PEACH FIRMNESS PREDICTION BY MULTIPLE LOCATION IMPULSE TESTING

M. L. Stone, P. R. Armstrong, D. D. Chen, G. H. Brusewitz, N. O. Maness

ABSTRACT. *Effe-gi firmness and acoustic impulse response were measured at four locations (2 sites per location) on the surface of two freestone peach cultivars, 'Loring' and 'Cresthaven'. The acoustical impulse response signal was interpreted by determining the energy content of the response signal between 150 to 200 Hz. The proportion of energy in this frequency band, compared to the total energy content between 0 and 500 Hz, was used as a predictor of firmness and was termed BM150-200. Spatial variation of Effe-gi firmness was found to be very small for 'Loring', but significant for 'Cresthaven'. Spatial variation of the parameter BM150-200 for both cultivars was significantly different for some sites. Correlations between Effe-gi firmness and BM150-200 for single site or two-site average were generally good with the 'Loring' cultivar which had little spatial Effe-gi firmness variation. Equivalent correlations for 'Cresthaven' peaches, which had significant spatial Effe-gi firmness differences between locations, were poor. Averaging Effe-gi and BM150-200 measurements from multiple test sites improved the correlation between these parameters for 'Cresthaven' peaches.*
Keywords. *Nondestructive, Acoustic, Spatial.*

Harvesting peaches at the proper stage of physiological maturity is essential for optimal storage and handling characteristics as well as delivering a premium quality product of good flavor and texture to the consumer. Physical properties such as size, color, flavor, sugar content and texture or firmness are commonly used to assess maturity. Most of these factors, excluding size and color, can only be evaluated on a sample basis which is then representative of the entire lot of marketable fruit. Flavor and firmness or texture attributes are subjectively judged by inspectors. As such, these individuals must possess considerable testing experience and knowledge of cultivars. Because of the large range of maturity within a lot of fruit considered ready for marketing, many fruit lack the desired quality attributes which may lead to immature or overmature, undesirable product, at retail. The ability to nondestructively sort individual fruit for firmness would improve product uniformity and quality as well as enhance a distributor's marketing strategy.

Considerable effort has been made to develop indices which objectively estimate fresh fruit maturity. As a nondestructive method, sonic impulse testing has gained increasing research interest due to the availability of high-speed data acquisition and digital signal processing technology. Measurements are generally obtained by applying a mechanical pulse to a specimen and measuring the resulting vibrations. The impulse generating and sensing methods can be implemented differently depending on the desired information from the impulse test. Spectral analysis of the vibrational response yields information pertaining to firmness, which is most often related to the modulus of elasticity of the tissue. Additional signal information may also be extracted such as viscous damping characteristics and the velocity of sound waves in the tissue.

A hand-held sensor was developed by Farabee and Stone (1991) to determine if watermelon texture and ripeness were related to melon resonance. This apparatus was modified and used by Chen (1993) and Zhang et al. (1994) to compare peach resonance parameters with firmness and color for several cultivars. Correlation between Effe-gi firmness and resonance parameters, measured at a cheek region, ranged from 0.59 to 0.83 for five peach cultivars (Chen, 1993). While these results were encouraging, significant spatial variation of internal peach firmness does occur as indicated by Maness et al. (1992) who found variations were cultivar dependent for 'Halehaven', 'Ranger', and 'Topaz'. The study of spatial differences of Effe-gi firmness and impulse response measurements around the fruit is thus important in developing a grading line sorting mechanism and determining the need for the fruit handling system to orient fruit prior to nondestructive sensing. The objectives developed to address this problem were:

1. Determine the spatial variation in Effe-gi firmness and impulse parameters for two peach cultivars; and
2. Determine the ability to predict Effe-gi firmness from impulse parameters for single and multiple location testing.

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Literature Review

Firmness has been used as a criterion for sorting fresh fruits and vegetables for many years. The methods used include squeezing between the fingers or hands, pushing a thumb into the flesh, biting and chewing, and the penetrometer method, generally referred to as a Magness-Taylor or Effe-gi test. Because of the destructive nature of these tests and an increasing emphasis on quality, non-destructive methods have been sought to quickly measure individual fruit for sorting. The ability to sort by firmness would help to obtain a more uniform pack of consistent high quality fruit and facilitate more timely marketing.

