Turk J Agric For
29 (2005) 469-482
© TÜBİTAK

Effect of Storage Time on Some Mechanical Properties and Bruise Susceptibility of Pears and Apples

Yeşim Benal YURTLU*
Agricultural Equipment and Machinery Test Center, Ministry of Agriculture and Rural Affairs, Ankara - TURKEY
Doğan ERDOĞAN
Department of Agricultural Machinery, Agricultural Faculty, Ankara University, Ankara - TURKEY

Received: 24.11.2004

Abstract: This research was conducted to evaluate the effect of storage time on some mechanical properties and bruise susceptibility of Williams and Ankara varieties of pear and Starkspur Golden Delicious and Starking varieties of apple. The research was performed in 2 stages. Firstly, compression tests were conducted to determine the mechanical properties of fruits. Secondly, an impact test was used to determine the bruise susceptibility of test materials. Impact tests were performed using a pendulum with 50 cm arm length. The tests were carried out at 5 storage times (harvest day, 1st, 2nd, 3rd and 4th month) and 3 drop heights for the impact tests (10, 15 and 20 cm). During the compression tests, a curve-ended cylindrical probe with 8 mm diameter was used to compress the fruit at 7 mm min^{-1} load velocity. Results of the compression tests indicate that the bioyield point force, modulus of elasticity and deformation energy of the pear and apple varieties decreased with increasing storage time. Modulus of elasticity decreased from 1.68 to 0.51 MPa for Williams, from 1.34 to 0.8 MPa for Ankara, from 1.45 to 0.88 MPa for Starkspur Golden Delicious and from 1.51 to 1.1 MPa for Starking with increasing storage time. The impact test results show that the bruise susceptibility values of Ankara and Starking are higher than those of the other varieties when a comparison is made between 2 varieties. The bruise susceptibilities of Williams and both apple varieties tended to decrease with increasing storage time, whereas that of Ankara increased. According to the analyses of variance results, variety and storage time are significant for the bioyield point force, modulus of elasticity, bruising volume, absorbed energy and bruise susceptibility. Furthermore, drop height significantly affected the bruise susceptibility of Ankara, while there was no significant effect on bruise susceptibility for Williams or the 2 apple varieties.

Key Words: Mechanical Properties, Modulus of Elasticity, Bruise, Bruise Susceptibility, Pear, Apple

Armut ve Elma Çeşitlerinde Depolama Süresinin Bazı Mekanik Özelliklere ve Zedelenme Duyarlılığına Etkisinin Belirlenmesi

Özet: Bu çalışma, depolama süresinin, Williams ve Ankara armut çeşitleri ile Starkspur Golden Delicious ve Starking elma çeşitlerinin bazı mekanik özellikleri ile zedeleneme duyarlılıkları üzerindeki etkisini araştırmak amacıyla yapılmıştır. Araştırma iki aşamada gerçekleştirilmiştir. İlk aşamada mekanik özelliklerin belirlenmesi amacıyla sıkıştırma testleri, ikinci aşamada ise zedelenme duyarlılığının belirlenmesi için kol boyu 50 cm olan bir sarkacın kullanıldığı çarpma testleri yapılmıştır. Testler beş farklı depolama süresi (0, 1, 2, 3, 4 ve 5. ay) ve çarpma testleri için üç farklı düşme yüksekliğinde (10, 15 ve 20 cm) gerçekleştirilmiştir. Sıkıştırma testlerinde 8 mm çaplı küresel sonlu silindirik uç kullanılmıştır. Tüm testlerde yükleme hızı 7 mm dak^{-1} olarak seçilmiştir. Sıkıştırma testleri sonuçlarına göre armut ve elma çeşitlerinin biyolojik akma noktasındaki kuvvet, elastiklik modülü ve deformasyon enerjisi değerleri depolama süresinin artmasıyla azalmaktadır. Elastiklik modülü değerleri depolama süresinin artmasıyla Williams için 1.68'den 0.51 MPa'a, Ankara için 1.34'den 0.8 MPa'a, Starkspur Golden Delicious için 1.45'den 0.88 MPa'a ve Starking için 1.51'den 1.1 MPa'a düşüş göstermektedir. Çarpma testi sonuçlarına göre, denemeye alınan armut ve elma çeşitleri içinde karşılaştırma yapıldığında Ankara armudu ve Starking elma çeşidinin zedelenmeye karşı daha duyarlı oldukları belirlenmiştir. Her iki elma çeşidinin ve Williams armut çeşidinin zedelenme duyarlılıkları artan depolama süresi ile azalma eğilimi gösterirken, Ankara armut çeşidi aynı koşullarda tersi bir eğilim göstermektedir. Varyans analizi sonuçlarına göre, çeşit ve depolama süresi biyolojik akma noktasındaki kuvvet, elastiklik modülü, zedelenme hacmi, absorbe edilen enerji ve zedelenme duyarlılığı değerlerini belirgin olarak etkilemektedir. Ayrıca, düşme yüksekliğinin, Ankara armut çeşidi için zedelenme duyarlılığı üzerinde belirgin olarak etkisi varken, Williams armut çeşidi ve elma çeşitleri üzerinde istatistiksel olarak bir etkisi bulunmamıştır.

