XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

DETERMINATION OF APPLE FIRMNESS BY ULTRASONIC MEASUREMENT

Ki-Bok Kim [1], Man-Soo Kim [2], Jeong-Gil Park [2], Sangdae Lee [1], Ghi-Seok Kim [2], Hyun-Mo Jung [3]

[1] Safety Metrology Group Korea Research Institute of Standards and Science 1 Doryong-dong Yuseong-gu, Daejeon, 305-340, Korea, kimkibok@kriss.re.kr

[2] Department of Bio-industrial Machinery, Chungnam National University, 220 Gung-dong, Yuseong-gu, Daejeon, 305-764, Korea, mskim@cnu.ac.kr

[3] Department of packing, Kyongbuk College of Science, 159 Bongsan-ri, Kisan-myeon, Chilgok-gun, Gyeongbuk, Korea, babong2@hanmail.net

Abstract: One of the most important quality indicators for fruit is the firmness which is highly correlated to the elastic modulus. This study was conducted to evaluate the potential use of ultrasonic parameters for determination of apple firmness. Ultrasonic transmission system consisted of ultrasonic pulser, two specially fabricated ultrasonic transmitting and receiving transducers for fruit, and digital storage oscilloscope. Ultrasonic parameters such as ultrasonic wave velocity, attenuation, and peak frequency were analyzed. Firmness of apple was measured by using compression test apparatus. A multiple linear regression model describing the relationship between firmness and ultrasonic parameters was proposed.

Keywords: firmness, elastic modulus, apple, ultrasonic parameters

1. BASIC INFORMATION

Firmness is one of the major quality indicators for fruits and has been used as a useful guide for producer, quality inspector and consumers. Especially, in many fruits, firmness is used as an indication of the handling characteristics of the fruit, and picking and grading of fruit may be based on firmness measurement. Traditionally, as destructive method, penetrometer or compression test have been used to estimate the firmness of fruit. A cylindrical rod in the penetrometer is pushed into the fruit and the force required is measured. Various types of penetrometers have been developed. The most common of them are Magness Taylor and Effegi varieties [1-3]. The firmness tests using destructive methods have the advantage of high accurate but fruits are destroyed and wasted.

Several methods to measure the firmness of fruit nondestructively have been suggested [3-8] and most of them are acoustic methods. Even though it is fast, accurate and nondestructive, the acoustic method for assessing fruit firmness has not been widely introduced in practice. As another nondestructive method, ultrasonic technique has been used for evaluating the quality of agricultural products [9-11]. Ultrasonic technique is very useful for nondestructive measurement of the mechanical properties of materials. But most ultrasonic transducers used in previous researches were not suitable for fruit because they were made for industrial usage. Hence the fruits should be sliced uniformly to contact to the surface of the ultrasonic transducers. Recently, the ultrasonic transducer for fruit was successfully developed [12].

The objective of the present study was to evaluate the ultrasonic parameters and firmness of apple and to establish relationship between the results of nondestructive ultrasonic measurements and firmness of apple.

2. MATERIALS AND METHODS

2.1. Fruit samples

Korean (*Sansa* cultivar) apples were purchased at market place. Extremely large and small pears were rejected. All apple samples were inspected to ensure that they were uniform, undamaged and not attacked by worm. After completing the inspection, the fruit samples were held room temperature (about 19-23 °C) for 1 to 25 days to accelerate ripening. The experiment was conducted on random samples of 30 fruits, after allowing samples to reach room temperature.

