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Full Length Article

Investigation on Mechanical Properties of Apples During Storage using Penetration Test

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ABSTRACT

In this study, three different cultivars of Iranian export apples ('Golden Delicious', 'Red Delicious' & 'Granny Smith') were stored at low temperature (4 - 5^{o}C) for six months (November to April). In each month penetration tests were conducted to determine the mechanical properties of apples included apparent modulus of elasticity, penetration force and penetration energy. Mean values of the apparent modulus of elasticity of 'Golden Delicious' ranged from 0.48 to 0.90 MPa, for 'Red Delicious' from 0.64 to 0.90 MPa and for 'Granny Smith' 0.94 to 1.43 MPa. Penetration force of 'Golden Delicious' from 12.74 to 23.91 N, for 'Red Delicious' 17.00 to 24.06 N and 'Granny smith' from 24.93 to 38.09 N. while penetration energy was from 24.86 to 51.62 N.mm for 'Golden Delicious', from 39.87 to 56.32 N.mm for 'Red Delicious' and from 54.14 to 81.53 N.mm for 'Granny Smith' during various months over study period. The results showed that effects of cultivar, time and interaction of cultivar and time were significant (at 1% probability) for all properties. Mean values for all properties had significant difference (at 5% probability) among different cultivars. Time had significant effect (at 5% probability) at first and last month for each cultivar than other months. We can conclude that the first and last time of test series were significantly different than other months for all the mechanical parameters. First series was higher and the last series was lower value.

Key Words: Apple; Storage; Mechanical properties; Penetration test

INTRODUCTION

Un-fortunately the crop waste from production to consumption in Iran is high. First step to reduce the waste is improving the production-consumption cycle, which is possible by knowing detailed characteristics of system and crop. Mechanical properties are critical aspects of apple quality and knowledge of these properties of apple flesh and intact apples is needed to develop a method to sort intact apples according to firmness. Apple price at the time of harvest is low, which lead farmers to store the apples for a long time. Hence, the apple biological and mechanical properties will differs period of time.

Many researchers have worked on different aspect of the variations but little information is available on the non-homogeneous and anisotropic mechanical properties of apples. Fletcher *et al.* (1965) showed the effect of different speed of loading rate on the yielding point at the force-deformation curve with low and high-speed penetration tests. The resistance of the specimen to skin-rupture forces was found to increase with increasing rate of loading up to a critical rate, after which it decreased with increased rate of loading. The location of the critical rate was found to vary with cultivar and stage of maturity. The mechanical properties of the selected fruits and vegetables differed with respect to the kind of product, cultivar, individual specimen, location on the specimen, stage of development, etc. However, the characteristics of a specific cultivar were found to fall within a general range (Fletcher *et al.*, 1965).

Fridley and Adrian (1966) determined the mechanical properties of peaches, pears, apricot and apples with compression and impact tests, which involved the effect of impact velocity, multiple impacts, fruit maturity and fruit specimen thickness. Apples were much more likely to be bruised than pears. Apricots and peaches have a much lower stiffness than either apples or pears (Fridley & Adrian, 1966). Pears and apples were less likely than either peaches or apricots to present problems of injury to the top fruit in containers. Apples were subject to impact bruises at all maturities. Maturity had an important effect on the mechanical properties of fruit, but the results were affected by the thickness of the fruit specimen (Fridley & Adrian, 1966). Abbot *et al.* (1984) examined the relationships among selected sensory textural attributes and data from modified Instron texture analysis (force-deformation curves obtained in compression of tissue cylinders) for apples (Malus domestica Borkh). Magness-Taylor and modified texture profile tests from an Instron showed that regression of sensory scores on instrument variables could be used to develop prediction equations to estimate sensory textural attributes in those cultivars, where the ranges of sensory scores and instrument values were broad (Abbot *et al.*, 1984).

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When prediction of the sensory textural characteristics of apples is important in evaluating the effects of pre- or post-harvest treatments on quality, it is recommended that a combination of several variables from a multivariable mechanical measurement such as Instron texture profile be used instead of a single variable test such as the Magness-Taylor firmness test. Mohsenin (1986) reported the calculation of modulus of deformability for apple with penetration and parallel plate loading tests. The mean values of modulus of deformability found by the use of Hertz theory in elasticity was 1.85 MPa and by the conventional method of compressing a cylindrical specimen of the flesh between two parallel plates was 1.70 MPa (Mohsenin, 1986). In recent years too many researcher have determined apples mechanical properties (Abbot, 1994; Garcia *et al.*, 1995; Konopacka *et al.*, 2002).

