Strength Behavior Study of Apples (cv. *Shafi Abadi* & *Golab Kohanz*) under Compression Loading

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Abstract

The mechanical properties data of fruits are important in the design of various handling, packing, storage and transportation systems. In this research some mechanical properties of two Iranian apple varieties (*Golab Kohanz* and *Shafi Abadi*) were analyzed in moisture contents 86% and 84% (W.b) for *Golab Kohanz* and *Shafi Abadi* varieties, respectively. Mechanical properties including rupture force and energy, deformation to rupture point, failure stress and strain, Young's modulus (initial tangent modulus, secant modulus, tangent modulus and chard modulus), toughness and hardness were studied under compression loading using standard methods and so firmness was determined by puncture test. Average values of rupture force and energy, failure stress, failure strain, deformation, toughness and hardness were determined,57.81N, 285.88 mJ, 0.37 MPa, 31.2%, 7.77 mm, 0.06 J/cm^3, 9.14 N/mm for *Shafi Abadi* variety, respectively. The corresponding values for *Golab Kohanz* variety were obtained 51.11 N, 157.51 mJ, 0.32 MPa, 23.36%, 5.6 mm, 0.04 J/cm^3 and 7.79 N/mm, respectively. Initial tangent modulus, secant modulus, tangent modulus and chard modulus were obtained 0.93, 1.76, 2.27 and 2.11 MPa for *Shafi Abadi* variety and 0.81, 1.52, 2.08 and 2.04 MPa for *Golab Kohanz* variety, respectively. The firmness obtained 59.26 N for *Shafi Abadi* variety and corresponding value was 47.69 N for *Golab Kohanz* variety, respectively. According to results *Shafi Abadi* variety had stiffer and resisterer issue to mechanical forces than *Golab Kohanz* variety.

Keywords: Mechanical properties, Elasticity modulus, Firmness, Rupture force, Rupture point

1. 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, 2009). 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 (Garcia *et al.,* 1995). 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 (Vursavuş *et al*., 2003). 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. Aydın, (2002) reported the several physical properties of hazelnut and kernels as a function of moisture content and found 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* & *Santa Maria*). Therefore, in this research mechanical properties of two apple varieties (*Golab Kohanz* & *Shafi Abadi*) investigated for establishing convenient reference tables by using mechanical data for mechanization and processing in agricultural operations.

2. Materials and methods

2.1 Material

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. *Golab Kohanz* and *Shafi Abadi* 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. After removing from the cool store apples were kept during 24 h at 23 ^{o}C before testing. 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).

2.2 Methods

Experiments are divided in two parts: first part was compression test and other part was puncture test. The tests were performed by Universal Testing Machine (Santam, MRT-5). This machine has three main components, which are a stable forced and moving platform, a driving unit (AC electric motor, electronic variable and reduction unit) and a data acquisition (load cell, PC card and software)system.

2.2.1 Compression test

All mechanical properties of apples exception firmness 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 (Fig. 4). 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 Universal Testing 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 present conditions and the curve of force-deformation is simultaneously curved until the curve arrived to rupture point (A point in Fig. 2).

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

$$\sigma_r = \frac{F_r}{A} \tag{1}$$

$$\varepsilon_r = \frac{D_r}{L_i} \times 100 \tag{2}$$

where: σ_r is rupture stress (MPa), ε_r is rupture strain (%), F_r is rupture force (N), A is cross section of sample (mm^2), D_r is deformation of sample to the failure point (mm) and L_i is specimen length of fruits (mm).

Modulus of elasticity is ratio of stress to corresponding strain below the proportional limit. For biological materials where the stress- strain relationship is curvilinear rather than linear,

One of the four following terms may be used (Fig. 3):

1) Initial tangent modulus (I.T.M): the slope of the stress- strain curve at the origin (OA slope).

2) Tangent modulus (T.M): the slope of the stress- strain curve at any specified stress or strain (CD slope)

3) Secant modulus (S.M): the slope of the secant drawn from the origin to any specified point on the stress-strain curve (OB slope).

