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COMPARISON OF MECHANICAL PROPERTIES OF TWO APPLE VARIETIES UNDER COMPRESSION LOADING

A. GORJI CHAKESPARI[1], A. RAJABIPOUR[2], H. MOBLI[3]

1 A.G. Chakespari, Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran , Karaj, Iran, a.gorji2008@Gmail.com
[1] A. Rajabipour, arajabi@ut.ac.ir
[1] H. Mobli, hmobli@ut.ac.ir

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ABSTRACT In this study strength properties of two Iranian apple varieties (Golab Kohanz and Shafi Abadi), under compression loading, were considered and compared using standard methods. The properties such as rupture force and energy, failure stress and strain, Young's modulus, toughness and hardness were determined in 86% and 84% moisture content (w.b) for Golab Kohanz and Shafi Abadi, respectively. Mechanical properties of apples were evaluated using 20 cylindrical specimens of each variety, taken in horizontal and vertical direction by Universal Testing Machine. Average values of rupture force and energy, failure stress, failure strain, Young's modulus, toughness and hardness were determined, 57.82 N, 285.88 mJ, 0.37 MPa, 31.26%, 0.93 MPa, 0.07 J/cm3 and 9.14 N/mm for Shafi Abadi variety, respectively. The corresponding values for Golab Kohanz were obtained as 51.11 N. 157.51 mJ, 0.32 MPa, 23.36%, 0.81 MPa, 0.04 J/cm3 and 7.79 N/mm respectively. According to results, effect of the sampling orientation was not significant on the mechanical properties in any two varieties.

Keywords: Golab Kohanz, Shafi Abadi, mechanical properties, toughness, hardness

INTRODUCTION The apple, with scientific name of *Malus domestica* is a pomaceous fruit from *Rosaceae* family. There are more than 7500 known cultivars of apples in world (Dobrzañski *et al.,* 2006). Iran, with 190000 ha of cultivation area (2.8% of the world production area) is tertiary country of apple producer posterior China and USA countries in world. In spite of 2.66 million tons of annual Iranian apple production, exportation of that is very low (FAO, 2007). One of the most important export problems is quality decrease of fruits in postharvest operations such as handling, processing, grading and packaging. These mechanical treatments are eventually related to the external forces exerted on each apple fruit. Existence of the external forces makes mechanical damages in apple texture. Crushing and fracture caused by forces exerted on an apple fruit that increase the susceptibility to deterioration during storage can be analysed with knowledge of the mechanical properties such as failure stress and strain as well as modulus of elasticity under the static loading (Kilickan *et al.,* 2007). Force deformation characteristics of fruits beyond the elastic limit may be important to simulate the destruction that occurs in bruising. Elastic modulus or Young's modulus is often used by engineers as an index of product firmness. Toughness and hardness are other important attributes of fruits and often use for fruits quality assessment (Vursavus *et al.,* 2006). Therefore the postharvest mechanical properties data of fruits are important in adoption and design of various handling, packaging, storage and transportation systems. The fruit compression test simulates the condition of static loading that fruit can withstand in mechanical handling and storage.

Research has been carried out for several years to determine the resistance of fruits and vegetables to compression force. Witz, (1954) reported resistance to bruising of potatoes to puncture by using a plunger. Studies on bruises to apples resulting from dropping and from application of pressure were reported by Gaston and Levin, (1951). Braga et al. (1999) investigated force, specific deformation, and energy required for the initial rupturing of macadamia nut shell under compression as a function of moisture content, nut size, and compression loading position. Liu et al. (1999) investigated the fracture behavior of macadamia nut shell under contact load between two rigid plates theoretically and numerically and found that the vertical crack was beneficial to cracking the nutshell while the horizontal crack was unhelpful unless it was long enough. Aydın, (2002) reported the several physical properties of hazelnut and kernels as a function of moisture content and found that rupture force of nut and kernel decreased with an increase in moisture content. Similarly, Gezer et al. (2002) evaluated some physical properties of *Hacıhaliloglu* apricot pit and its kernel and found the applied force decreased with the increase of moisture content for apricot pit and its kernel. The maximum rupture force was found to be 656.2 N through length for pit and 118.80 N through width thickness for kernel. kheiralipour *et al.* (2008) investigated some mechanical and nutritional properties of two varieties of apple in Iran. Ozturk *et al.* (2009) studied some chemical and physico-mechanical properties of pear cultivars (Deveci and Santa Maria). Therefore, the present research aimed to investigate the mechanical properties of two apple varieties (Golab Kohanz and Shafi Abadi) and then estabilishing convenient refrence tables by using mechanical data for mechanization and processing.