Anahtar Sözcükler: Mekanik Özellikler, Elastiklik Modülü, Zedelenme, Zedelenme Duyarlılığı, Armut, Elma

*Correspondence to: yurtlu@tamtest.gov.tr

Introduction

The main reason for the decreasing market values and quality of agricultural products is damage occurring between the point of harvesting and consumption. Fruits are susceptible to bruising when they impact each other or a hard surface during picking, packing, transportation, and retailing at stores and during other handling steps. Although it is well known that bruising results from excessive force on the fruit surface, it is still not clear which factors determine the differences in susceptibility of fruit to a given force (Topping and Luton, 1986). Most research on the mechanical properties and bruising of fruit has focused on apples (Schoorl and Holt, 1978, 1980; Klein, 1987; Abbott and Lu, 1996; Aydın and Çarman, 1998; Vursavuş and Özgüven, 1999, 2000). There is also some information on pears (Chen et al., 1987; Garcia et al., 1995). Several factors have been found to influence bruise susceptibility, but frequently researchers have obtained conflicting results. Diener et al. (1979) reported that, at harvest, more mature apples were less easily bruised, whereas Klein (1987) claimed the opposite. He also noted a decrease in damage after longer storage periods following harvest. However, Schoorl and Holt (1978) found increased bruise susceptibility with increasing storage time.

Pears and apples are important fruits in Turkey. According to statistical data, 380,000 t of pears and 2,400,000 t of apples are produced in Turkey (Tarımsal Yapı, 2000). The origin of the Ankara pear is Anatolia and it takes its name from the capital city of Turkey. Information on origin, descriptions of horticultural requirements and photographs of these varieties can be found in catalogues (TC Tarım ve Köyişleri Bakanlığı Elma ve Armut Katalogları, 1991, 1993) and Özbek (1978).

The objectives of this study were to (1) determine some mechanical properties such as deformation energy, deformation volume and modulus of elasticity of Williams and Ankara varieties of pear and Starkspur Golden Delicious and Starking varieties of apple; (2) determine bruise susceptibility of these materials; and (3) evaluate the effects of varieties, storage time and drop heights on selected mechanical properties and bruise susceptibility. The results provide useful data to be used by engineers in the design of suitable harvest and post-harvest equipment and machines.

Materials and Methods

Pear varieties, namely Williams and Ankara, and apple varieties, namely Starkspur Golden Delicious and Starking, were used for all the experiments in this study. Williams pears and Starkspur Golden Delicious and Starking apples were harvested from Ankara University Agricultural Experiment Station orchard in Ankara on 21 August, 25 September and 28 September 2001, respectively. Ankara pears were harvested in commercial orchards in Ankara on 8 October 2001.

On the harvest date, 31 fruits of each variety were placed in a 20 °C room and the remaining 124 fruits of each variety (93 fruits for Williams) were stored in a 0 °C room (85-90% relative humidity) for future testing. In the 20 °C room 10 fruits were used for determining flesh firmness, soluble solids and Poisson's ratio. The others were tested on the day of storage at 20 °C (day 0). Twenty-one replications were conducted for each storage time in compression and impact tests. At the end of each month following the harvest date, 31 fruits of each variety were taken from the 0 °C room and placed in the 20 °C room and tested in the same manner as the first 31 fruits. After the fruits were taken from the storage room, they were kept in the 20 °C room for 5-6 h to reach normal room temperature. The same procedure was repeated at the end of each month for 5 months (for Williams 4 months). The last test was conducted for Williams at the end of the 4th month and for the others at the end of the 5th month after harvest.

