Proceedings of the 2016 International Conference on Food Properties (ICFP2016)
Bangkok, Thailand, May 31-June 2, 2016

Evaluation and comparison firmness of "Golab Apple" with two methods of acoustic and penetration during cold storage

Mohammad Reza Bayati, Former Ph. D. Student, Department of Agricultural Machinery Engineering, Tehran University, Karaj, Iran, m.r.bayati@ut.ac.ir
(Now, Assistant professor, Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran, bayati@um.ac.ir)
Ali Rajabipour, Professor, Department of Agricultural Machinery Engineering, Tehran University, Karaj, Iran, arajabi@ut.ac.ir
Hossein Mobli, Professor, Department of Agricultural Machinery Engineering, Tehran University, Karaj, Iran, hmobli@ut.ac.ir
Afshin Eyvani, Research Assistant Professor, Agricultural Engineering Research Institute (AERI), Agricultural Research, Education and Extension Organization (AREEO), Karaj ,Iran , eyvani@yahoo.com
Fojan Badii, Research Associate Professor, Agricultural Engineering Research Institute (AERI), Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran, fjbadii@gmail.com

Abstract

Firmness of 60 apples (Kohanz GOLAB local variety)during 10 weeks storage at 2°C and 85% RH was evaluated using non destructive acoustic and destructive penetration tests. Aim of this study was , determine of Golab apple firmness by two methods of acoustic test and puncture test during storage. Values of firmness index for apples in storage time changed between 21.76-8.44($\times 10^6 Hz^2 gr^{2/3}$).To find the dominant frequency of apples ,by a pendulum device, non destructive impulses was hit to apples and by a hand held analyzer, related waves were recorded and to determine penetration firmness on apples ,was used texture analyzer. Decreasing linear functions of acoustic parameters and penetration firmness , estimated firmness of apples. Furthermore a linear relation, between acoustic parameters and penetration measurements obtained and the correlation between them , was found. The results obtained in this study showed, acoustic technique, compared with puncture technique ,is more sensitive for representation of firmness changes of apples in during storage life.

Keywords
Golab apple, acoustic test , penetration test

1. Introduction

Apple fruit (*Mauls domestica* Borkh, Rosaceae) after citrus fruits, grape and banana , is the fourth important fruit of the world and is considered the most important fruit of temperate regions [1]. On terms of trade , Iran is fourth producer and 17th exporter in the world. Among Iranian cultivars of apple fruit , known as "GOLAB apple", due to earliness and having a certain flavor , have reputation an special desirability [2]. On the other , this apple is very sensitive to the physical pressures, more ever , it may even when picking fruit , place of finger pressures causes a noticeable effect on the fruit. Therefore , inevitable destruction of surface texture of fruit during harvesting and transportation has resulted, that it is considered, capable of keeping it in storage. The quality of every fruit and including apple can be assessed by examining the internal and external properties related to fruit. External characteristics, such as: shape, mass, color and internal characteristics such as :firmness, presence or absence of internal damage, the amount of sugar and acidity, pH and brix index can be determined by different methods. Firmness and ripening of agricultural products significantly changes during storage. This properties can be measured by two main methods: Use of puncture test , based on force - deformation curve (destructive test) and use of natural frequency of fruit(non destructive test) related to products. Abbott and et. al.[3] measured firmness changes in Delicious and Golden Delicious apples by three methods sonic vibration spectra , magness-taylor puncture and axial