The objective of this study was to determine the effects of storage on mechanical properties of apples. Penetration tests were performed on 'Golden Delicious', 'Red Delicious' and 'Granny Smith' apples using a universal testing machine.

MATERIALS AND METHODS

Three cultivars of 'Golden Delicious', 'Red Delicious' and 'Granny Smith' apples were selected for good storage lifetime and export quality. All the sample of apple was randomly selected from Sorkdashat Damavand storage in first of October 2003. These samples were placed in a wooden box placed next to each other and stored in a cold storage at 4 to 5°C temperature with 65 to 70% relative humidity (RH). The apple sample boxes were transferred to a cold storage in the College of Agriculture. Six different series of tests were done to sample of apples after first two month of cold storage. Before each test the apple was transferred to the laboratory at 20 - 22°C temperature for 24 h.

For all experiments dry bulb temperature and RH of the laboratory were recoded by a digital psychrometer (Jenway Model 5100) as shown in Table I. These parameters were measured at three different times: 9 a.m., 12 noon and 3 p.m. and then averaged. Relative humidity over the six series started low at first two series and then was very high in next two series and became low again in last two series, but not as low as first two series. Even though, the temperature variation over the six series was around 5°C. The moisture content of apple was measured by cutting nine random apples selected from the box of each test series. The samples of apples were weighed and placed in an aluminum box and positioned inside oven for 10 days at 77°C. The moisture content of the samples was determined for each test series (Table II). The moisture content for all three cultivars was almost similar in the six test series. But 'Golden Delicious' apple had shown 1 to 2% gain of moisture over several months, which was negligible.

The mechanical properties of apples were determined in different test series from December, January, February, March, April and May. The tests were conducted with universal testing machine (Hones field HTI model, England) in the laboratory. Penetration tests were took place at four different locations on apple sample equator. At first, with a sharp knife the skin of those four points were cut off on whole apple samples. Then apples were placed on a flat plate and were punched by a spherical indenter with 11 mm diameter at each four locations. The force and deformation data were instantly recorded four times electronically from same apple. Loading rate was 25.4 mm min^{-1} and penetration was done only 15 mm. The apparent modulus of elasticity, penetration force and penetration energy was determined from the force–deformation curve for only 4 mm of penetration.

Penetration energy was measured from the area under the force–deformation curve only to 4 mm penetration (point A) as shown in Fig. 1. 'Photoshop Software' selected this area and then the area was determined by a surface meter program. The apparent modulus of elasticity was calculated from the Hertz theory by applying Eq. (1) ASAE standard No. S368.3, MAR95 (ASAE, 1998).

$$E = \frac{0.531F}{D^{3/2}}\left(\frac{2}{r}\right)^{1/2}(1-\mu^2) \qquad (1)$$

Where E, Apparent modulus of elasticity (Mpa); F, Penetration force at 4 mm penetration in apple flesh (point A on Fig. 1) (N); D, Penetration length (4 mm); r, Radius of indenter curvature (5.5mm); μ, Poisson ratio for apple cultivars that was reported from 0.21 to 0.34, it was assumed 0.25 in this study.

A split plot in time with a randomized design using nine replicates and four samplings was conducted. The treatments were the six time series with the three cultivars of apple as independent variables. Aapparent modulus of elasticity, penetration force and penetration energy for Golden Delicious, Red Delicious, and Granny Smith in different test series from December, January, February, March, April and May were determined and analyzed using the ANOVA (SAS V.8) program. The number of replicates per treatment was nine.

RESULTS AND DISCUSSION

Apparent modulus of elasticity. The trend of variation of the apparent modulus of elasticity over six test series showed that apparent modulus of elasticity for all the three cultivars showed a decreasing trend (Fig. 2). The 'Granny Smith' had higher value of apparent modulus of elasticity than the other two cultivars, which was 1.43 and 0.94 MPa for the first and last test series. Six months of storage had 34% effect on apparent modulus of elasticity of this cultivar. The strength variation of the 'Granny Smith' was higher with little flexibility. For 'Golden Delicious' the apparent modulus of elasticity in first test series was 0.90 MPa and

Table I. Laboratory atmospheric characteristics

Test series	Daily dry temperature (°C)	Relative Humidity (%)
1	23.89 – 25.56	29 - 30
2	19.39 – 23.56	24.5 – 34.3
3	21.89 – 23.11	88 – 94.5
4	21.56 – 22.44	84 – 85.10
5	19.94 – 20.11	57 - 59
6	25.17 – 26.23	48 - 62