4) Chord modulus (Ch.M): the slope of the chord drawn between any two specified points on the stress- strain curve (EF slope)

The specified point in calculation of secant modulus was 50% of rupture point and for chord modulus were 25% and 75% of rupture point (Kheiralipour *et al.,* 2008). The rupture energy (mJ) was calculated by the area under the force- deformation curve to the rupture point (A point in Fig. 2). The work required to cause rupture in the material can be approximated by the area under the stress- strain curve up to the point selected as the rupture point (J/mm^3) that was calculated by Eq. (3), (Gupta and Das, 2000):

$$P = \frac{E_r}{V} \qquad (3)$$

Where: P is Toughness (J/mm^3), E_r is rupture energy (mJ) and V is sample volume (mm^3).

Hardness (Q) was calculated by dividing the rupture force (F_r) by the deformation to the rupture point (D_r), (Sirisomboon *et al*., 2007):

$$Q = \frac{F_r}{D_r} \qquad (4)$$

2.2.2 Puncture test

The Magness-Taylor firmness test was used for obtain apple issue firmness and was measured force required for indenter penetration to determined depth (Abbott *et al*., 1976; Bourne, 1974). A cylindrical indenter, 11 mm in diameter, with a hemispherical tip was used in this experiment. Penetration speed was set 25.4 mm/min and test was stopped after penetration to 10 mm depth in equatorial line region of the whole apple. Penetration test on equatorial line of the whole apple was first carried out at two opposite points with skin (a and b in Fig. 4) and two opposite peeled points between two previous points (c and d in Fig. 4). The round tip of the plunger was pressed in to the apple to a marked depth (10 mm), and force- deformation curve was traced in the computer simultaneously. The penetration force was calculated to 10 mm depth by force- deformation curve and penetration energy was obtained by measurement of area under the force- deformation curve to 10 mm depth. 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.

3. Results and discussion

The mass and dimensional attributes of *Golab Kohanz* and *Shafi Abadi* varieties used in compression and puncture tests are shown in table 1. As seen in Table 1, the moisture contents were 86% and 84% (w.b.), for Golab Kohanz and Shafi Abadi varieties, respectively. Based on the results of Duncan's multiple range tests, the dimensions of the two apple varieties were significantly different ($p<0.01$). These significant findings could be the result of the individual properties of apple varieties, and environmental and cultivation conditions. 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 2. According to Table 2, effect of variety on rupture energy (E_r), rupture point (D_r), rupture strain (ε_r), toughness (P) and firmness was significant in 1% statistical level. The effect of variety on these five mechanical properties were shown in Figure 5 (A- E). Effect of sample orientation (with skin and without skin) and interaction effect of variety × orientation sample on none mechanical properties were not significant. The mean and standard deviation values of obtained mechanical properties in compression test were shown in Table 3. As seen in Table 3, the values average of rupture force, rupture energy, deformation, rupture stress and strain obtained, 57.82 N, 285.88 mJ, 7.77 mm, 0.37 MPa and 31.2% for *Shafi Abadi* variety and corresponding values for *Golab Kohanz* variety obtained, 51.11 N, 157.51 mJ, 5.6 mm, 0.32 MPa and 23.36%, respectively. According to these results *Shafi Abadi* variety has stiffer issue than *Golab Kohanz* variety therefore durability of *Shafi Abadi* variety in relative to compression loading 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 *et 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 0.06 Jcm^{-3} and 9.14 N/mm, respectively, and for *Golab Kohanz* obtained 0.04 Jcm^{-3} and 7.79 N/mm, respectively. Apparent elasticity modulus in four technique, initial tangent modulus, secant modulus, tangent modulus and chard modulus obtained, 0.93, 1.76, 2.27 and 2.11 MPa for *Shafi Abadi* variety and 0.81, 1.52, 2.08 and 2.04 for *Golab Kohanz* variety, respectively. In total techniques, elasticity modulus of *Shafi Abadi* variety was obtained bigger than elasticity modulus of *Golab Kohanz* variety. These results too shown that *Shafi Abadi* variety texture is stiffer than *Golab Kohanz* variety texture. According to Table 4, affect of variety on firmness and penetration energy were significant in 1% statistically level ($P<0.01$) and affect of with skin and skinless sample was not significant. The mean and standard deviation values of firmness and penetration energy were shown in Table 4. The average values firmness and penetration energy were obtained 59.26 N and 370.84 mJ for *Shafi abadi* variety and corresponding values for *Golab Kohanz* variety were obtained 47.69 N and 306.33 mJ, respectively. According to results, the firmness of *Golab Kohanz* was lower than *Shafi Abadi* variety therefore *Shafi Abadi* variety has more durability than *Golab Kohanz* variety. In compartion The force- deformation curves in puncture test was shown in Fig. 6. In this figure, A and B curves are related to *Golab kohanz* variety and C an D curves are related to *Shafi Abadi* variety. These results showed force required for penetration in *Golab Kohanz* texture is lower than *Shafi Abadi* variety (Fig 5E). For example in *Golab Kohanz* variety, the output from a whole apple (with skin) at constant strain rate primary presents a linear part with a maximum force (F_t). After this , the load falls to a lower level as the indenter moves through the tissue. The affect of friction on the side of the indenter may have been the primary cause of the slight rise in force for additional displacement. The first and largest peak (F_t) representing skin bursting occurs when the flesh elasticity limit is reached and then the flesh collapses. In skinless state primary the penetration force increased almost linear and reached to F_d, respectively, after that with increase displacement the force increase slowly. This is because the primary penetration force is more than force required for movement continuance. In spite of effect of with skin and skinless apples was not significantly on firmness but in with skin state, firmness was more than skinless state. This is because force addition for skin bursting. This results are not agree with those result that obtained by Shafiee *et al* . (2008) that skin firmness was higher than flesh firmness. It's seem this difference is for difference between condition of growers and storage of apples.