Compression tests were performed with a biological material testing device. The device, developed in Ankara University, Agricultural Faculty, Department of Agricultural Machinery Lab., has a driving unit, a horizontally moving platform, a holder for fruits and a data acquisition system (Figure 1).

A curve-ended cylindrical probe 8 mm in diameter was used to compress the fruit at 7 mm min^{-1} loading velocity during all the tests (Agricultural Engineers Yearbook, 1994). The test fruit was placed on the holder vertically and positioned against the cylindrical probe. Thus, compression force was applied to the middle of the flower-stalk axis. The holder was moved towards the cylindrical probe during the test. From the compression speed and time, the fruit deformation was computed and a force-deformation curve for each fruit was plotted. Bioyield point is in the force-deformation curve where

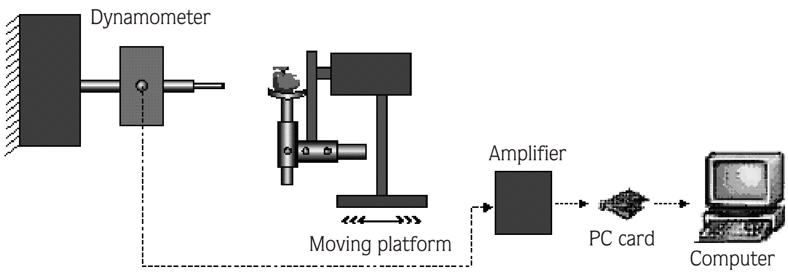

Figure 1. Biological material compression test device.

there occurs an increase in deformation with a decrease or no change in force (Mohsenin, 1980). In some agricultural products, the presence of this bioyield point is an indication of initial cell rupture in the cellular structure of the material. Mechanical properties at the bioyield point were measured using these curves. The modulus of elasticity E in MPa of the test fruits was calculated using Boussinesq techniques as follows (Mohsenin, 1980):

$$E = \frac{F(1 - \mu^2)}{d_p \Delta D} \quad (1)$$

where F is the force applied to the material in N, μ is Poisson's ratio, d_p is the diameter of the cylindrical probe in mm, and ΔD is deformation in mm.

Deformation energy was determined directly from the chart by measuring the area under the force-deformation curves. Deformation energy and deformation volume at the bioyield point were calculated using the following equations (Vursavuş and Özgüven, 1999):

$$E_A = \frac{\Delta D_A F_A}{2} \quad (2)$$

$$V_A = \left(\frac{\pi d_p^2}{4}\right) \Delta D_A \quad (3)$$

where E_A is deformation energy in Nmm, ΔD_A is deformation at the bioyield point in mm, F_A is deformation force at the bioyield point in N and V_A is deformation volume in mm^3.

A pendulum apparatus with 50 cm arm length was used for impact tests (Figure 2). These tests were conducted by dropping each fruit from 10, 15 and 20 cm drop heights onto an ink-smeared metal surface on their cheek. Each impact was separated by a 90° rotation of the fruit. In the pendulum apparatus, these drop points are equal to 53.13°, 44.43° and 36.87° angles to the horizontal, respectively. The fruit was caught to prevent it from impacting again. After each impact, rebound height was read from the pendulum scale and recorded (Parke, 1963).

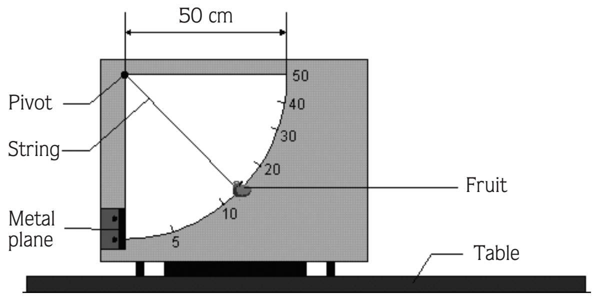

Figure 2. Pendulum apparatus for impact testing.