MATERIALS AND METHOD Two Iranian apple varieties (Golab Kohanz, Shafi Abadi) were prepared in 2009 summer season from an orchard located at the Horticultural Research Center, Agricultural Faculty, University of Tehran, Karaj, Iran. GK and SA are premature and middle maturing varieties, respectively. The experiments were carried out during the period of July–August in 2009. The fruits were harvested carefully by hand at their commercial maturity stage and transferred to the laboratory in plastic bags to reduce water loss during transport. The fruits were cleaned to remove all foreign matters such as dust, dirt and chaff as well as immature and damaged fruits. The analysis was carried out at a room temperature of 23°C. The initial moisture content of fruit was determined by using dry oven method at 77°C for 10 days (kheiralipour *et al.,* 2008).

Mechanical properties of apples were evaluated using 20 cylindrical specimens of each variety. Samples are taken in vertical and horizontal orientations with diameter as 14 mm and height as 24 mm. Vertical orientation was along length (equivalent distance of the stem to the calyx) and horizontal orientation was in radial direction, tangent to the stem-calyx axis. The tests performed by Universal Testing Machine (Santam, MRT-5). The machine was equipped with a load cell of 20 N and two parallel plates that one is fixed and the other is versatile that moves at a compressive rate of 25.4 mm/min (Fig. 1). The individual sample was loaded between two parallel plates of the machine and was compressed under the preset conditions and the curve of force-deformation is simultaneously curved until the curve arrived to rupture point (A point in Fig. 2).

