PEACH FIRMNESS DETERMINATION USING TWO DIFFERENT NONDESTRUCTIVE VIBRATIONAL SENSING INSTRUMENTS

P. R. Armstrong, M. L. Stone, G. H Brusewitz

ABSTRACT. *Two nondestructive methods employing acoustic resonance analysis were used to test for firmness of fresh market peaches ('Red Haven' and 'Crest Haven'). Both devices deliver an impulse to the fruit to induce resonance but vibrations are sensed differently. One device uses a contacting piezo-electric disk (piezo instrument) while the other uses a non-contacting microphone (acoustic instrument). Frequency spectral parameters were defined to characterize the fruit's impulse response. Objectives were to determine if spectral parameters generated from fruit resonance could be used to determine Effe-gi pentrometer firmness.*

Multiple linear regression between derived spectral parameters and Effe-gi firmness for the acoustic instrument revealed the strength of the relationships were about the same for two peach cultivars (adjusted $r^2 = 0.64$ to 0.74). The piezo instrument produced a poor relationship for the 'Crest Haven cultivar but a closer relationship for the 'Red Haven' cultivar (adjusted $r^2 = 0.26$ to 0.53, respectively). Including mass as a variable with spectral parameters in MLR analysis generally increased the r^2 values by a small amount for both instruments and cultivars. The ability to accurately predict Effe-gi firmness with either instrument was limited due to the lack of a strong relationship between spectral parameters and Effe-gi firmness. However, there is potential for sorting out excessively soft, ripe or hard, immature fruit from desirable fruit with the acoustic instrument. This could result in a longer or more predictable shelf life. Sorting cost would be influenced by the percentage of good fruit falsely rejected (based on Effe-gi firmness) which ranged from 5% to 14% in this study. **Keywords.** *Acoustic, Effe-gi, Magness-Taylor.*

Fruit firmness, color, and aroma were the most important characteristics by which the quality of California peaches were selected in the marketplace (Bruhn, 1995). This survey found that nearly 50% of consumers were dissatisfied with peach quality and indicated a desire for a sweeter and juicier fruit; there was an extreme dissatisfaction for mealy peaches. These findings were supported by retailers comments that consumers complaints also indicated a strong dissatisfaction with flavor and mealiness.

Techniques for nondestructive firmness and maturity sensing of fruits and vegetables have received much attention due to consumer expectations for better quality and the increased competition brought on by the globalization of the fresh fruit and vegetable trade. Producers and suppliers must continue to improve quality and production efficiency in order to compete with regional and international production. Firmness has long been established as a good measurement of fruit maturity and quality. In many commodities, such as apples, pentrometer tests for firmness are used as an indication of crispness and maturity. Pentrometer tests, in addition to skin ground color, are also a good indicator of peach maturity (Rood, 1957; Shewfelt et al., 1987). For these reasons much research has been directed towards finding methods to nondestructively measure firmness.

Previous research involved in nondestructive firmness sensing has utilized vibrational behavior of fruit as an indicator of tissue strength or rigidity. Early work by Abbott et al. (1968) indicated vibrational behavior was indeed related to maturity. Cooke (1970) presented a theoretical elastic sphere model of whole fruit resonance and explained the effects of skin, tissue strength and core strength on resonant modes. Later work by Peleg (1989), Armstrong et al. (1990), Chen (1993), and Abbott and Massie (1995) attempted to define relationships between penetrometer tests and resonance characteristics of fruit. While these studies were not completely successful, vibrational properties were found to be related to the elastic properties of the tissue and were generally indicative of maturity. Other techniques that have been investigated to characterize maturity or firmness include light scattering (Tu et al., 1995), magnetic resonance (MR) (Stroshine et al., 1994) and near infrared reflectance (Kawnao et al., 1992).

Firmness in peaches can be an indicator of immaturity or overmaturity. Excessive firmness indicates an immature peach in which the mesocarp is tightly bound to the stone with little free juice. An overmature, soft peach can be excessively juicy and yields easily to thumb pressure. In contrast to other fruit, peach firmness does not consistently relate to full flavor development but is still used by consumers when buying fruit. Previous investigations of

Article was submitted for publication in May 1996; reviewed and approved for publication by the Food & Process Engineering Inst. of ASAE in February 1997.