Among the various non-destructive methods investigated, frequency response techniques have received considerable attention. Previous studies primarily focused on resonant frequency analysis using different excitation, supporting and sensing methods to determine the correlation between specific resonant frequencies and measured fruit properties. Abbott et al. (1968) used a forced frequency sweep on an apple to determine resonant frequencies. They reported that the first resonant frequency was not associated with apple ripeness, while the second resonance did correlate with firmness, although it was mass dependent. Similar conclusions were drawn by Finney (1970) and Yong et al. (1979) using different vibration systems to measure resonance. They reported that the first resonant frequency was excitation dependent, varied from device to device, while the second resonant frequency provided an appropriate measure for fruit properties. Yamamoto et al. (1980) studied fruit response through sonic impulse excitation using a striker to hit the fruit and a microphone to sense the acoustic vibration. The resonant frequencies, fruit mass, and density were highly correlated with the flesh firmness for apple, but not for watermelon. Armstrong et al. (1990) used an impulse method to predict modulus of elasticity of whole apple fruit. Resonant frequencies of an apple were determined by the tapping the apple and sensing the signal by microphone. Using a particular resonant frequency (f) and apple mass (m), elasticity correlated reasonably well with the function $f^2\, m^{2/3}$. Penetrometer firmness however did not have good correlation with $f^2\, m^{2/3}$. Chen et al. (1992) reported that the impulse striking and fruit holding methods did not affect the resonance frequencies of apple, but did have an affect on the amplitude of vibration at each resonant frequency.

Other firmness sensing techniques have examined impact characteristics. De Baerdmaker et al. (1982) dropped fruit onto a piezoelectric transducer to sense the generated impact force. Spectral analysis of the impact signal was used to identify the magnitude at a specific frequency as an index of apple firmness. Delwiche et al. (1987) similarly performed an impact test by dropping a peach on a rigid load cell surface and band pass filtering the signal at several frequencies. The energy contents in these narrow frequency bands were calculated and correlated with tissue firmness.

Farabee and Stone (1991) used a hand-held sensor to determine the acoustical impulse response of watermelon. The impulse response signal was analyzed in the frequency domain. Spectrum parameters, calculated from the energy content between specific frequency bands, were used to reflect the spectrum's magnitude variations. The energy content of the signal between the frequencies of 85 to 160 Hz and the center frequency of the narrowest 50% energy band were significantly correlated with sugar content and flesh firmness. The same device was used by Chen (1993) and Zhang et al. (1994) to predict peach firmness although different frequency bands were also examined. They also observed that the energy content was very sensitive to large signal levels (since energy is a squared function of the signal) and therefore emphasized large sample-to-sample variation in spectrum magnitude. A simple way of alleviating this problem was to define a normalized band magnitude function which is the summation of the magnitudes for a certain frequency band and reflects the relative energy content of the band to that of the entire signal. As a result, band magnitude, was found to be the one of the best impulse parameters correlated with peach firmness for several cultivars and storage times.

Materials and Methods

Forty peaches each of the freestone cultivars, 'Loring' and 'Cresthaven', were carefully hand picked on 16 August 1993 in the early morning from the Perkins Research Orchard of Oklahoma State University. All testing was completed indoors before noon. Fruit temperature was approximately 23°C. Each peach was weighed and numerically identified before testing ('Loring' 102.01 g avg; 'Cresthaven', 131.45 g avg). Effe-gi and impulse tests were applied at eight sites on each peach, consisting of four opposite pairs, on the cheek, suture, stem, and blossom end. The exact site was not marked until the mechanical impulse was applied to the specific peach spot. Note that the term "location" used by the authors refers to the positions on the peach of cheek, suture, stem and blossom end while "sites" are the numeric locations, cheek1, cheek2, etc. (fig. 1).