4. Conclusions

This paper concludes with information on mechanical properties of *Golab Kohanz* and *Shafi abadi* varieties which may be useful in design a specific machine for harvesting and post harvesting operation. Therefore, the differences between the mechanical properties of apple varieties should be considered in optimizing apple mechanization and processing. It is recommended that other engineering properties be measured or calculated to prepare comprehensive information fairly in design parameters.

- Failure force and energy, young's modulus, failure stress and strain, toughness, hardness and firmness for *Shafi abadi* variety were bigger than *Golab Kohanz* variety.
- Effect of sample orientations (horizontal and vertical) on discussed mechanical properties was not significant for two varieties.

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Table 1. The mass and dimensional attributes of *Golab Kohanz* and *Shafi Abadi* varieties

Properties	Number of observations	Shafi Abadi			Golab Kohanz			Significant level
		Max	Min	Mean±SD	Max	Min	Mean±SD	
Moisture , %w.b	3	84.7	83.5	83.9±0.7[b]	86	84.94	85.61±0.58[a]	*
Fruit mass, (g)	100	123.13	44.11	75.67±14.42[a]	97.33	46.61	64.22±13.2[b]	*
Fruit length, (mm)	100	62.77	43.05	53.09±3.86[a]	60.32	44.41	51.56±3.82[b]	*
Fruit width, (mm)	100	71.6	51.8	59.37±3.83[a]	64.28	48.85	54.86±3.83[b]	*
Fruit thickness, (mm)	100	67.6	46.36	57.02±3.97[a]	63.76	40.41	53.03±3.98[b]	*

*Corresponding to 1% significance level.