compression. They found that acoustic stiffness coefficients were satisfactory predicts of the firmness of Golden Delicious apples compared to compression or puncture test. Costa and et. al.[4] the response of the apples fruits flesh tissue to compression assessed by using of a texture analyzer coupled with an acoustic device and also they performed sensory evaluation by panelists on a selected of apples. Their tests results proved the good performance combined acoustic-mechanical method in measuring apple crispness compared with human senses. By some researcher similar tests have been carried out for postharvest quality evaluation and determination of dominant frequency, firmness index, coefficient of elasticity and penetration index as functions of time for products such as persimmon[5], pear[6,7],peach[8], nectarine and plum[9] mandarin[10]. Tropical fruits including mango, avocado, guava, and banana[11-14],.Products of kitchen garden including: tomato and cucumber, watermelon[15-20].The results of above researches generally shows that the changes in acoustic and penetration parameters ,have been decline with different slopes and also acoustic tests have more sensitivity to firmness changes than puncture tests during postharvest storage. Different methods introduced to excite of fruit and analyze the acoustic signal related to acoustic impulse response. Natural frequencies of fruits is obtained by recording of acoustic waves resulted from a non-destructive impact fruit and applying the Fourier Transform to the received signal. Firmness of a spherical fruit is determined with stiffness factor that by Abbot and et.al. [21] and Cooke and et. al. [22] introduced and identified. Also this formula obtained by two Taiwanese researchers by finite element model[23]. Firmness index of fruits is determined by the following formula :

$$FI = f^2.m^{2/3} \quad (1)$$

Where *F1*, Hz^2. $kg^{2/3}$,is firmness index, *f*, Hz, is natural frequency and *m*,gr, is the mass of fruit. This researchers also, offered a mathematical equation to describe the vibrational behavior of fruit against nondestructive impact received.

$$E = f^2.m^{2/3}.\rho^{1/2} \quad (2)$$

Where ρ, gr/cm^3, is density of fruit and *E*, $Hz^2gr^{2/3}(gr/cm^3)^{1/3}$, is coefficient of elasticity.
To reduce possible errors, three impacts is applied on equatorial diameter of fruits. Best response signal impact is generated when it is received in the interval from 0 to 180 degrees[24,25].
This method is simple, rapid and repeatable and also is a reliable and effective way to show changes in the mechanical properties of fruits. The aim of this study was to describe the firmness of apples after harvest and in storage cold using two methods of acoustic test and puncture test and compare them with each other.

2. Material and Methods

Apples were harvested manually from the garden and then were transferred to the laboratory. From the harvested fruits were selected and numbered 60 apples considering the uniformity of color and size. The apples were placed in 10 boxes each with 6 apples to 10 weeks in the cold storage at 2°C and 85%RH.From the first week to tenth week was done the destructive and nondestructive evaluation tests on them. Also weight losses was measured for apples stored under this condition. Non- destructive impacts was hit to apples by a pendulum impactor. Acoustic signals caused by non- destructive impacts were sensed by Hand Held Analayzer, model B&K2270, Denmark, 2009. After recording all impacts responses to all apples, data were transferred to a computer . Data were analyzed by softwares of Sound Level Meter BZ-7222, Frequency Analyzer BZ-7223 and FFT Analyzer BZ-7230. These programs display acoustic spectra of non invasive impacts on apples. Selected waves were changed with the Fourier Transform from the time domain to the frequency domain and then obtained the natural frequency of apples.

2.1 Measuring of acoustic impulse response

To record and measure of acoustic response of apples against impact, they were placed in a quiet environment to avoid unwanted noise interference. In one side of the fruit , microphone was deployed to recording waves and in the other side , fruit receives non destructive impacts. Frequency of all fruits was individually measured. Measurement was performed at three points and in any point , three impacts. and with distance of approximately 120 degrees from each other on equatorial diameter. In total were applied 9 impacts to each apple.