2.2. Ultrasonic measurement

Tests to measure the ultrasonic wave velocity, attenuation for the whole fruit were carried out using the transmission mode of the ultrasonic measurement setup, as shown in Fig. 1. As ultrasonic transducer to transmit and receive the ultrasonic wave, the specially fabricated ultrasonic transducer having curved wear plate to direct contact to the surface of apple was used. The central frequency and diameter of ultrasonic transducer were 100 kHz and 40 mm, respectively. To match the acoustic impedances between ultrasonic transducers and apple, vacuum grease was used. To generate the ultrasonic wave, PUNDIT 6 (CNS FARNELL Inc., US) was connected to the ultrasonic transmitter. The PUNDIT is high power and low frequency ultrasonic pulser-receiver. The through-transmission mode was selected for the ultrasonic arrangement, with one transducer acting as a transmitter, and the other as a receiver. The transmitted ultrasonic wave signal through apple obtained by the ultrasonic receiver was connected to the digital storage oscilloscope (WaveRunner, LeCroy Co., US). Figure 1 shows the overall experimental setup consisting the ultrasonic transducers, apple, ultrasonic pulse, and oscilloscope.

Fig. 1. Photo of experimental setup with ultrasonic transducers for fruit, apple, ultrasonic pulser and digital storage oscilloscope.

2.3. Firmness measurement

After the ultrasonic experiments, the firmness of each whole fruit was measured using universal testing machine. The loading rate of the crosshead was fixed at 25 mm/min, which was within the range of loading rate (2.5 to 30 mm/min) specified by the ASAE S368.3 MAR95 [13]. The elastic modulus was measured by taking in the equatorial region of the apple using a crosshead controlled by universal testing machine.

3. RESULTS AND DISCUSSION

Progressive changes in elastic modulus during storage time are demonstrated in figure 2 and 3. The changes in wave shape of transmitted ultrasonic signals at storage times of 1, 10, 19 and 25 days were shown in figure 2. Figure 2 shows the original obtained signals. From figure 2, the maximum amplitudes of the signal are decreasing according to storage time.

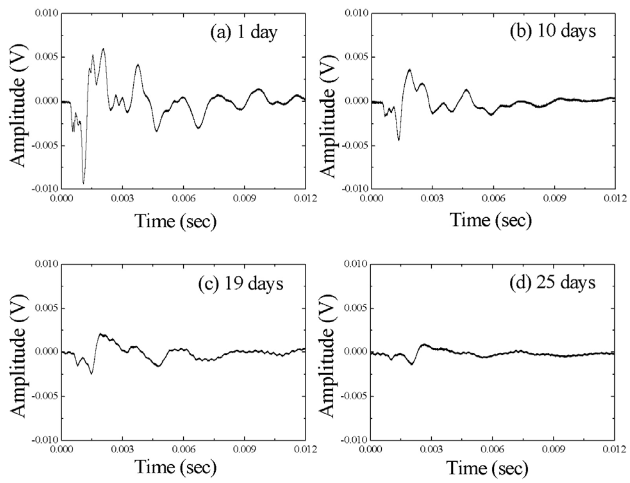

Fig. 2. Changes of ultrasonic transmitted signals of apple at several storage times.

The effect of ripening (or storage time) on the elastic modulus of apples is shown in figure 3. It can be seen that the change in elastic modulus with storage time decreased linearly. The mean values of the measured firmness of the apple, shown in figure 1, diminished monotonically during storage at room temperature from a very firm fruit with a firmness value of about 1150kPa on the first day to a very soft fruit with a firmness of about 450kPa at the end of the 25 days softening process. At this stage, the fruit was too soft to measure the firmness.

The relationships between ultrasonic parameters such as ultrasonic wave velocity and attenuation coefficient and elastic modulus were analyzed as shown in figure 4. The correlation coefficients between elastic modulus and ultrasonic wave velocity and attenuation coefficient were 0.976 and 0.930, respectively. The correlation between ultrasonic wave velocity and attenuation measurements and storage time (or firmness) suggests that it is possible to predict the shelf life of a batch of apples by measuring their ultrasonic parameters.