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

Table 2. Analysis of the variance of mechanical properties considered for *Golab Kohanz* and *Shafi Abadi* varieties

Mean Squares													
Variation source	DF	F_r	E_r	D_r	σ_r	ε_r	I.T.M	S.M	T.M	Ch.M	P	Q	Firmness
Treatment	3	75.07^{ns}	29702.79^{**}	8.92^{**}	0.002^{ns}	109.12^{**}	0.1^{ns}	0.13^{ns}	0.1^{ns}	0.04^{ns}	0.0015^{ns}	5.28^{ns}	211.36^{*}
A	1	224.91^{ns}	82387.22^{*}	23.5^{*}	0.008^{ns}	311.41^{*}	0.06^{ns}	0.3^{ns}	0.18^{ns}	0.02^{ns}	0.0042^{*}	9.11^{ns}	633.03^{*}
B	1	0.15^{ns}	4520.87^{ns}	1.69^{ns}	0.000045^{ns}	8.24^{ns}	0.07^{ns}	0.008^{ns}	0.02^{ns}	0.02^{ns}	0.00024^{ns}	3.05^{ns}	0.57^{ns}
A×B	1	0.15^{ns}	2200.27^{ns}	1.59^{ns}	0.000005^{ns}	7.71^{ns}	0.16^{ns}	0.09^{ns}	0.1^{ns}	0.08^{ns}	0.00012^{ns}	3.68^{ns}	0.49^{ns}
Error	16	202.91	6827.1	2.3	0.008	39.66	0.08	0.11	0.19	0.22	0.0005	5.65	10.8

A: apple variety (Shafi Abadi and Golab Kohanz), B: sample orientation (horizontal and vertical orientation for compression test and with skin and skinless for puncture test)

ns: Corresponding to no significant difference

** Corresponding to confidence of interval, 95%

* Corresponding to confidence of interval, 99%

Table 3. The mean and standard deviation values of obtained mechanical properties in compression test.

	Variety				
	Shafi Abadi		Golab Kohanz		
Sample orientation	Vertical	Horizontal	Vertical	Horizontal	
Mechanical properties	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Significant level
Rupture force (N)	58^{a}±9.52	57.64^{a}±14.36	51.11^{a}±15.65	51.11^{a}±16.42	ns
Rupture energy (mJ)	260.35^{a}±95.41	311.4^{a}±99.75	152.97^{b}±57.47	162.06^{b}±70.34	*
Deformation (mm)	7.19^{a}±2.09	8.34^{a}±1.39	5.59^{b}±1.02	5.61^{b}±1.34	*
Rupture stress (MPa)	0.37^{a}±0.06	0.36^{a}±0.09	0.33^{a}±0.1	0.32^{a}±0.1	ns
Rupture strain (%)	30^{a}±8.74	32.52^{a}±5.7	23.34^{b}±4.25	23.39^{b}±5.61	*
I.T.M	1.08^{a}±0.2	0.84^{a}±0.21	0.78^{a}±0.42	0.77^{a}±0.28	ns
S.M	1.85^{a}±0.15	1.68^{a}±0.34	1.47^{a}±0.36	1.57^{a}±0.4	ns
T.M	2.38^{a}±0.31	2.16^{a}±0.47	2.05^{a}±0.46	2.11^{a}±0.54	ns
Ch.M	2.2^{a}±0.4	2.07^{a}±0.47	2.01^{a}±0.46	2.01^{a}±0.55	ns
Toughness (J/mm^3)	0.064^{a}±0.02	0.07^{a}±0.02	0.04^{b}±0.01	0.042^{b}±0.01	*
Hardness (N/mm)	9.1^{a}±2.58	9.18^{a}±1.7	8.61^{a}±2.41	6.97^{a}±2.67	ns

*Corresponding to 1% significance level.

ns: Corresponding to no significant difference.

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

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Table 4. The mean and standard deviation values of firmness in puncture test.

variety				
	Shafi Abadi		Golab Kohanz	
	skin	skinless	skin	skinless
Mechanical properties	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Firmness	59.28^{a}± 5.8	59.26^{a}± 2.1	48.34^{b}±1.37	47.69^{b}± 1.77
Penetration Energy	382.13^{a}± 43.36	359.56^{a}± 34.45	316.84^{b}± 11.75	295.82^{b}± 13.62