Approved for publication by the Director, Oklahoma Experiment Station, Stillwater.

The authors are **Paul R. Armstrong**, ***ASAE Member,*** Assistant Researcher, **Marvin L. Stone**, ***ASAE Member Engineer,*** Professor, and **Gerald H. Brusewitz**, ***ASAE Fellow Engineer,*** Regents Professor, Biosystems and Agricultural Engineering Dept., Oklahoma State University, Stillwater, Oklahoma. **Corresponding author:** Paul R. Armstrong, Oklahoma State University, 214 Ag Hall, Stillwater, OK 74078-6021; tel.: (405) 744-5289; fax: (405) 744-6059; e-mail: <parmstr@agen.okstate.edu>.

nondestructive firmness measurement for peaches utilized impact parameters of a fruit that was bounced onto a load cell (Delwich, 1987). This work led to the development of an impact sensing head for the peach processing industry (Delwich, 1989), but it was not intended for fresh market peaches. Previous research by Zhang et al. (1994) utilized the piezo instrument used in this research to predict firmness for fresh market peaches. Whole fruit Effe-gi firmness and piezo instrument measurements were site dependent. Reasonable correlations (r = 0.535 to 0.844) between Effe-gi penetrometer firmness and spectral parameters were found.

The primary objective of this research was to compare two non-destructive sensing devices for their ability to determine Effe-gi firmness. Both are fundamentally similar in concept but implementation is different, as will be explained. The applicability of this work was to seek methods which could be used for on-line firmness sorting in commercial packing houses to enhance product quality. A major difficulty in implementing any firmness sensing device for commercial grading is that some degree of fruit orientation is required (Brusewitz et al., 1995). If a firmness sensing concept does prove to be successful, its implementation could be very different for a commercial application.

METHODS

This research utilized two methods previously developed by Farabee and Stone (1991) and Armstrong et al. (1993) that were used to test for firmness of fresh market peaches and apples respectively. Both instruments deliver an impulse to the fruit but the former instrument uses a piezo-electric disk (piezo instrument) to sense vibrations while the latter uses a microphone (acoustic instrument).

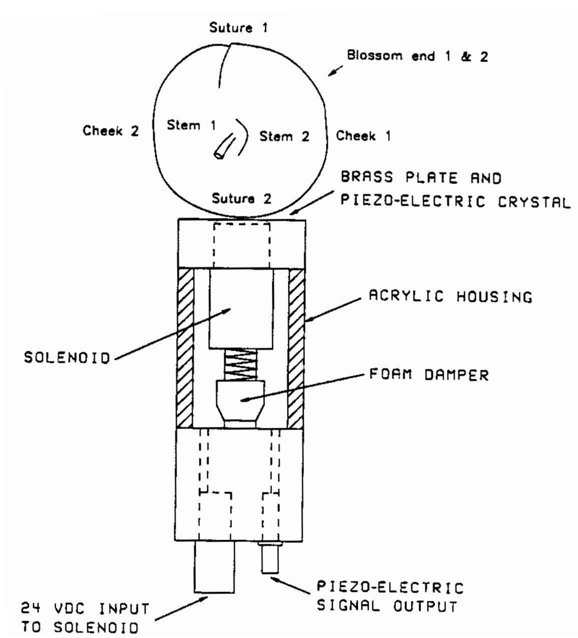

Figure 1–Schematic of piezoelectric instrument.

NONDESTRUCTIVE IMPULSE AND ACOUSTIC TESTS

The piezo instrument developed by Farabee and Stone (1991) and used in this research is depicted in figure 1. The probe is a closed end, Plexiglas cylinder approximately 5 cm in diameter and 15 cm long. A thin, disk-shaped ceramic piezoelectric element, bonded to a similar sized thin brass disk, is mounted at the top end of the cylinder in contact with the peach. A solenoid, inside the cylinder, is used to deliver a mechanical impulse to the flat face of the piezo ceramic. The impulse is transferred through the ceramic to the fruit. The resulting vibration of the peach due to the impulse, drives the piezo element. The signal from the element is amplified and filtered through a fourth order low-pass active filter before digitization by a data acquisition unit. Anti-aliasing and noise removal is accomplished with the filter.