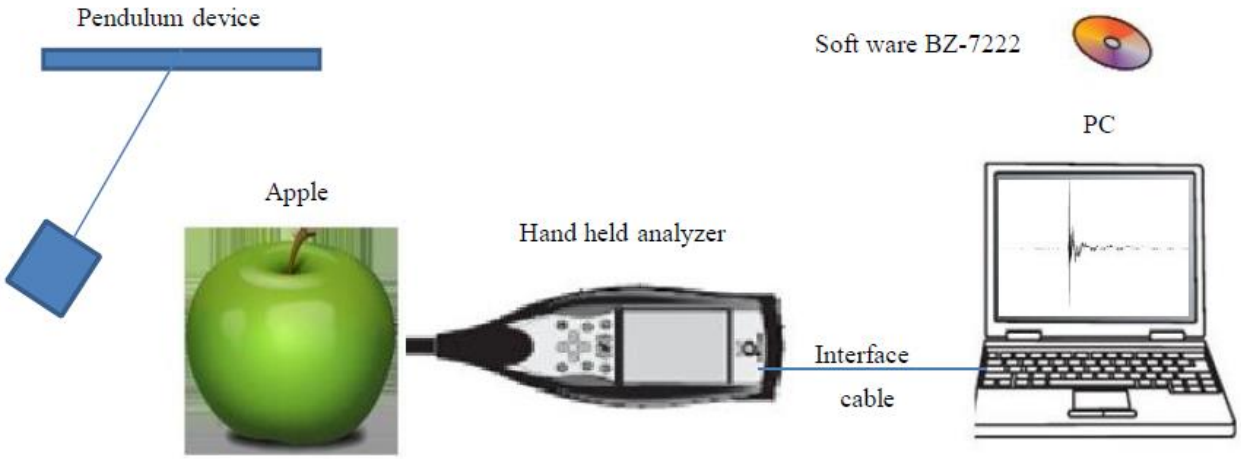


Figure 1 : Setup of experimental system for acoustic impulse response measurement on apple fruit

Determining of firmness index and elasticity coefficient of each apple was conducted with equation (1) and (2) respectively by using of the characteristics of the first frequency with the largest domain.
For measuring the weight loss of apples during storage , weight of each fruit was measured in every week. Scale used had a precision of 0.01 gram . weight difference and its losses percentage was obtained from the following formula:

$$W = [(W_i - W_f)]/W_i \quad (3)$$

Were W is weight loss percentage, W_i is initial weight(gr) before storage and W_f is final weight(gr) of apples in the end of every week.

2.2 Penetration test

Test was conducted by using Texture Analyzer model Hounsfield-H5KS. For this test was used a probe with diameter of 6.4 mm. Probe tip speed and penetration depth was 25 mm/min and 8 mm , respectively. In this test fruit skin in place of hole was removed. This test was separately performed on all the fruits. Graphs of force – deformation was extracted and mechanical properties of apples was investigated from them.

3. Results and Discussion

Changes of acoustic parameter including, natural frequency, acoustic index and coefficient of elasticity resulting and firmness changes resulting from penetration test, are shown in figures (2),(3),(4)and (5).