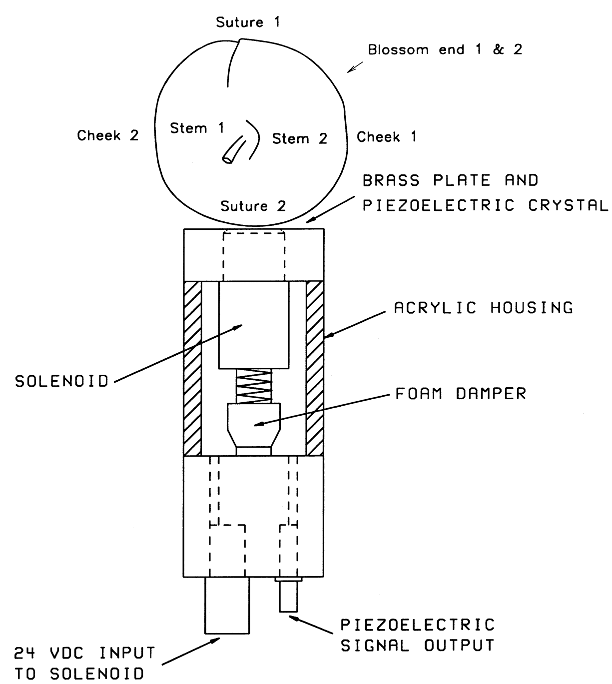

Figure 1–Schematic of impulse device. Locations for Effe-gi and impulse measurements are shown on the fruit.

The impulse testing apparatus employed in this study was the same one used previously by Farabee and Stone (1991), Chen (1993), and Zhang et al. (1994). The sensor shown in figure 1 consists of a disk shaped piezoelectric ceramic, bonded to a thin brass disk (27 mm diameter). Fruit is positioned to rest upon the brass disk and receives an impulse through the sensor from a solenoid hammer beneath the sensor. Control of the sensor/solenoid is with a PC based program which interfaces with a data acquisition and control board (DaqBook/100, IOTech. Inc, Cleveland, Ohio). Resonant vibrations are sensed by the piezo device and recorded and analyzed by the PC.

Chen (1993) used this instrument to perform tests on the opposite cheeks of a peach with the fruit resting naturally and directly upon the flat surface of the bonded piezoelectric transducer. The placement of the peach in this way was limited due to the peach assuming a natural rest position. In this study a curved wall and jig fixture were used to provide support for the peach to obtain the desired contact between the sensor surface and peach site (fig. 2). The plastic curved wall was attached to a jointed aluminum parallelogram linkage to provide some vertical adjustment. An adjustable counter weight balance was used to apply just enough pressure to hold the peach. The linkage was attached to a platform which rested on a table top. Peach placement was achieved by locating the impulse site of the peach against the surface center of the transducer with one or two points of the peach touching the curved wall. Wall contact points were dependent on peach shape and the relative position between the peach and the curved wall. The position of the curved wall could be adjusted by using the balance weight or positioning the platform on the table. The curved wall was essentially isolated from the sensor unit except through the peach contact points. While it was impossible to determine if the fixture interfered with the impulse response of the peach, impulse parameters obtained in this manner were not greatly different from those obtained from a natural rest positions.

Testing was completed, site by site, for each peach by applying the mechanical impulse, recording the response and marking the exact spot. The resulting vibrations were automatically recorded and processed by the computer.

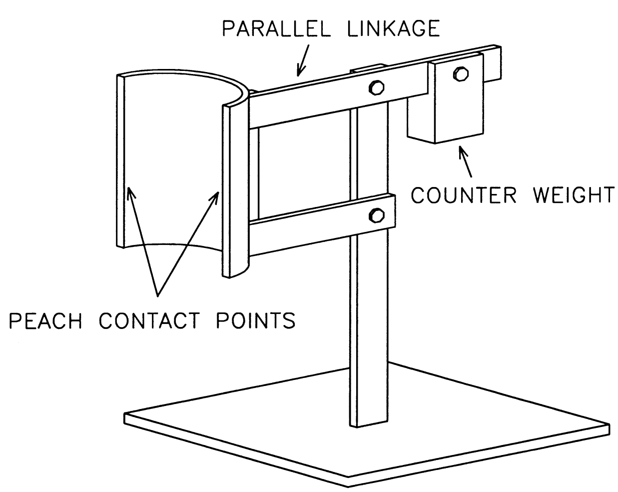

Figure 2–Apparatus used to hold fruit in position when measurement sites were not a natural rest position.