Acoustic measurements were taken using the instrument described by Armstrong et al. (1993). The technique involves providing a mechanical impulse to the cheek of the fruit and sensing the resulting vibrations, directly opposite the impulse, with a microphone (fig. 2). The impulse is delivered by a solenoid driven, nylon arm which gently taps the fruit.

The spectral content of the resulting piezo and acoustic signals were analyzed similarly. A data acquisition unit (I/O Tech model 100, Cleveland, Ohio) was used for signal sampling for both the piezo and acoustic instruments. The signal sampling frequency was 5000 Hz (1024 pts) with 12-bit precision. An Intel 486 based PC was used to process data and control the operation of the data acquisition unit. The Fast Fourier transform of the data was normalized using the frequency with the largest amplitude. Eight acoustic parameters were evaluated for spectral characterization. These parameters were, $BM_{1 \text{ to } 7}$, and CFN50 where BM signifies the band magnitude (table 1). The bandwidths associated with the band magnitudes (BM) were based on the previous study by Farabee and Stone (1991). BM values were calculated by summing the normalized spectrum magnitudes between the encompassing frequencies and dividing by the sum of

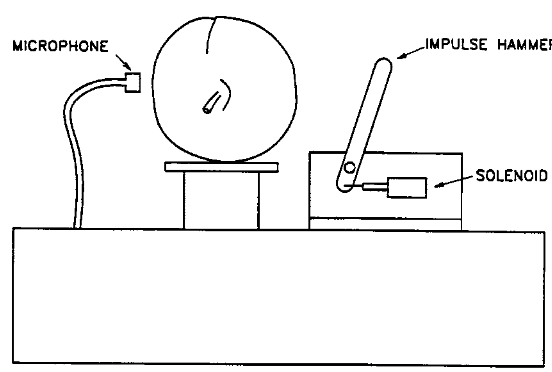

Figure 2–Schematic of acoustic instrument.

Table 1. Band Magnitude variables and their encompassing frequency range

BM_1	BM_2	BM_3	BM_4	BM_5	BM_6	BM_7
			Hz			
40-90	60-110	70-120	80-130	85-160	100-180	120-200

spectrum magnitudes between 0 and 500 Hz. BM values were thus proportional to the energy content between these frequencies. The energy content beyond 500 Hz was insignificant and therefore ignored. CFN50 was the center frequency of the narrowest 50% energy band and was calculated by searching through the spectrum, from 0 to 500 Hz, to find the narrowest frequency band that contained 50% of the total energy of the spectrum.

TESTING PROCEDURE

Two cultivars of peaches, 'Red Haven' and 'Crest Haven', were used for testing. Both were obtained at the OSU Horticultural Research Farm and were harvested at the beginning of optimal commercial maturity. Individual fruit mass was recorded. Nondestructive (piezo and acoustic) and Effe-gi firmness measurements (7.8-mm-dia probe, Effe-gi, Alfonsine, Italy) were taken on ten fruit on the lapsed days after picking as indicated in table 2. All fruit waiting to be tested were separated into lots of ten fruit, placed in plastic bags to minimize moisture loss, and held in cold storage (7 ±2°C, 40-60% RH). Prior to measurements, fruit were allowed to warm to room temperature (approximately 20°C). Two measurements for each firmness parameter (piezo, acoustic and Effe-gi) were taken for each peach on mid-cheek areas, 90° from the suture. The impulse parameters, BM_{1-7}, CFN50, and Effe-gi firmness obtained from two replicate measurements, were averaged for data analysis.

RESULTS AND DISCUSSION

Multiple linear regression (MLR) between piezo and acoustic spectral parameters and Effe-gi firmness were performed for the two cultivars. MLR analysis included spectral parameters with and without mass. Tables 4 and 5 show the regression equation coefficients and adjusted r^2 values obtained from MLR analysis for the two cultivars. All spectral parameters were found to be significant in determining the regression equation except for CFN50. True Effe-gi firmness is plotted against the Effe-gi firmness calculated from the regression equation (spectral parameters only) in figures 3, 4, 5, and 6.