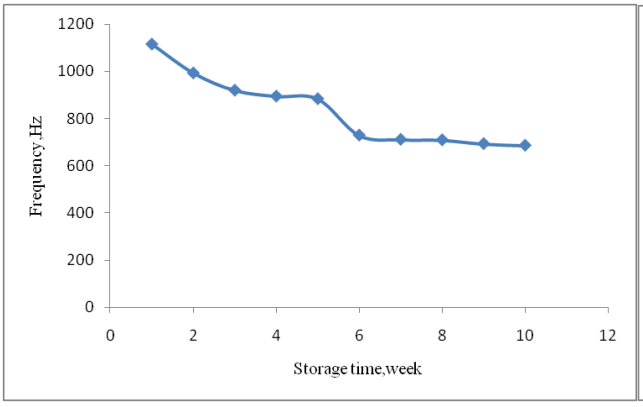


Figure 2: Changes of natural frequency during storage

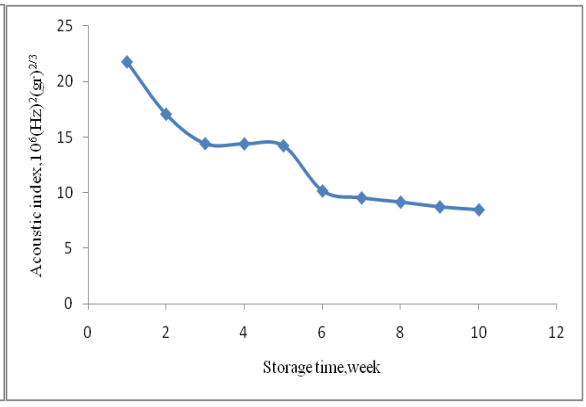
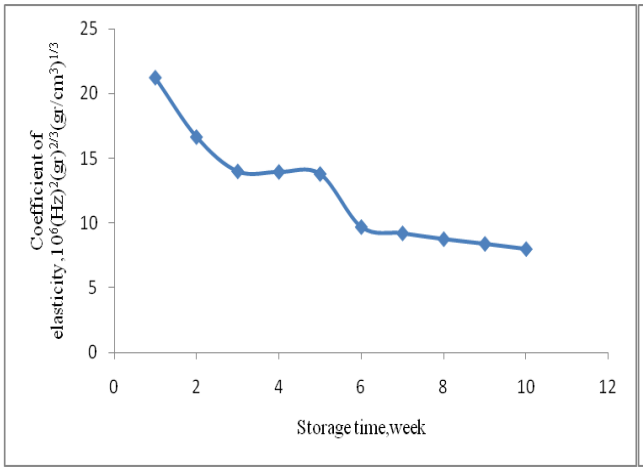


Figure 3: Changes of acoustic index during storage



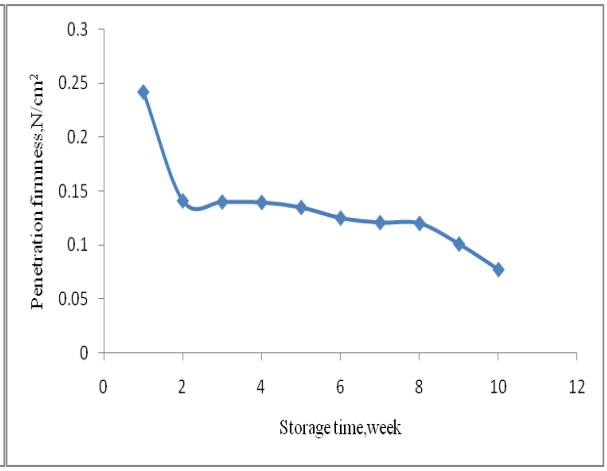


Figure 4: Changes of coefficient of elasticity during storage Figure 5:Changes of penetration firmness during storage

Figure (2) shows the frequency has continuously decreased during storage. In figures 3,4,and 5, acoustic index, coefficient of elasticity and penetration firmness have a similar behavior with frequency and all of them have been decreased. Decrease of acoustic index and penetration firmness about apples variety "Golden Delicious", "Royal Gala" and "Golden Smoothy" has been reported by De Belie and et. al., Molina Delgado and et. Al., and Zdunec and et. Al.[26-28]. These decreases are more evident in the first three weeks, that is due to softness of texture of apples. From the fifth week until the end of the storage period, decrease of texture firmness continues with less slope, that indicates the relative stability of apple tissue. From the regression analysis performed on each of the graphs, the following linear equations was obtained.

Natural Frequency, R^2=0.897, Y=-46.66X+1089.6
Acoustic Index, R^2=0.876 , Y=-1.353X+20.22
Coefficient of Elasticity, R^2=0.879 , Y=-1337X+19.71
Penetration Firmness, R^2=0.681 , Y=-0.011X+0.198

In the above equations, X is the duration of storage(week). These equations show that there is the negative correlation between frequency, firmness index, coefficient of elasticity and penetration firmness with period of postharvest storage. Figure (6) shows the percentage of apples weight losses.