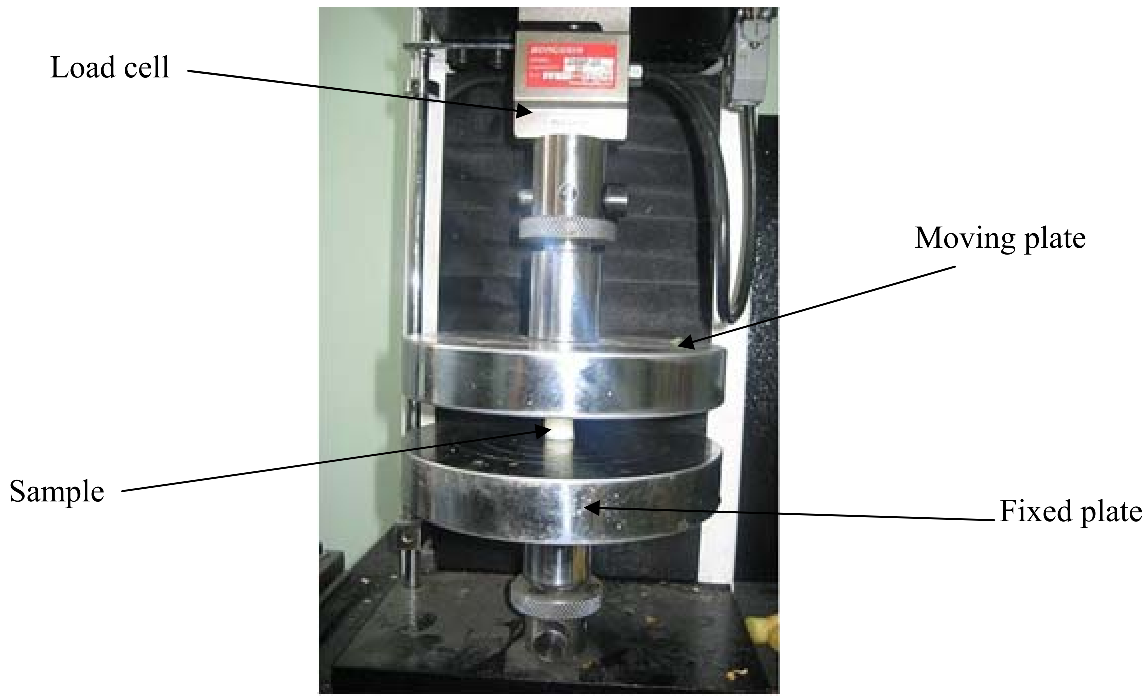

Figure 1. Universal Testing Machine

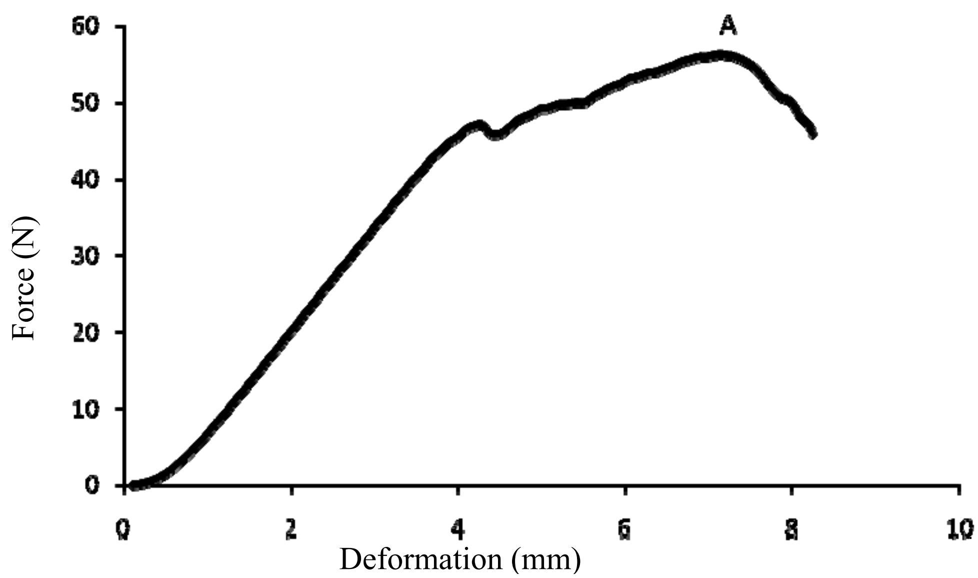

Figure 2. The curve of force-deformation

Failure stress and strain of apples are calculated by following equations (Vursavus *et al.*, 2006):

$$\sigma_f = \frac{F_f}{A} \tag{1}$$

$$\varepsilon_f = \frac{D_f}{L_i} \times 100 \tag{2}$$

where: σ_f is failure stress (MPa), ε_f is failure strain (%), F_f is failure force (N), A is cross section of sample (mm^2), D_f is deformation of sample in the failure point (mm) and L_i is specimen length of fruits (mm).

Young's modulus (apparent elastic modulus, MPa) was obtained from the slope of the stress-strain curve from the origin (0:0) to 50% of failure point and failure energy (mJ) was also calculated by the under area of force-deformation curve until failure point (Mohsenin, 1986).

Toughness (*P*), the ratio of energy absorbed by the fruit up to the rupture point to the volume of the fruit or in the other hand, the work required to cause rupture in the material, was calculated from the following formula (Gupta and Das, 2000):

$$P = \frac{E_f}{V} \tag{3}$$

where: P is toughness (J/cm^3), E_f is failure energy (mJ) and V is sample volume (mm^3).

Hardness (Q) was calculated by dividing the rupture force by the deformation at rupture (Sirisomboon et al., 2007):

$$Q = \frac{F_f}{D_f} \tag{4}$$

where: Q is hardness (N/mm), F_f is failure force (N) and D_f is deformation of sample in the failure point (mm).