The amount of energy absorbed by the fruit during impact was calculated from the difference between energy at impact and rebound:

$$E_a = m\,g(h_1 - h_2) \quad (4)$$

where E_a is energy absorbed in Nmm, m is mass of the fruit in kg, g is a gravitational constant in m s^{-2}, h_1 is drop height in mm, h_2 is rebound height in mm.

When the fruit comes into contact with the metal surface, it leaves an ink mark on the area of contact. Each contact point was labeled, and the bruises on the fruit were allowed to develop for 24 h. Bruise diameter and depth were measured with dial calipers with accuracy of 0.05 mm. Bruise volumes were calculated from measured bruise diameter and depths (Schoorl and Holt, 1980):

$$V_z = V_1 + V_2 \quad (5)$$

where V_z is total bruise volume in mm^3, V_1 is bruise volume below the contact plane in mm^3, and V_2 is bruise volume above the contact plane in mm^3 (Figure 3).

The volumes were calculated from bruise dimensions (Schoorl and Holt, 1980):

$$V_Z = \frac{\pi h}{24}(3d^2 + 4h^2) + \frac{\pi x}{24}(3d^2 + 4x^2) \quad (6)$$

$$x = R - \sqrt{R^2 - \frac{d^2}{4}} \quad (7)$$

where R is the radius of the fruit in mm, d is bruise diameter in mm, and h is bruise depth below the contact plane in mm.

Bruise susceptibility was calculated using the following equation (Schoorl and Holt, 1980):

$$C = \frac{V_Z}{E_a} \quad (8)$$

where C is bruise susceptibility in ml J^{-1}.

Other measurements covered flesh-firming reading, the percentage of soluble solids of the fruit juice, Poisson's ratio and the mass of the fruit. On each test day, 10 fruits were used for these measurements. Flesh-firmness was measured with an Ft 327 fruit firmness tester on the peeled surface of the fruit, with a 7.8 mm diameter cylindrical plunger for pears and 11.1 mm for apples. The percentage of soluble solids was measured with a refractometer. Mass of the fruit was measured with scales (measuring capacity 2000 g, measuring sensitivity 0.019).

The data were analyzed statistically using the 3-factor completely randomised design to study the effect of varieties (Williams and Ankara varieties of pear and Starkspur Golden Delicious and Starking varieties of apple), storage times (harvest day, 1st, 2nd and 3rd month for pears; 1st, 2nd, 3rd and 4th month for apples) and drop heights (10, 15 and 20 cm) on the test results. For Ankara pears, 4th month data were obtained but not used in the statistical analysis, because it was not possible to store the Williams variety until the 4th month. Furthermore, Duncan's multiple range test was used to compare the means. From the results of the analysis, the effects of the main factors and their interactions were determined.

Statistical analysis of the data was performed using the ANOVA and Duncan's multiple range test procedures of STATISTICA.

Results and Discussion

Table 1 shows the average values of flesh firmness, soluble solids and Poisson's ratio of the varieties of fruit tested. The average flesh firmness value and soluble solid contents of Williams and Starkspur Golden Delicious are higher than those of the other varieties in comparison with their species. Similarly Ankara and Starkspur Golden Delicious have higher Poisson's ratio values.

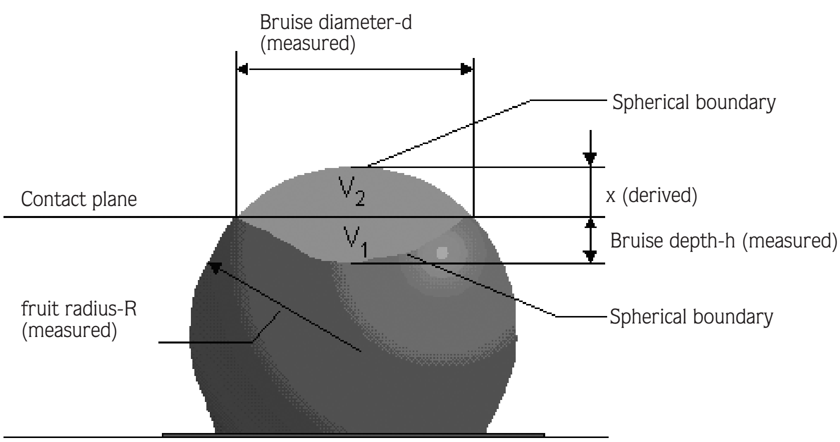

Figure 3. Idealized bruise showing symbols used in bruise volume determination (Schoorl and Holt, 1980).