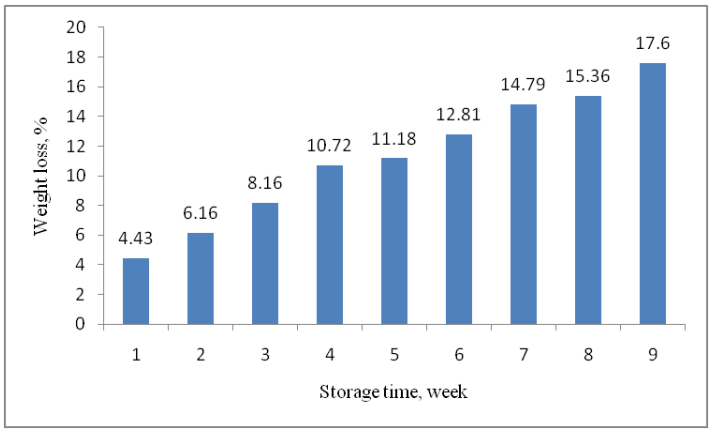


Figure 6: Weight loss of apples

As the chart shows, weight loss increases with increasing the storage time. The fruit weight loss per week that was obtained from mass difference between mass of each apple , before and after the storage period was 14.9 gr. Increase of approximately 4.4% weight loss at the end of the first week, indicates start of biological changes of apples. In this period simultaneously accures , firmness decrease. Also at this time, 21.6% of firmness index has

been reduced. This amounts at the end of the tenth week reached to 61.2% and 17.6% for firmness index and weight, respectively. This situation represents a logical process of fruit storage after harvest. Based on rate of fruit ripening , fruit frequency is changed. The coefficient of variability of apple is increased with continuation of storage period and apple softening .

Table 1: The correlation matrix between apples properties

	Natural Frequency	Firmness Index	Coefficient of Elasticity	Penetration Firmness
Natural Frequency	1			
Firmness Index	0.994	1		
Coefficient of Elasticity	0.995	0.999	1	
Penetration Firmness	0862	0.899	0.898	1

Table (1) indicates positive correlation between firmness index and coefficient of elasticity with penetration firmness 0.899 and 0.898 respectively..Also , numbers of table indicate coefficient of correlation of 0.994 and 0.995 between natural frequency with firmness index and coefficient of elasticity. There is a high correlation between the firmness index and coefficient of elasticity equal 0.999. This can prove that the acoustic index and coefficient of elasticity are more suitable parameters for the control of apple ripening during storage.
Therefore, method of acoustic test is an effective and non-destructive method to determine of situation of apples during storage. Also, the results of test data shows that both firmness index and coefficient of elasticity can be used to determine of different levels of apple ripening after harvest.

4. Results

Acoustic test is a reliable and valid method for determining the amount of ripening Gala(Golab Kohanz)apples during cold storage.. Acoustic parameters including: the first resonance frequency, firmness index and coefficient of elasticity are steadly reduced during storage. Correlation between acoustic parameters and penetration firmness is reduce in storage period.. Non destructive acoustic test can be a appropriate alternative for conventional destructive tests to determine the fruit firmness and desired storage life.

Acknowledgements

The authors would like to thanks the Agricultural Engineering Research Institute, KRAJ, IRAN for their support and for helping to carry out this research.

References

1. Janick, J., Cummins, J.N., Susan, K., Brown, S.K., and Hemmat, M., 1996, “Apples In: Fruit Breeding, sons, Inc Vol. 1: Tree and Tropical Fruits, Janick and Moore, J. N. (eds), John Wiley and. 1-77.
2. Naghshin, F., Bahar, M., Tabatabaei, B.E.S., and Hajnajari, H., 2008, “Evaluation of Genetic Diversity of ‘GOLAB’ Apple Genotypes Using Microsatellite (SSR) Markers” Iranian Journal of Horticultural Science and Technology, 9(2), 69-82.
3. Abbott, J. A., Massie, D. R., Upchurch, B. L., and Hruschka , W. R., 1995, “Nondestructive Sonic Firmness Measurement of Apples” Transactions of the ASABE(American Society of Agricultural and Biological Engineers), 38(5), 1461-1466.
4. Costa, F., Cappellin, L., Longhi, S., Guerra, W., Magnago, P., Porro, D., Soukoulis, C., Salvi, S., Velasco, R., Biasioli, F., and Gasperi, F., 2011, “Assessment of Apple (Malus domestica Borkh.) Fruit Texture by a Combined Acoustic-Mechanical ProfilingSstrategy” Postharvest Biology and Technology, 61(1), 21-28.
5. Taniwaki, M., Hanada, T., and Sakurai, N., 2009, “Postharvest Quality Evaluation of “Fuyu” and “Taishuu” Persimmons Using a Nondestructive Vibrational Method and an Acoustic Vibration Technique” Postharvest Biology and Technology, 50, 80-85.
6. Gómez, A. H., Wang, J., and Pereira, A. G., 2005, “Impulse Response of Pear Fruit and its Relation to Magness-Taylor Firmness During Storage” Postharvest Biology and Technology, 35(2), 209-215.