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

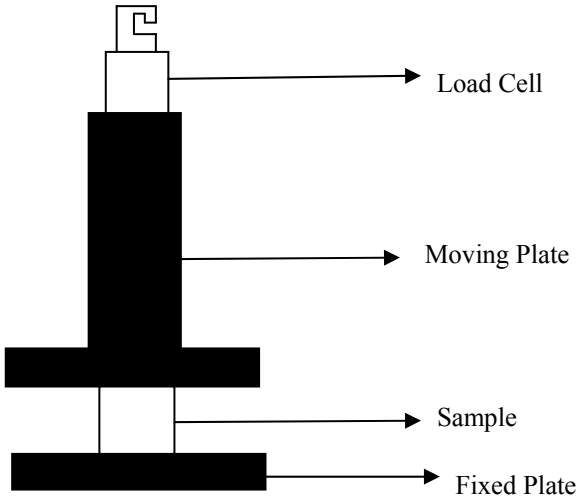


Figure 1. Universal Testing Machine.

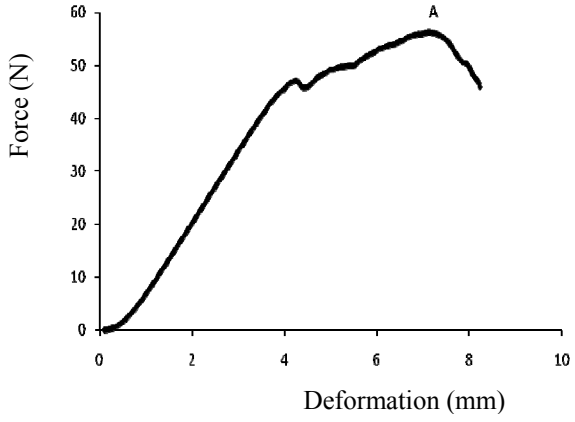


Figure 2. The curve of Force-Deformation in compression test (A is rupture point).

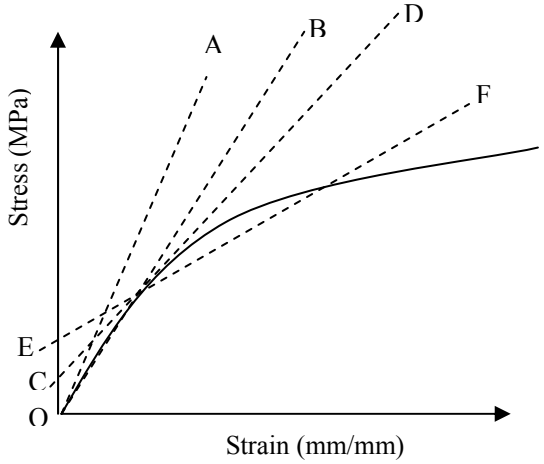


Figure 3. Methods for defining the modulus in non- linear stress- strain diagrams.