The impulse parameter, BM150-200, was used as a firmness index because of its high sensitivity to the firmness of fresh peaches (Chen, 1993). The parameter was derived from the discrete frequency spectrum (4.88 Hz resolution) of the impulse response by summing the normalized magnitude of the spectrum from 150 to 200 Hz. Normalization was achieved calculating all amplitudes within the spectrum as fractions of the maximum spectrum amplitude. This negated the differences in spectra amplitude found between tests. BM150-200 is essentially the energy content within this frequency band relative to the energy content between 0 and 500 Hz. Signal content beyond 500 Hz was negligible. Peach flesh firmness was measured, after impulse testing, at each site using an Effe-gi firmness tester (model FT 327 AlFolsine, Italy) with an 11 mm probe.

Results and Discussion

Statistical parameters for Effe-gi and BM150-200 measurements on the two peach cultivars are summarized in table 1. The overall mean Effe-gi firmness for the 'Loring' cultivar was higher than that for 'Cresthaven' but is affected by maturity of the fruit. Most interesting is the observation that the mean impulse parameter BM150-200 for 'Loring' peaches is almost double the mean for 'Crest Haven'.

Table 1. Mean firmness, standard deviation and impulse parameters for eight sites on two peach cultivars

		Effe-gi Firmness (N)		BM150-200	
Cultivar	Site	Mean	STD	Mean	STD
'Loring'	cheek1	58.11 A	24.05	13.02 A	3.27
	cheek2	57.92 A	26.46	12.49 AB	3.68
	suture1	55.66 A	25.96	12.12 AB	3.54
	suture2	60.86 A	24.72	11.70 AB	4.45
	stem end1	54.78 A	23.06	10.66 BC	3.39
	stem end 2	56.35 A	23.53	9.72 C	3.47
	blossom end1	61.54 A	30.22	11.31 ABC	3.85
	blossom end2	62.72 A	29.57	10.77 BC	3.57
	Total Mean	58.49		11.47	
'Cresthaven'	cheek1	53.99 ABC	18.54	6.13 A	1.24
	cheek2	50.86 BC	21.57	5.88 AB	1.40
	suture1	34.20 E	15.52	5.59 AB	1.61
	suture2	40.96 DE	18.19	5.31 B	1.44
	stem end1	44.69 CD	18.80	5.30 B	1.44
	stem end2	46.06 CD	19.62	5.21 B	1.58
	blossom end1	56.84 AB	23.17	5.47 AB	1.41
	blossom end2	60.76 A	24.29	5.85 AB	1.23
	Total Mean	48.54		5.59	

Note: Mean separation within columns for each cultivar by Duncan's multiple range test, P = 0.05, df = 312.

Site Effect

For 'Loring' peaches, Effe-gi firmness was not significantly different by site whereas firmness for 'Cresthaven' peaches was different for many sites. Mean values of Effe-gi firmness and BM150-200 for each site are graphically shown in figures 3 and 4. The values shown in these figures have been normalized (site value divided by overall mean) so that Effe-gi and BM150-200 value can be compared more easily. The firmest location for 'Cresthaven' was the blossom end, and the softest, the

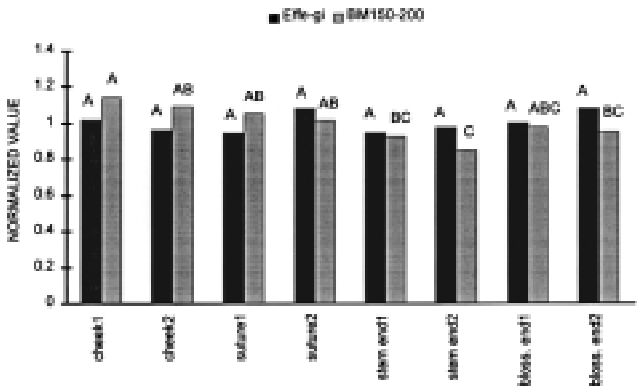

Figure 3–Normalized average Effe-gi firmness and impulse parameter, BM150-200, for each site on 'Loring' peaches.