Lastly, All data were subjected to statistical analysis using the analysis of variance (ANOVA) test, and means were compared using Duncan's multiple range tests at 5% level of significance.

RESULTS AND DISCUSSION Initial moisture contents were 86% and 84% (w.b) for Golab Kohanz and Shafi Abadi varieties, respectively. Results of variance analysis about effect of variety and sample orientation on mechanical properties of two apple varieties were shown in Table 1.

Table 1. Analysis of the variance of mechanical properties considered for Golab Kohanz and Shafi Abadi varieties

Variation source	DF	Mean squares							
		Failure force (N)	Failure energy (mJ)	Deformation (mm)	Young's modulus (MPa)	Failure stress (MPa)	Failure Strain (%)	Toughness (Jcm^{-3})	Hardness (N/mm)
Treatment	3	75.07^{ns}	29702.79^{*}	8.92^{*}	0.04^{ns}	0.002^{ns}	109.12^{ns}	0.001^{ns}	5.28^{ns}
Variety	1	224.91^{ns}	82387.22^{ns}	23.5^{**}	0.02^{ns}	0.008^{ns}	311.41^{*}	0.004^{*}	9.11^{ns}
Sample Orientation	1	0.15^{ns}	4520.87^{ns}	1.69^{ns}	0.02^{ns}	0.00^{ns}	8.24^{ns}	0.00^{ns}	3.05^{ns}
Intraction	1	0.15^{ns}	2200.27^{ns}	1.59^{ns}	0.08^{ns}	0.00^{ns}	7.71^{ns}	0.00^{ns}	3.68^{ns}
Error	16	202.91	6827.1	2.3	0.22	0.008	39.66	0.00	5.65
Coefficient variance	-	26.15	37.27	22.7	20.97	26.67	23.05	40.08	28.08

ns: no significant difference

* significant at 5% level

** highly significant at 1% level

According to Table 1, effect of variation on deformation in failure point was significant in 1% statistical level and on Failure stress and toughness was significant in 5% statistical level for each two varieties. Effect of sample orientations on none mechanical properties were not significant. The mean and standard deviation values of discussed mechanical properties under of variety effect are shown in Table 2. According to results, the mean of force and energy failure, stress and strain failure and young' modulus obtained 57.82 N, 285.88 mJ, 0.37 MPa, 31.2% and 1.76 MPa for Shafi Abadi variety, respectively, and corresponding values for Golab Kohanz variety obtained 51.11 N, 157.51 mJ, 0.32 MPa, 23.36% and 1.52 MPa, respectively. According to these results is specified texture of Shafi Abadi variety is stiffer than texture of Golab Kohanz variety and is more resistant than it relative to compression loading therefore durability of Shafi Abadi variety is more and placement height of Shafi Abadi variety in boxes is more than Golab Kohanz variety (Sitkei, 1986). In research of Kheiralipour *et al*, (2008), the mean values of the failure stress and strain for the Redspar variety obtained 0.43 MPa and 20%, respectively, and corresponding values for Delbarstival variety were 0.41 MPa and 15%, respectively. In comparison with results of Kheiralipour *et al*, (2008) is specified texture of Golab Kohanz and Shafi Abadi varieties are softer than Redspar and Delbarstival varieties. Masoudi *ea al*, (2004), reported results for failure stress and strain relative to Red Delicious (0.39 MPa and 7%), Golden Delicious (0.42 MPa and 13%) and Grani Smith (0.44 MPa and 11%). The mean values of toughness and hardness for Shafi Abadi variety were 0.07 Jcm^{-3} and 9.14 N/mm, respectively, and for Golab Kohanz obtained 0.04 Jcm^{-3} and 7.79 N/mm, respectively. These results also denoted texture of Shafi Abadi variety is more resistant than texture of Golab Kohanz variety.