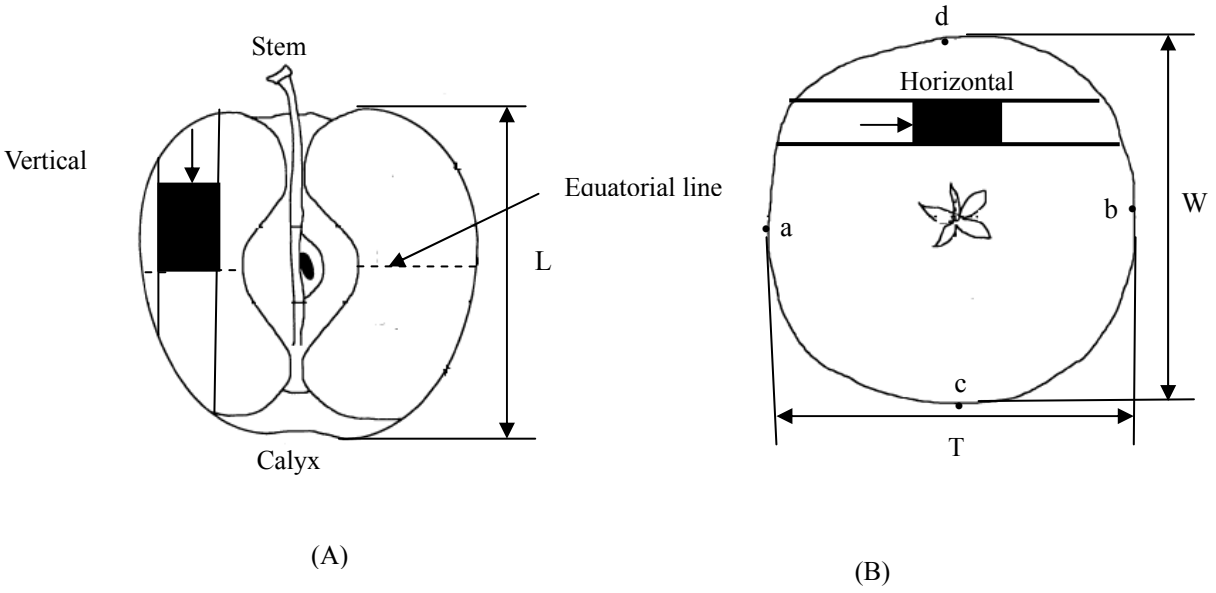
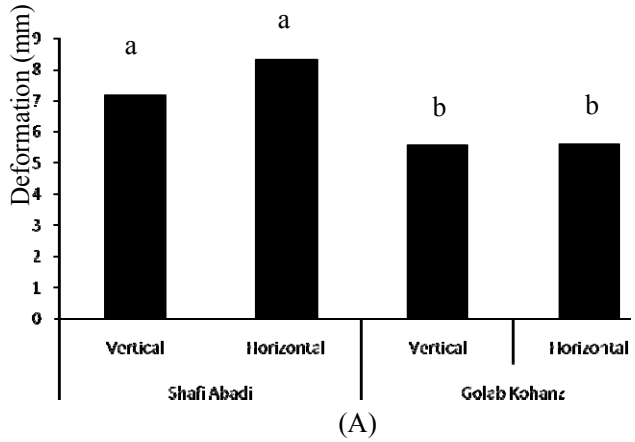
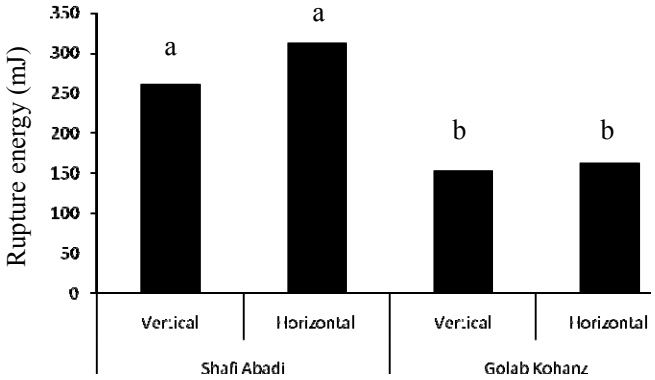


Figure 4. Sample orientations in two directions of vertical (A) and horizontal (B) vertical for compression test and the indenter penetration location on equatorial line of apple, a and b with skin, c and d skinless.



(A)