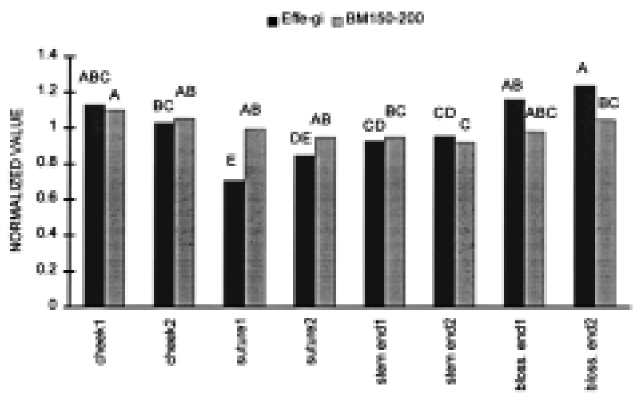

Figure 4–Normalized average Effe-gi firmness and impulse parameter, BM150-200, for each site on 'Cresthaven' peaches.

suture. This is in agreement with research by Horton (1992). The BM150-200 parameter was significantly different between several sites for both cultivars. The results indicate the uniformity of Effe-gi firmness in 'Loring' peaches while firmness for 'Cresthaven' was site dependent.

CORRELATIONS WITH FIRMNESS

Results of similar previous research indicated that the impulse parameter at a specific frequency band and measured at the same peach location, was directly proportional to the local Effigi firmness (Zhang et al., 1994). Correlations between individual site measurements of local Effe-gi firmness and the site impulse parameter, BM150-200, are shown in table 2. For 'Loring' peaches the local impulse parameter had good correlation with local Effe-gi firmness except for the suture2, stem2, and blossom2 sites. For 'Cresthaven', correlations were poor suggesting that the local impulse parameter could be a poor estimator of local Effe-gi firmness when there are significant firmness variations within a fruit.

Table 2. Correlation coefficients (r) between Effe-gi firmness and BM150-200 by individual site

	cheek1	cheek2	suture1	suture2	stem1	stem2	blossom1	blossom2
'Loring'	0.82	0.81	0.79	0.47	0.73	0.62	0.82	0.49
'Cresthaven'	0.23	0.37	0.26	0.25	0.32	0.27	0.26	0.36

Table 3. Correlation coefficients (r) between firmness and BM150-200 by location (two-site average Effe-gi firmness and two-site average BM150-200 parameters)

	cheek	suture	stem end	blossom end
'Loring'	0.87	0.71	0.78	0.76
'Cresthaven'	0.42	0.46	0.43	0.44

Table 4. Correlation coefficients (r) between 8-site average Effe-gi firmness and single site and two-site average BM150-200 parameters

	Location or Site							
	cheek location	cheek1 site	cheek2 site	suture location	suture1 site	suture2 site	stem end location	blossom end location
'Loring'	0.87	0.81	0.78	0.72	0.81	0.52	0.79	0.77
'Cresthaven'	0.37	0.27	0.29	0.52	0.31	0.43	0.62	0.52

Correlations were generally improved when Effe-gi firmness and impulse parameters were averaged for the two sites at each location. The correlation coefficients between Effe-gi firmness and BM150-200 by location are shown in table 3. Correlations improved in all cases over corresponding single site correlations for 'Cresthaven'. Correlations for 'Loring', by location, remained about the same as for site measurements. Because 'Loring' peaches already exhibited reasonably good correlation between single-site Effi-gi firmness and BM150-200 values, there is less potential for improvement by averaging two or more sites.

The correlation between Effe-gi firmness averaged over all eight sites and single and two-site BM150-200 averages at each location were determined (table 4). The choice of these comparison combinations was based on the assumption that multiple nondestructive measurements at specific locations on a single fruit would not be practical due to fruit orientation requirements. A more feasible solution would be to measure at the natural rest positions such as the cheek or suture side. Correlations values did not appreciably increase or decrease though from those shown in tables 2 and 3 for their respective locations or sites.

Average values of eight-site Effe-gi and eight-site BM150-200 measurements were calculated. Correlations obtained using average values were $r = 0.91$ for 'Loring' and $r = 0.74$ for 'Cresthaven'. Thus, averaging all eight BM150-200 values gave a good prediction of the average or whole-fruit Effe-gi fruit firmness.