Table 2. The get mean and standard deviation values for discussed mechanical properties under of variety effect

Variation source		Mechanical properties: Failure force (N)	Failure energy (mJ)	Deformation (mm)	Young's modulus (MPa)	Failure stress (MPa)	Failure Strain (%)	Toughness (Jcm^{-3})	Hardness (N/mm)
Variety	Safi Abadi	$57.82^{a}\pm11.49$	$285.88^{a}\pm95.88$	$7.77^{**a}\pm1.78$	$1.76^{a}\pm0.26$	$0.37^{a}\pm0.07$	$31.2^{*a}\pm7.08$	$0.07^{*a}\pm0.02$	$9.14^{a}\pm2.29$
	Golab Kohanz	$51.11^{a}\pm15.12$	$157.51^{a}\pm60.74$	$5.6^{b}\pm1.12$	$1.52^{a}\pm0.37$	$0.32^{a}\pm0.09$	$23.36^{b}\pm4.69$	$0.04^{b}0.01$	$7.79^{a}\pm2.4$

**Corresponding to 1% significance level.

*Corresponding to 5% significance level.

a and b: means followed by different letters are significantly different from others (P<0.05).

CONCLUSION This paper presents information on mechanical properties of Golab Kohanz and Shafi abadi varieties which may be useful in design of different machines for harvest and post harvest operations. Therefore, the differences between the mechanical properties of apple varieties should be considered in optimizing apple related mechanization and processing. It is recommended that other engineering properties also be measured or calculated to prepare comprehensive information fairly in design of the apple related machinery. Finally it is obvious from the results that:

- Failure force and energy, young's modulus, failure stress and strain, toughness and hardness for Shafi abadi variety was bigger than Golab Kohanz variety.

- Effect of sample orientations (horizontal and vertical) on discussed mechanical properties was not significant for two varieties.

REFERENCES

Aydın, C. 2002. Physical properties of hazelnuts. Biosystems Engineering 82(3): 297–303.

Braga, G.C., S. M. Couto, T. Hara, and J. T. P. A. Neto. 1999. Mechanical behaviour of macadamia nut under compression loading. J. Agricultural Engineering Research 72(3): 239–245.

Dobrzañski, B., J. Rabcewicz, and R. Rybczyñski. 2006. Handling of Apple. IA PAS Press, Lublin, Poland.

FAO. 2007. FAOSTAT database. Available at: http://faostat.fao.org/.

Gaston, H. P., and J.H. Levin. 1951. How to reduce apple bruising. Michigan State College Special Bulletin 374.

Gezer, I., H. Hacısefero gulları, and F. Demir. 2002. Some physical properties of Hacıhaliloglu apricot pit and its kernel. J. Food Engineering 56(1): 49–57.

Gupta, R. K., and S.K. Das. 2000. Fracture resistance of sunflower seed and kernel to compressive loading. J. Food Engineering 46(1): 1–8.

Kheiralipour, K., A. Tabatabaeefar, H. Mobli, A. Sahrarow, S. Rafiee, A. Rajabipour, and A. Jafari. 2008. Some mechanical and nutritional properties of two varieties of apple (Malus domestica Borkh L.) in Iran. American-Eurasian J. Agric. & Environ. Sci 3(3): 343-346.

Liu, R., Wang. C. H, and Bathgate. R. G. (1999). Fracture analysis of cracked macadamia nut shells under contact load between two rigid plates. J. Agricultural Engineering Research 74(3): 243–250.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Press, New York.

Ozturk, I., S. Ercisli, F. Kalkan, and B. Demir. 2009. Some chemical and physico-mechanical properties of pear cultivars. Afric. J. Bio 8(4): 687-693

Sitkei, G. 1986. Mechanics of agricultural materials. Budapest: Akademiai Kiado.

Sirisomboon, P., P. Kitchaiya, T. Pholpho, and W. Mahuttanyavanitch. 2007. Physical and mechanical properties of Jatropha curcas L. fruits, nuts and kernels. J. Food Eng 97(2): 201-207.

Witz, R. L. 1954. Measuring the resistance of potatoes to bruising. Agricultural Engineering 34(4): 241–244.