76.3
h*	77.6	3.5	49.0	91.8	74.3	3.9	50.5	87.3

[a] Mean and standard deviation of 12,609 peaches.

[b] Mean and standard deviation of 531 peaches.

[c] All mean values are significantly different ( $\alpha = 0.01$ ) between firm and soft peaches.

**Table 2. Summary of flesh color and firmness values for mature and immature peaches.**

	Mature Peaches <sup>[a]</sup>				Immature Peaches <sup>[b]</sup>			
	Mean <sup>[c]</sup>	Std. Dev.	Min	Max	Mean <sup>[c]</sup>	Std. Dev.	Min	Max
Impact firmness score	21.8	5.2	3.0	43.0	26.9	4.6	9.5	43.7
Penetrometer firmness (N)	25.4	8.5	3.6	61.8	33.8	9.3	8.5	64.1
L*	69.5	3.2	48.9	79.7	69.8	2.3	55.4	78.8
C*	62.0	5.1	16.2	83.0	60.4	5.2	47.3	80.0
h*	76.8	3.3	49.0	91.8	81.8	2.6	65.4	89.4

[a] Mean and standard deviation of 11,561 peaches.

[b] Mean and standard deviation of 1579 peaches.

[c] All mean values are significantly different ( $\alpha = 0.01$ ) between mature and immature peaches.

accuracy in predicting which fruit would be classified into immature and mature categories. A hue angle threshold of 79.8 degrees gave a balanced error rate across all cultivars for immature fruit incorrectly classified as mature and for mature fruit incorrectly classified as immature. The total error rate of the hue angle classifier for all cultivars was 17%, with a standard deviation of error rate of 12.9%. If a three-dimensional color model using  $L^*$ ,  $C^*$ , and  $h^*$  was used the total error rate dropped from 17% to 14%. One-dimensional models using either  $L^*$  or  $C^*$  were inferior to the hue angle model having total error rates of 42% and 45%, respectively. Models using the impact firmness score or penetrometer firmness were not as accurate as hue angle in classifying immature and mature fruit with total error rates of 30% and 31%, respectively.

In categorizing fruit into soft and firm classes (as determined by the inspector's tactile evaluation), the impact firmness score gave good results with a total error rate of 17% and a standard deviation of error rate of 12.3% across cultivars. An impact firmness threshold of 17.5 gave a balanced error rate across all cultivars for soft fruit incorrectly classified as firm and for firm fruit incorrectly classified as soft. The classification model based on penetrometer firmness did not agree as well with the inspector's tactile evaluation, having a total error rate of 22%. A penetrometer firmness threshold of 19.2 N (4.3 lb) gave a balanced error rate across all cultivars for soft fruit incorrectly classified as firm and for firm fruit incorrectly classified as soft. The superior classification performance of the nondestructive impact firmness method may be due to the fact that tactile evaluation is also a nondestructive measure of the elastic properties of the fruit, while the penetrometer measures the destructive tissue failure properties. Using flesh color to categorize soft and firm fruit was not as accurate as either firmness measure. The three-dimensional model using  $L^*$ ,  $C^*$  and  $h^*$ , and one-dimensional  $L^*$  and  $h^*$  models gave similar performance with total error rates of 31%, 32%, and 34%, respectively, in categorizing soft and firm fruit.

There was better agreement between the instrumented measures and human inspection for some cultivars than for others (cultivar specific results can be found at Slaughter et al., 2004). For cultivars with classification accuracies below the average, it is possible to improve their classification rate if individual classification models are developed for those cultivars. For color, in some cases small changes in the hue threshold can significantly improve the classification rate, while for others switching to a two-dimensional model using both  $h^*$  and  $L^*$  values is superior. Since the current inspection system uses a single criterion to classify soft versus firm or immature versus mature fruit and does not use cultivar specific grading criteria no further analysis of cultivar specific models were investigated. It may be of value to the industry to investigate the use of special criteria for certain types of peach cultivars, such as white-fleshed cultivars, if a single criterion does not give adequate performance.

#### COMPARISON OF IMPACT AND PENETROMETER FIRMNESS IN CLINGSTONE PEACHES

The relationship between nondestructive impact firmness scores and traditional destructive penetrometer firmness scores was investigated. The scatter plot for all 24 cultivars is shown in figure 1. The data show a non-linear relationship between impact firmness score and penetrometer firmness with a level of scatter that is consistent with the data collected in 2002 by Metheney and Crisosto except that the Sinclair impact firmness scores obtained in 2002 were about half those obtained in this study (for a similar range of penetrometer scores) and showed a more linear relationship. Metheney and Crisosto used an early commercial prototype of the Sinclair bench top firmness instrument in their study. In order to improve the suitability of the system to a wide range of produce types, the manufacturer modified the Sinclair iQ firmness score definition by a multiplicative factor between the 2002 prototype and the 2004 model used in this study that is consistent with the differences in Sinclair iQ firmness scores observed between these two studies (Howarth, 2006).