7. Taniwaki, M., Hanada, T., Tohro, M., and Sakurai, N., 2009, "Non-Destructive Determination of the Optimum Eating Ripeness of Pears and Their Texture Measurements Using Acoustical Vibration Techniques" Postharvest Biology and Technology, 51,305-310.
8. Gómez, A. H., Pereira, A. G., Jun, W., and Yong, H., 2005, "Acoustic Testing for Peach Fruit Ripeness Evaluation During Peach Storage Stage" Revista Ciencias Técnicas Agropecuarias, 14(2), 28-34.
9. Muramatsu, N., Sakurai, N., Yamamoto, R., and Nevins, D. J., 1996, , "Nondestructive Acoustic Measurement of Firmness for Nectarines, Apricots, Plums, and Tomatoes" HortScience, 31(7), 1199-1202.
10. Wang, J., Gomez, A. H., and Pereira, A. G., 2006, "Acoustic Impulse Response for Measurment the Firmness of Mandarin During Storage" Journal of Food Quality, 29, 392–404.
11. Valente, M., Leardi, R., Self, G., Luciano, G., and Pain, J. P., 2009, "Multivariate Calibration of Mango Firmness Using VIS/NIR Spectroscopy and Acoustic Impulse Method" Journal of Food Engineering, 94, 7-13.
12. Shmulevich, I., Howarth, M. S., and Ioannides, Y., 2003, "Comparison Between Acoustic Response and Low Mass Impact Measurment Teqniques to Assess Avocado Firmness" Proceedings V World Avocado Congress, 19 -24 October, Granada - Málaga, Spain, 687-694.
13. Barriga-Te´llez, L. M., Garnica-Romo, M. G., Aranda-Sa´nchez, J. I., Correa, G. A., Bartolome´-Camacho, M. C., and Martı´nez-Flores, H. E., 2011, "Nondestructive Tests for Measuring the Firmness of Guava Fruit Stored and Treated with Methyl Jasmonate and Calcium Chloride" International Journal of Food Science and Technology, 46, 1310–1315.
14. Jagannath, J. H., Das Gupta, D. K., Bawa, A. S., Sebastin, R., and Vishnu, B., 2005, "Assessment of Ripeness/Damage in Banana (Musa Paradisiacal) by Acoustic Resonance Spectroscopy' Journal of Food Quality, 28, 267–278.
15. Baltazar, A., Isidro Aranda, J., and Gonza´ lez-Aguilar, G., 2008, "Bayesian Classification of Ripening Stages of Tomato Fruit Using Acoustic Impact and Colorimeter Sensor Data" Computers and Electronics in Agriculture, 60, 113–121.
16. Lu, Q., Wang, J., Gomez, A. H., and Pereira, A. G., 2009, "Evaluation of Tomato Quality During Storage by Acoustic Impulse Response" Journal of Food Processing and Preservation, 33, 356–370.
17. Felföldi, J., and Zsom-Muha, V., 2010, "Investigation of Ripening Process of Fruit and Vegetable Samples by Acoustic Method" ISHS Acta Horticulturae, 858, 393-398.
18. Stone, M. L., Armstrong, P. R., Zhang, X., Brusewitz, G. H., and Chen, D. D., 1996, "Watermelon Maturity Determination in the Field Using Acoustic Impulse Impedance Techniques" Transactions of the ASAE, 39 (6), 2325-2330.
19. Taniwaki, M., Tohro, M., and Sakurai, N., 2010, "Measurement of Ripening Speed and Determination of the Optimum Ripeness of Melons by a Nondestructive Acoustic Vibration Method" Postharvest Biology and Technology, 56, 101–103.
20. Saadatnia, M., 2011, "Determining the Internal Quality of Watermelon Using Acoustic Methods" Msc. Thesis, The Ferdowsi University of Mashhad, Iran.
21. Abbot, J. A., Bachman, G. S., Childers, N. F., Fiztgerald, J. V., and Matusik, F. J., 1968, "Sonic Techniques for Measuring Texture of Fruit and Vegetables" Food Technol, 22(5), 635-645.
22. Cooke, J. R. and Rand, R. H., 1973, "A Mathematical Study of Resonance in Intact Fruit and Vegetables Using a Three Media Elastic Sphere Model" Journal of Agricultural Engineering Research, 18, 141-157.
23. Cherng, A P., and Ouyang, F., 2003. "A Firmness Index for Fruits of Ellipsoidal Shape" Biosystems Engineering, 86(1), 35-44.
24. Tiplica, T., Vandewalle, P., Verron, S., Grémy-Gros, C., and Mehinagic, E., 2010, "Identification of Apple Varieties Using Acoustic Measurements" International Metrology Conference CAFMET, April 18-23, Cairo, Egypt. 1-8.
25. Duprat, F., Grotte, M., Pietri, E., and Loonis, D., 1997, "The Acoustic Impulse Response Method for Measuring the Overall Firmness of Fruit" Journal of Agricultural Enjineering Research, 66, 251 – 259.