Table II. Apple moisture content (WB) for each test series (%)

Test series	Golden Delicious	Red Delicious	Granny Smith
1	82.12	83.2	83.34
2	83.94	84.21	84.14
3	82.92	83.82	84.37
4	84.49	83.75	84.20
5	84.69	84.38	83.10
6	84.54	83.80	82.87

Table III. Analysis of variance for all properties

Source	DF	Mean Square		
		Aapparent modulus of elasticity	Penetration force	Penetration energy
Cultivar	2	11.275**	8020.572**	42684.492**
Error	24	0.063	45.463	206.236
Time of Test Series	5	2.051**	1440.473**	6900.252**
Cultivar time	10	0.171**	116.737**	598.141**
Experimental Error	119	0.048	33.849	152.329
Sampling Error	483	0.013	9.475	51.191
Total	643			
CV (%)		13.841	14.075	15.030

** Significant at 1% probability level

NOTE: The number of missing values was 4, and variables are consistent with respect to the presence or absence of missing values

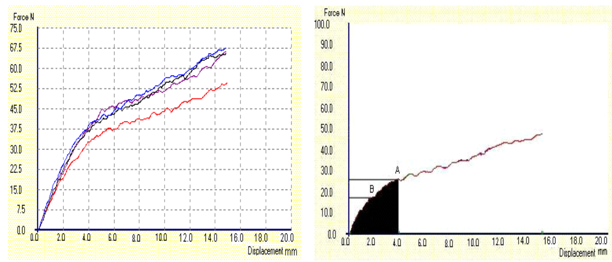
Table IV. Parameter means comparison applying Duncan test

Parameters		Modulus of elasticity (MPa)	Penetration force (N)	Penetration energy (N.mm)
Cultivar	Granny Smith	1.1a*	28.8a	62.9a
	Red Delicious	0.73b	19.4b	44.6b
	Golden Delicious	0.65c	17.3c	35.2c
Time	1	1.1a	28.9a	63.4a
	2	0.84b	22.3b	48.4b
	3	0.84b	22.3b	46.5bc
	4	0.74c	19.8c	43.6cd
	5	0.72c	19.1c	42.5d
	6	0.72c	19.2c	41.7d

* All the column with the same letter is not significant at 5% probability level

then decreased to 0.51 MPa in the last series. This cultivar showed better uniformity on apparent modulus of elasticity over several months of storage. For 'Red Delicious' apple, six months of storage had an effect of 43% on apparent modulus of elasticity. This variation was also noticed on liner curve for 'Red Delicious' with coefficient of determination R^2 of 0.568. For 'Red Delicious' the apparent modulus of elasticity ranged from 0.90 MPa to 0.71 MPa and six months of storage had an effect off 21% on modulus of elasticity with much higher variation in each series. Apparent modulus of elasticity had liner curve decrease

Fig. 1. Force-deformation curve for four locations on one apple (A) and the properties calculation procedure (B)



(A) (B)

Fig. 2. Apparent modulus of elasticity of apple cultivars trend over six test series

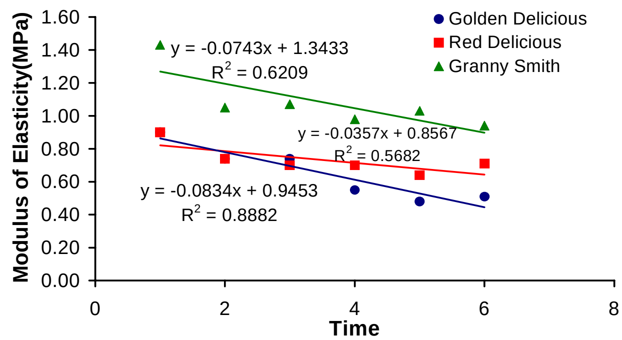
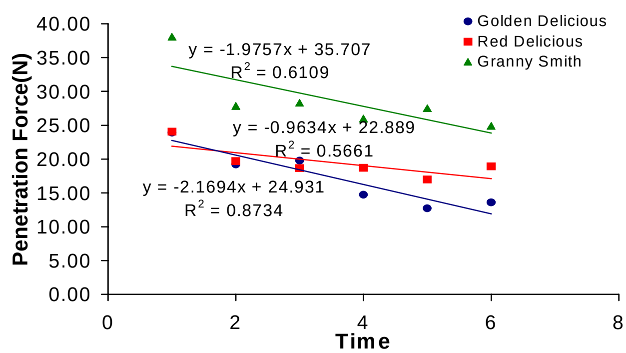