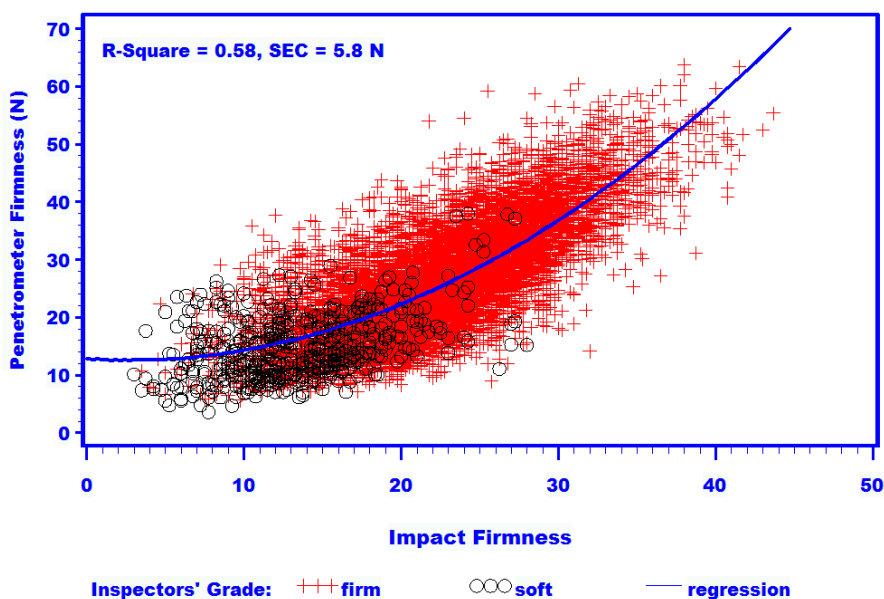


Figure 1. Relationship between the traditional destructive penetrometer firmness value and the nondestructive impact firmness score.

A quadratic model between penetrometer firmness and impact firmness score (statistically significant at  $\alpha = 0.01$ ) has a coefficient of determination of  $r^2 = 0.58$  and a standard error of calibration of 5.8 N. The level of prediction between penetrometer firmness and impact firmness is similar to that observed in other studies comparing destructive and nondestructive firmness measurements. As with other studies of this type, the level of correlation of this regression model is affected by the fundamental differences between nondestructive elastic properties of the flesh and the tissue failure properties. Some of the scatter may result from the presence of the skin when the impact measurement was taken while the skin was removed when the penetrometer firmness was determined. Additional error may be associated with the viscoelastic nature of the flesh and the very large difference in loading rates between impact and penetrometer measurements. These plots illustrate the challenge of relating destructive and nondestructive measures of firmness.

The variability in firmness among the four equatorial positions was evaluated to determine if there were variability differences between destructive and nondestructive measures of firmness. The coefficient of variation (CV) of the four firmness measurements taken at each of the four equatorial cheek positions was determined for each of the firmness methods. The CV values were compared using a Kruskal-Wallis test and found to be significantly different ( $\alpha = 0.01$  level). The CV value of the impact firmness score (16%) was lower than the CV of the traditional penetrometer firmness (19.7%). This assessment incorporates both the natural variability in flesh firmness among the four equatorial positions as well as the variability associated with the measurement error of each method.

The ability to predict flesh firmness scores using flesh color was quite poor which is consistent with the lower classification performance found when using flesh color to categorize soft and firm fruit and is consistent with the data collected in 2002 by Metheny and Crisosto. The coefficient of determination between the impact firmness score and  $h^*$ ,  $C^*$ , and  $L^*$  were  $r^2 = 0.13$ ,  $r^2 = 0.07$ , and  $r^2 = 0.05$ , respectively. The coefficient of determination between the penetrometer firmness value and  $h^*$ ,  $C^*$ , and  $L^*$  were  $r^2 = 0.13$ ,  $r^2 = 0.05$ , and  $r^2 = 0.02$ , respectively. This confirms that flesh color cannot be used to predict firmness in clingstone peaches.

## CONCLUSIONS

The nondestructive impact firmness measurements on over 13,000 clingstone peaches harvested in 2004 were moderate ( $r^2 = 0.58$ ) predictors of the traditional maximum force penetrometer firmness measurements on an individual fruit basis. The lack of predictability was thought to result from impact firmness being related to the elastic properties of the flesh while penetrometer firmness is related to the tissue failure properties. The vast differences in loading rates and the presence of skin in the nondestructive measure may also contribute to the poor predictability.

When used to grade fruit into firm and soft categories determined by human tactile evaluation, both impact firmness and penetrometer firmness measurements gave fairly good performance. When compared to manual inspection, the impact firmness measurement had the best performance

with a 17% total error rate, while the penetrometer firmness measurement had a total error rate of 22%. Using flesh color to classify firm and soft fruit was not as accurate as classification using firmness measurements, with the best color model having a total error rate of 31%. These results show that nondestructive firmness measurements can be effective in identifying soft fruit at inspection stations.

Classification of fruit into mature and immature categories using  $L^*$ ,  $C^*$ , and  $h^*$  gave the lowest classification error rate of 14%, while a model using only  $h^*$  had a total error rate of 17%. Classification models using firmness measurements were not as accurate in classifying fruit into mature and immature categories with total error rates of about 30%.

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