The inclusion of individual peach mass as another independent variable generally improved correlation for both instruments. With mass included, the acoustic instrument had reasonably consistent correlation with Effe-gi firmness for both cultivars (adj. r^2 = 0.636 to 0.737). The piezo instrument relationship was slightly weaker for 'Red Haven' (adj. r^2 = 0.515), and improved, but still poor for 'Crest Haven' (adj. r^2 = 0.334). Effe-gi firmness at the beginning of the test period was high (70-80 N) and had dropped to 10 to 20 N as indicated in figures 3 to 6.

Relationships indicate that the ability to accurately predict Effe-gi firmness for individual fruit with either instrument is limited due to the lack of strong relationships.

Table 2. Test number and days lapsed since picking for the two peach cultivars tested

	Test							
Cultivar	1	2	3	4	5	6	7	8
'Red Haven'	0	1	2	3	6	8	10	-
'Crest Haven'	0	2	4	6	8	10	12	14

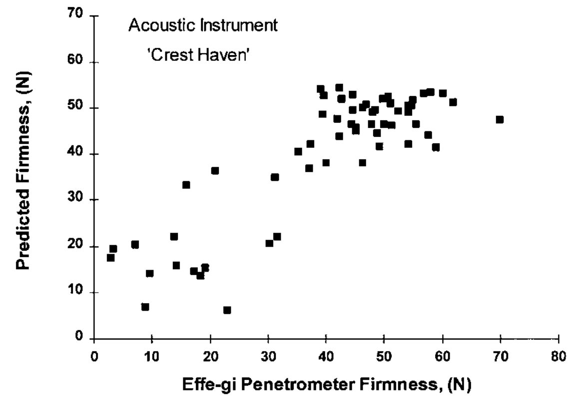

Figure 3–Effe-gi firmness determined from the MLR equation and true Effe-gi firmness for individual peaches. Peach cultivar was 'Crest Haven' and MLR independent variables were spectral parameters.

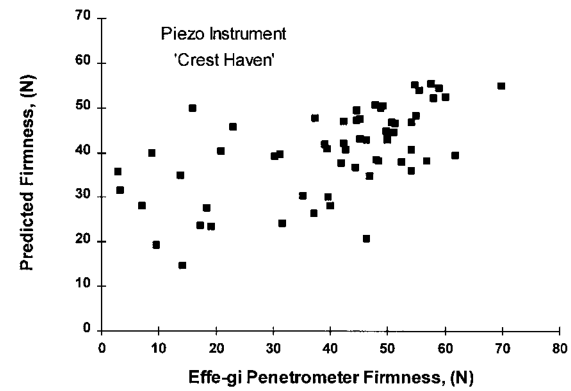

Figure 4–Effe-gi firmness determined from the MLR equation and true Effe-gi firmness for individual peaches. Peach cultivar was 'Crest Haven' and MLR independent variables were spectral parameters.

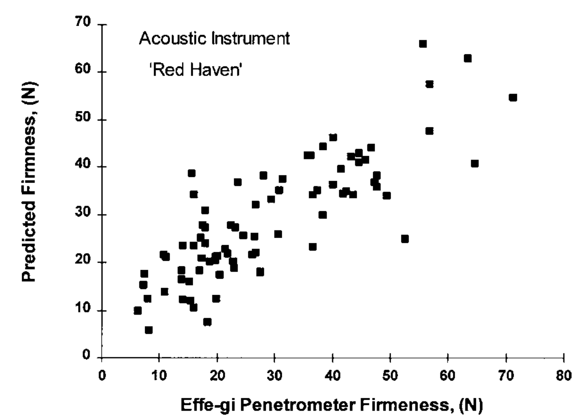

Figure 5–Effe-gi firmness determined from the MLR equation and true Effe-gi firmness for individual peaches. Peach cultivar was 'Red Haven' and MLR independent variables were spectral parameters.

Highly correlated relationships are unlikely due to the natural variation of Effe-gi firmness within an individual peach (Maness et al., 1992). In other words, perfect correlation would not be expected between two Effe-gi

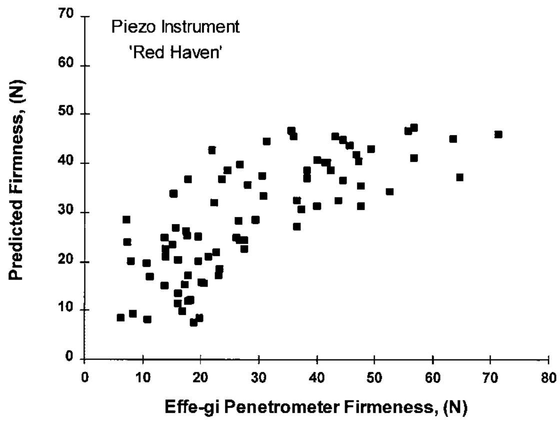

Figure 6–Effe-gi firmness determined from the MLR equation and true Effe-gi firmness for individual peaches. Peach cultivar was 'Red Haven' and MLR independent variables were spectral parameters.

firmness measurements taken at different sites on a peach, although averaging multiple Effe-gi measurements would improve correlation.