Overall correlation results suggest single and two site average BM150-200 measurements do not consistently correlate well with single-site, two-site and eight-site average Effe-gi firmness for both cultivars. However, average multiple site BM150-200 measurements could provide reasonable prediction of average Effe-gi firmness. The practicality of commercially implementing a multiple site test at specific locations would prove to be more difficult though because of orientation requirements.

CONCLUSIONS

Firmness characteristics of the two cultivars indicate firmness uniformity can vary significantly. Spatial variation in Effigi firmness was not significantly different for the 'Loring' cultivar for different locations; whereas, significant differences were found for the 'Cresthaven' cultivar with the suture and stem ends being the softest.

Significant differences between locations were observed for the BM150-200 impulse parameter for both cultivars.

Local measurements of the BM150-200 impulse parameter do not readily or reliably predict Effe-gi firmness for the peach cultivar 'Cresthaven' while 'Loring' peach firmness was more readily predicted from location averages. It cannot be determined if the firmness uniformity for the 'Loring' cultivar, and the lack of uniformity for the 'Cresthaven' cultivar, had an affect on the ability to predict Effe-gi firmness It is anticipated that these observations would be true for other cultivars as well.

Eight-site average Effe-gi firmness, which represents whole-fruit firmness, has a good relationship with eight-site average BM150-200 impulse measurements for both cultivars. The usefulness of these relationships for commercial implementation into a packing line could be limited though because of orientation requirements for multiple measurements.

REFERENCES

Abbott, J. A., N. F. Childers, G. S. Bachman, J. V. Fitzgerald, and F. J. Matusik. 1968. Acoustic vibration for detecting textural quality of apples. *Proc. Am. Soc. Hort. Sci.* 93:725-737.

Armstrong, P. R., H. R. Zapp, and G. K.Brown. 1990. Impulsive excitation of acoustic vibrations in apples for firmness determination. *Transactions of the ASAE* 33(4):1353-1359

Chen, D. 1993. Peach maturity estimation by sonic impulse testing. Unpubl. M.S. thesis. Stillwater, Okla.: Oklahoma State University.

Chen, P., Z. Sun, and L. Huarng. 1992. Factors affecting acoustic responses of apples. *Transactions of the ASAE* 35(6):1915-1920.

De Baerdmaker, J., L. Lemaitre, and R. Meire. 1982. Quality detection by frequency spectrum analysis of the fruit impact force. *Transactions of the ASAE* 25(1):175-178.

Delwiche, M. J., T. McDonald, and S. V. Bowers. 1987. Determination of peach firmness by analysis of impact force. *Transactions of the ASAE* 30(1):249-254.

Farabee, M. L., and M. L. Stone. 1991. Determination of watermelon maturity with sonic impulse testing. ASAE Paper No. 91-3013. St. Joseph, Mich.: ASAE.

Finney, E. E. 1970. Mechanical resonance within 'Red Delicious' apples and its relation to fruit texture. *Transactions of the ASAE* 13(1):177-180.

Horton, B. D. 1992. Ripening patterns within a peach as indicated by force and soluble solids concentration. *J. Am. Soc. Hort. Sci.* 117(5):784-787

Maness, N. O., Gerald. H. Brusewitz, and T. Gregory McCollum. 1992. Internal variation in peach fruit firmness. *HortSci.* 27(8):903-905

Yamamoto, H., M. Iwamoto, and S. Haginuma. 1980. Acoustic impulse response method for measuring natural frequency of intact fruits and preliminary application to internal quality evaluations of apples and watermelons. *J. Texture Studies* 11(2):117-136.

Yong, Y. C., and W. K. Bilanski. 1979. Model of vibration of spheroids at the first and second resonant frequencies. *Transactions of the ASAE* 22(6):1463-1466.

Zhang, X., M. L. Stone, D. Chen, N. O. Maness, and G. H. Brusewitz. 1994. Peach firmness determination by puncture resistance, drop impact, and sonic impulse. *Transactions of the ASAE* 37(2):495-500.