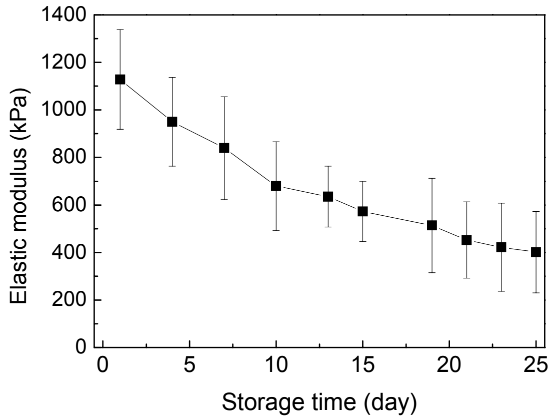

Fig. 3 The variation of the mean value of elastic modulus with the storage time for apple. Each point represents the mean value of 30 apples, Vertical lines represent confidence intervals (confidence probability is 95 percent)

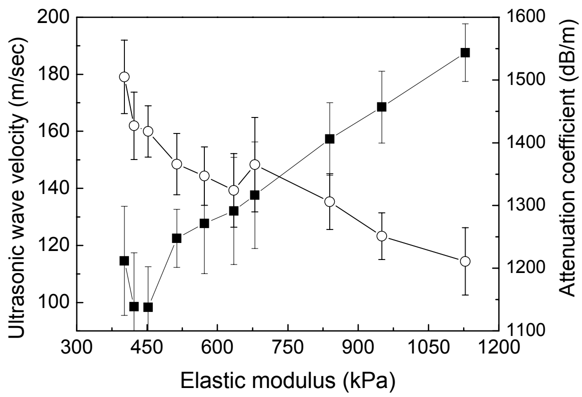

Fig. 4. The variation of the mean values of ultrasonic wave velocity and attenuation coefficient with elastic modulus for apple. ○, attenuation coefficient; ▪, ultrasonic wave velocity. Each point represents the mean value of 30 apples. Vertical lines represent confidence intervals (confidence probability is 95 percent)

From figure 4, because of the changes in the ultrasonic wave velocity and attenuation coefficient were dependent on the firmness (elastic modulus) it was concluded that the determination of firmness (elastic modulus) of apple using ultrasonic wave velocity and attenuation coefficient will be possible.

In order to estimate the capability of determining the elastic modulus with ultrasonic wave velocity and attenuation coefficient, a multiple linear regression model was assumed as

$$E = a_0 + a_1 \mathrm{V} + a_2 A \qquad (1)$$

where, E is the elastic modulus [kPa], V is ultrasonic wave velocity [m/s], A is attenuation coefficient, and a_0, a_1 and a_2 are regression coefficients.

The statistical regression analysis results are summarized in table 1. The coefficient of determination (R^2) of regression model is 0.972. From the result of regression analysis, the firmness of apple will be predictable using ultrasonic measurement. Figure 5 shows the predicted value vs. measured values of elastic modulus and this study demonstrates the feasibility of ultrasonic technique to estimate the firmness of fruit.

Table 1. Results of regression analysis for elastic modulus as a function of ultrasonic wave velocity and attenuation coefficient.

Model	Regression coefficients			R^2	RMSE
	a_0	a_1	a_2		
Eq.(1)	*1004.6*	*5.91*	*-0.84*	*0.972*	*46.0*

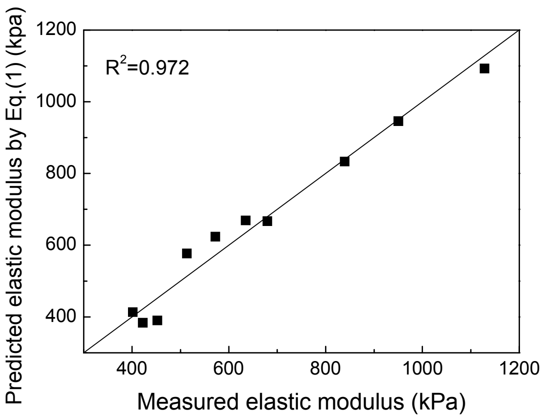

Fig. 5 Relationships between measured value and predicted value of elastic modulus of apple.

4. CONCLUSION

This study was performed to determine the firmness (elastic modulus) of apple as a function of ultrasonic wave velocity and attenuation coefficient of the transmitted ultrasonic signal through the whole fruit using multiple linear regression method. The elastic modulus decreased with storage time of apple. The attenuation coefficient increased with storage time of apple. It was shown that by using the nondestructive ultrasonic transmission system to measure the ultrasonic wave velocity and attenuation coefficient of apple it might be possible to assess its maturity and to estimate its shelf life.