26. De Belie, N., Schotte, S., Coucke, P., and De Baerdemaeker, J., 2000, "Development of An Automated Monitoring Device to Quantify Changes in Firmness of Apples During Storage" Postharvest Biology and Technology, 18, 1-8.
27. Molina-Delgado, D., Alegre, S., Puy, J., Recasens, I., 2009, "Relationship Between Acoustic Firmness and Magness Taylor Firmness in Royal Gala and Golden Smoothee Apples" Food Science and Technology International, 15(1), 31-40.
28. Zdunek, A., Cybulska, J., Konopacka, D., and Rutkowski, K., 2010, "New Contact Acoustic Emission detector for texture evaluation of apples" Journal of Food Engineering, 99, 83–91.

Biography

Mohammad Reza Bayati is an Assistant Professor in Department of Biosystems Engineering at the Ferdowsi University of Mashhad, Mashhad, Iran. He earned B.S. in Agricultural Machinery from Shiraz University, Masters in Agricultural Machinery Engineering from Shiraz University, Shiraz, Iran and PhD in Biosystems Engineering from Tehran University, Tehran, Iran. He has published journal and conference papers. His research interests include technical infrastructure services in developing bio-industries and evaluation of food and agricultural products quality.

Hossein Mobli is a Professor of Mechanical Engineering of Agricultural Machinery in Department of Agricultural Machinery Engineering of University of Tehran. He earned B.S. in Agricultural Machinery from Shiraz University, Masters and PhD in Mechanical Engineering of Agricultural Machinery from Tarbiat Moddares University in Tehran. He has published over than 166 Journals and 63 conference papers and 76 of Graduate students were under his Supervision and his Advisor. He published seven books in Agricultural Machinery, too. He taught in Department of Agricultural Machinery Engineering of University of Tehran, Harvesting Machines, Tillage, Material sciences and Design of Farm Machinery and now is teaching, Mechanics of material, Machine tools shop, Metal Working Shop, Welding shop and Strength of Material lab. His mail address is hmobli@ut.ac.ir. Phone No. 09123614284

Fojan Badii is currently an Associate Professor in Agricultural Engineering Research Institute (AERI), Agricultural Research, Education and Extension organization (AREEO), Iran. She earned her B.S. and MSc. Degrees in Food Science and Technology from Tehran University, Iran and her PhD in Food Polymer Science from the University of Nottingham, UK. She was a research visitor in the University of Melbourne, Australia. She has published several journal and conference papers. Dr Badii has been an invited lecturer in Shahid Beheshti University and Tehran University.