While relationships were not particularly strong there is still potential for sorting excessively soft or hard fruit with the acoustic instrument and possibly the piezo instrument. Mature, soft fruit (<20 N Effe-gi) and immature fruit (>50 N Effe-gi) could be sorted with a percentage of false rejects. At these threshold levels (<20 N and >50 N) the percentage of total false rejects for the acoustic instrument is 5% for 'Red Haven' and 14% for 'Crest Haven' peaches using the regression equation that included mass. In terms of decreasing the variability in the packout, the average and standard deviation of firmness for 'Red Haven', prior to sorting, would be 29.0 N (s.d., 15.3 N) and after sorting, 31.2 N (s.d., 12.8 N). For 'Crest Haven' pre-sort and post-sort values would be 40.2 N (s.d., 16.3 N) and 41.6 N (s.d., 8.6 N), respectively. These results, also shown in table 3, show that sorting can increase firmness and uniformity by narrowing firmness variance. The disadvantages of discarding some good fruit and the cost of implementing the sorting process must be offset by prices which reflect the quality of the fruit.

As previously stated, consumers rate firmness as one of the most important quality attributes when selecting fruit along with color and aroma. Further research is needed to determine if firmness sorting by resonance methods does indeed translate to better quality to the consumer or if firmness needs to be combined with other maturity indices such as color and soluble solids for a more complete indication of quality.

Table 3. Mean fruit firmness resulting from sorting using the regression relationship for the acoustic instrument*

	Pre-sort Firmness		Post-sort Firmness	
Cultivar	Mean N	S.D. N	Mean N	S.D. N
'Red Haven'	29.0	15.3	31.2	12.8
'Crest Haven'	40.2	16.3	41.6	8.6

* Threshold values were (<20 N predicted Effe-gi) and (>50 N predicted Effe-gi).

Table 4. Intercept and coefficients for multiple regression between Effe-gi firmness and spectrum parameters and mass for 'Red Haven' peaches

	Acoustic Parameters	Piezo Parameters	Acoustic Parameters & Mass	Piezo Parameters & Mass
Intercept	144.57	49.89	197.96	52.07
BM1	117.78	–64.68	73.17	–65.32
BM2	–96.83	–104.01	–84.02	–104.96
BM3	38.55	157.66	19.97	158.73
BM4	85.56	–228.52	62.09	–226.57
BM5	–10.043	116.00	–16.83	114.92
BM6	–585.09	29.00	–574.82	25.36
BM7	87.50	17.16	52.45	22.49
BM8	181.66	–4.70	189.61	–7.71
Mass			–0.13	–0.02
adjusted r^2	0.64	0.53	0.64	0.53

Table 5. Intercept and coefficients for multiple regression between Effe-gi firmness and spectrum parameters and mass for 'Crest Haven' peaches

	Acoustic Parameters	Piezo Parameters	Acoustic Parameters & Mass	Piezo Parameters & Mass
Intercept	65.08	58.79	100.47	101.03
BM1	–129.64	–181.38	–143.91	–123.56
BM2	81.06	–89.45	165.13	–144.02
BM3	150.57	193.21	20.53	229.08
BM4	–309.00	72.95	–268.15	73.06
BM5	319.41	11.73	324.37	–40.67
BM6	–429.50	–201.18	–377.97	–159.25
BM7	62.34	118.52	–2.98	90.16
BM8	49.33	5.563	94.71	69.03
Mass			–0.37	–0.48
adjusted r^2	0.68	0.26	0.74	0.34