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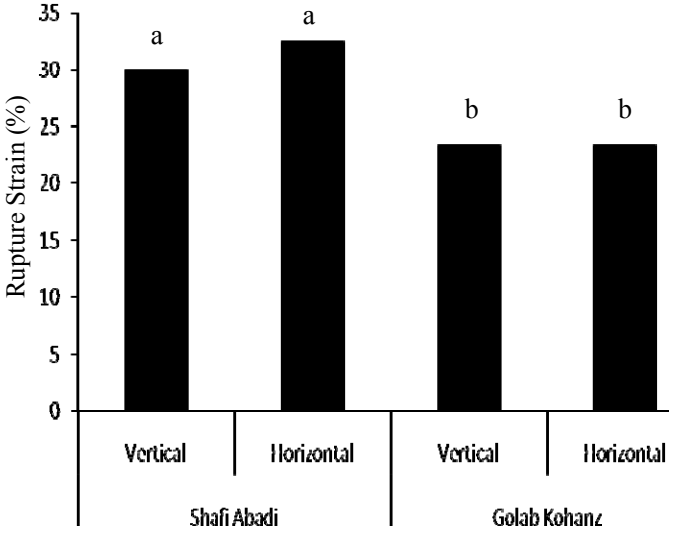
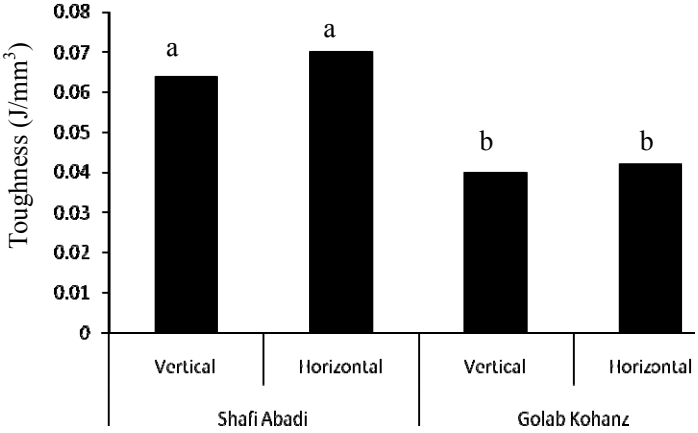
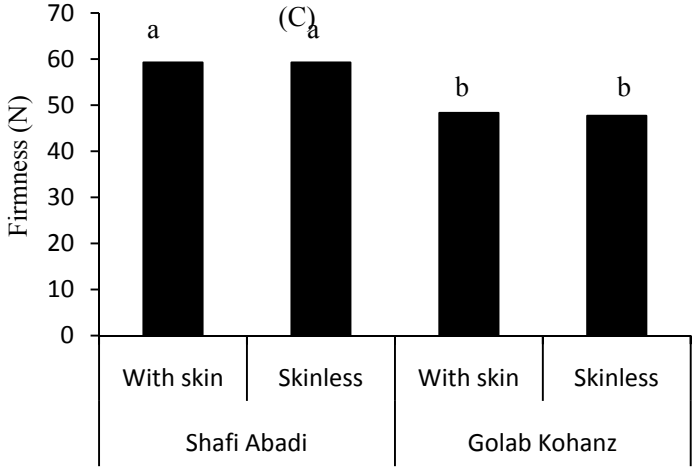


(C)



(D)



(E)

Figure 5. Effect of variety (*Shafi Abadi* & *Golab Kohanz*) on the deformation (A), Rupture energy (B), Rupture strain (C), Toughness (D) and Firmness (E), (bars with different letters are significantly different at $P<0.01$).

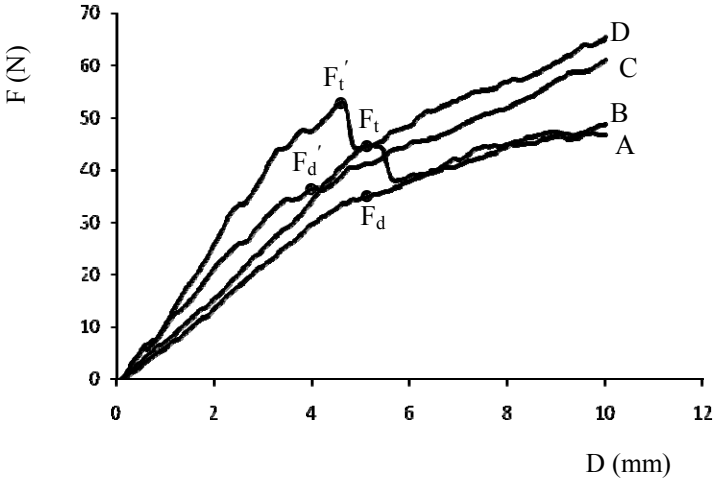


Figure 6. Force- deformation curve related to puncture test, (A) related to without skin and (B) related to with skin for Golab Kohanz variety and (C) related to without skin and (D) related to with skin for Shafi Abadi variety, F_t and F_t' are bursting skin forces, F_d and F'_d are Forces corresponding to the elasticity limit of the flesh.

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