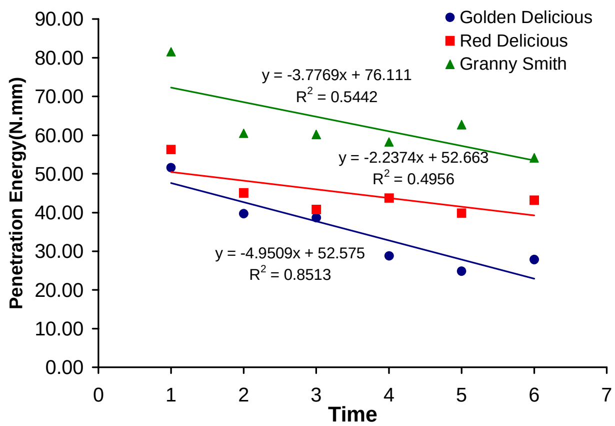
Fig. 3. Penetration force of apple cultivars trend over six test series



with higher coefficient of determination. Such a range of values was also reported by Mohsenin (1986). The cultivar, time of test series and the interaction between cultivar and time of test series had significant (at 1% probability) effect on the apparent modulus of elasticity (Table III). Abbott and Lu (1996) reported that location of radial sample had no significant effect on the strength of material.

Penetration force. Penetration force over six series followed the trend similar to modulus of elasticity. Penetration force of 'Golden Delicious' was 23.9 N in first test series and 13.6 N in sixth test series. 'Golden Delicious' apple penetration force sharply decreased sharper in first and second test series and then at fifth and sixth test series (Fig. 3). This attribute for 'Red Delicious' was 24 N in first test series and 19 N in sixth test series. 'Granny Smith' apple

Fig. 4. Penetration energy of apple cultivars trend over six test series



had highest values of penetration force than other cultivars; in first test series was 38.1 N to 24.9 N in last test series. 'Granny Smith' apple penetration force at the first test series had 36% greater over the 'Golden Delicious' and 37% over the 'Red Delicious', respectively. Over period of time, the penetration force will decrease as reported by Mohsenin *et al.* (1962). Penetration force for all the cultivar at first test series was significantly different from others. Analyses of variance were applied to penetration force on all the cultivar, time of test series and interactions between all of them (Table III). The time of test series, cultivar and the interaction between time of test series and cultivar had significant effect on the penetration force at 1% probability level.

Penetration energy. This attribute of 'Golden Delicious' was 51.6 N.mm in first test series and 27.8 N.mm in sixth test series (Fig. 4). Penetration energy of 'Red Delicious' was 56.3 N.mm in first test series and 43.2 N.mm in sixth test series. 'Granny Smith' apple had highest values of penetration energy than other cultivars; in first test series was 81.5 N.mm to 54.1 N.mm in last test series. 'Granny Smith' apple penetration energy at the first test series had 37% increase over the 'Golden Delicious' and 30% over the 'Red Delicious', respectively. Penetration energy for all the cultivar at first test series was significantly different than other test series. Analyses of variance were applied to penetration energy on all the cultivar, time of test series and interactions between all three of them (Table III). The time of test series, cultivar and the interaction between time of test series and cultivar had significant effect on the penetration energy at 1% probability level but other parameters did not have any significant effect. Mean comparison of all the mechanical parameters was significantly (at 5% probability) different for all three cultivars. Mean value of all parameters for 'Granny Smith' was higher than other parameters. Therefore, this cultivar had higher strength against mechanical harvest, impact and transportation vibration. 'Golden Delicious' had lowest value for all the mechanical parameters include of apparent modulus of elasticity, penetration force and penetration energy. The first and last time of test series were significantly different than other months for all the mechanical parameters (Table IV). First series had higher and the last series lower value. Last two series of test had shown similar value for all mechanical parameters. All the parameters were significantly different between the first and second test series. Variation on modulus of elasticity and penetration energy was in decreasing trend, but their value was different.

CONCLUSION

Results showed that all the mechanical properties had decreased from first test series to next one. 'Granny Smith' had higher strength than other cultivars. Therefore, this cultivar will show more strength against mechanical harvest, impact and transportation vibration. All the mechanical parameters for 'Red Delicious' were low, which shows less strength against outside forces and stresses. Values of mechanical properties had shown to decrease over time of storage. The parameters had significant difference between first test series and last one; therefore, it is recommended not to store the apples for more than six months.

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