CONCLUSIONS

- Multiple linear regression between spectral parameters for the acoustic instrument and Effe-gi firmness indicated that the strength of the relationships were about the same for the two peach cultivars 'Red Haven' and 'Crest Haven' (adjusted r^2 = 0.64 to 0.74) The same was not true for the piezo instrument (adjusted r^2 = 0.26 to 0.53), although relationships for the 'Red Haven' cultivar are approaching those found for the acoustic instrument.
- Including mass as a variable with spectral parameters in MLR analysis generally increased the adjusted r^2 values by a small amount in most cases.
- The ability to accurately predict Effe-gi firmness for individual fruit with either instrument is limited due to the lack of a significantly strong relationship. However, there is potential for sorting out excessively soft or firm fruit with the acoustic instrument which would be of some benefit in eliminating unmarketable fruit and providing more uniformity in pack-out.

REFERENCES

Abbott, J. A. and D. R. Massie. 1995. Nondestructive dynamic force measurements of kiwifruit firmness (*Actinidia deliciosa*). *Transactions of the ASAE* 38(6):1809-1812.

Abbott, J. A., G. S. Bachmann, N. F. Childers, J. V. Fitzgerald and K. F. Matusik. 1968. Sonic techniques for measuring texture of fruits and vegetables. *Food Technol.* 22(5):635-646.

Armstrong, P. R. and G. K. Brown. 1993. Non-destructive firmness measurement of apples. ASAE Paper No. 93-6023. St. Joseph, Mich.: ASAE.

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.
Bruhn, C. 1995. Consumer and retailer satisfaction with the quality and size of California peaches and nectarines. *J. Food Qual.* 18(4):241-256.
Brusewitz, G. H., M. L. Stone and M. P. Rigney. 1995. Peach physical characteristics for orientation. *Transaction of the ASAE* 39(4):1493-1497.
Chen, H. 1993. Analysis on the acoustic impulse resonance of apples for nondestructive estimation of fruit quality. Ph.D. diss. Leuven, Belgium: Katholieke Universiteit.
Cooke, J. R. 1970. A theoretical analysis of the resonance of intact apples. ASAE Paper No. 70-345. St Joseph, Mich.: ASAE.
Delwich, M. J., T. McDonald and S. V. Bowers. 1987. Determination of peach firmness by analysis of impact forces. *Transactions of the ASAE* 30(1):249-254.
Delwich, M. J. 1989. An impact force response fruit firmness sorter. *Transactions of the ASAE* 32(1):186-188.
Farabee, L. M. and M. L. Stone. 1991. Determination of watermelon maturity with sonic impulse testing. ASAE Paper No. 91-3013. St Joseph, Mich.: ASAE.
Kawnao, S., H. Watanabe and M. Iwamoto. 1992. Determination of sugar content in intact peaches by near infrared spectroscopy with fiber optics in interactance mode. *J. Japanese Soc. Hort. Sci.* 61(2):445-451.
Maness, N. O., G. H. Brusewitz and T. G. McCollum. 1992. Internal variation in peach fruit firmness. *HortScience* 27(5): 903-905.
Peleg, K., U. Ben-Hanan and S. Hinga. 1989. Classification of avocado by firmness and maturity. *J. Texture Studies* 21(2):123-139.
Rood, P. 1957. Development and evaluation of objective maturity indices for California freestone peaches. *Proc. Amer. Soc. Hort Sci.* 70(1):104-112
Shewfelt, R. L., S. C. Meyers, A. V. A. Resurreccion. 1987. Effect of physiological maturity at harvest on peach quality during low temperature storage. *J. Food Qual.* 10(1):9-20
Stroshine, R. L, W. K. Wai, K. M. Keener and G. W. Krutz. 1994. New developments in fruit ripeness sensing using magnetic resonance. ASAE Paper No 94-6539. St Joseph, Mich.: ASAE.
Tu, K., R. DeBusscherr, J. DeBraerdemaeker and E. Schrevens. 1995. Using laser beam as light source to study tomato and apple quality non-destructively. In *Proc. of the FPAC Conference,* 3-5 Nov, 528-536. St Joseph, Mich.: ASAE.
Yamamoto, H., M. Iwamoto and S. Haginuma. 1980. Acoustic impulse response method for measuring natural frequency of intact fruits and preliminary applications to internal quality evaluations of apples and watermelons. *J. Texture Studies* 11(2):117-136.
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.