The correlation coefficients between elastic modulus and ultrasonic wave velocity and attenuation coefficient were 0.976 and 0.930, respectively. Multiple-linear regression model describing the relationship between the firmness of apple and ultrasonic parameters (ultrasonic wave velocity and attenuation coefficient) was proposed and found to be a reliable method for predicting the firmness of fruits. The elastic modulus could be predicted with coefficient of determination of 0.972 for apple. The technique for firmness measurement based on ultrasonic wave velocity and attenuation may provide a promising method for development of practical instruments in measuring the firmness of fruit.

ACKNOWLEDGMENT

This study was supported by the Agricultural R&D Promotion Center, Ministry of Agricultural and Forestry, Korea.

REFERENCES

[1] P.D. Dresselhaus, Y. Chong, J.H. Plantenberg, and S.P. Benz, "Stacked SNS Josephson Junction Arrays for Quantum Voltage Standards," IEEE Transactions on Applied Superconductivity Vol. 13, No. 2, pp. 930-933, June 2003.

[1] M. C. Bourne, "Studies on punch testing of apples", Food Technol., Vol. 19, pp.413-415, 1965.

[2] J. A. Abbot, A. E. Watada, and D. R. Massie, "Effe-Gi, Magness-Taylor, and Instron fruit pressure testing devices for apples, peaches and nectarines", J. Am. Soc. Hortic. Sci., Vol. 101, No. 6, pp.698-700, 1976.

[3] J. A. Abbot, H. A. Affeldt, L. A. Liljedahl, "Firmness measurement of stored 'Delicious' apples by sensory methods, Magness Taylor, and sonic transmission", J. Am. Soc. Hortic. Sci., Vol. 117, pp.590-595, 1992.

[4] S. Falk, C. H. Hertz, and H. I. Virgin, "On the relation between turgor pressure and its relation to fruits rigidity", Physiol. Plant. Vol. 11, pp.802-807, 1958.

[5] E. E. Finney, "Mechanical resonance within 'Red Delicious' apples and its relation to fruits texture", Trans. ASAE Vol. 13, pp.177-180, 1970.

[6] H. Yamamoto, M. Iwamoto M., and S. Haginuma, "Acoustic impulse response method for measuring natural frequency of intact fruits and preliminary applications to internal quality evaluation of apples and watermelons", J. Texture Stud., Vol. 11, pp.117-136, 1980.

[7] F. Duprat, M. Grotte, E. Pietri, and D. Loonis, "The acoustic impulse response method for measuring the overall firmness of fruit", J. Agric, Engng. Res. Vol. 66, pp.251-259, 1997.

[8] S. Schotte, N. D. Belie, and J. D. Baerdemaeker, "Acoustic impulse-response technique for evaluation

and moodelling of firmness of tomato fruit", Postharv. Biology & Tech. Vol. 17, pp.105-115, 1999.

[9] N. Sarker, and R. R. Wolfe, "Potential ultrasonic measurements in food quality evaluation", Trans. ASAE Vol. 26, No. 2, pp.624-629, 1983.

[10] A. Mizrach, N. Galili, and G. Rosenhouse, "Determination of fruit and vegetable properties by ultrasonic excitation", Trans. ASAE Vol. 32, No. 6, pp.2053-2059, 1989.

[11] K.-B. Kim, H.-M. Jung, M.-S. Kim, and G. S. Kim, "Evaluation of fruit firmness by ultrasonic measurement", Key Eng. Mater. Vol. 270-273, pp.1049-1054, 2004.

[12] K. B. Kim, S. D. Lee, and M. S. Kim, "Ultrasonic probe design and fabrication for contact measurement of fruit", Proceedings of Asia-Pacific Conference on Non-destructive Testing, pp. 233, 2003.

[13] ASAE STANDARDS : ASAE Standard S368.3 MAR95, 1996.