Table 1. Flesh firmness, soluble solids, Poisson's ratio of pear and apple varieties.

Species	Variety	Flesh firmness (kg)	Soluble solids (%)	Poisson's ratio
Pear	Williams	6.606 ± 0.360	13.755 ± 0.380	0.302 ± 0.011
	Ankara	5.785 ± 0.267	12.433 ± 0.457	0.427 ± 0.012
Apple	Starkspur Golden Delicious	7.298 ± 0.380	14.760 ± 0.211	0.367 ± 0.007
	Starking	6.471 ± 0.368	14.606 ± 0.254	0.342 ± 0.009

Analysis of variance test results are summarized for pear in Table 2 and for apple in Table 3. As seen in Table 2, variety and cold storage time affected significantly all measurements for pear at 1% significance. Table 3 indicates that variety and cold storage time affected significantly all measurements for apple at 1% significance except for deformation, deformation energy and deformation volume in the compression test (in the compression test for force at 5% significance). Bruise volume in the impact test increased significantly at 1% significance with drop heights for pear and apples. Bruise susceptibility of Williams and the 2 apple varieties had no significant differences among the drop heights.

The mean values and standard errors in the compression and impact tests and Duncan's multiple range test results are given in Tables 4 and 5 for pears and in Tables 6 and 7 for apples. Duncan's multiple range test showed that the differences among cold storage times were not significant for modulus of elasticity after the 1st month in Starking. The difference between 2 varieties for modulus of elasticity and bruise susceptibility was generally significant at the 5% level in the pear and apple varieties. The bruise susceptibility differences caused by drop heights occurred in the 1st and 2nd months for Ankara. The differences among cold storage times for bruise susceptibility were not significant after the 1st

Table 2. Effects of pear variety, cold storage time and drop height on various test measurements and calculations.

Measurements and calculations	Level of significance						
	Variety (A)	Time in cold storage (B)	A x B				
In compression test, bioyield point values							
Deformation	0.000**	0.000**	0.000**				
Force	0.000**	0.000**	0.000**				
Modulus of elasticity	0.000**	0.000**	0.000**				
Deformation energy	0.000**	0.000**	0.005**				
Deformation volume	0.000**	0.000**	0.000**				
	Variety (A)	Time in cold storage (B)	Drop height (C)	A x B	A x C	B x C	A x B x C
In impact test							
Bruising volume	0.000**	0.000**	0.000**	0.000**	0.000**	0.243^{ns}	0.011*
Absorbed energy	0.000**	0.000**	0.000**	0.004**	0.000**	0.000**	0.000**
Bruise susceptibility	0.000**	0.000**	0.000**	0.000**	0.077^{ns}	0.954^{ns}	0.554^{ns}

** 1% significance level
* 5% significance level
ns not significant

Table 3. Effects of apple variety, cold storage time and drop height on various test measurements and calculations.

Measurements and calculations	Level of significance						
	Variety (A)	Time in cold storage (B)	A x B				
In compression test, bioyield point values							
Deformation	0.266^{ns}	0.000**	0.000**				
Force	0.017*	0.000**	0.000**				
Modulus of elasticity	0.004**	0.000**	0.000**				
Deformation energy	0.932^{ns}	0.000**	0.000**				
Deformation volume	0.266^{ns}	0.000**	0.000**				
	Variety (A)	Time in cold storage (B)	Drop height (C)	A x B	A x C	B x C	A x B x C
In impact test							
Bruising volume	0.000**	0.000**	0.000**	0.005**	0.202^{ns}	0.110^{ns}	0.435^{ns}
Absorbed energy	0.000**	0.001**	0.000**	0.003**	0.000**	0.000**	0.002**
Bruise susceptibility	0.000**	0.000**	0.538^{ns}	0.030*	0.239^{ns}	0.004**	0.106^{ns}

** 1% significance level
* 5% significance level
ns not significant

Table 4. The mean values and standard errors of compression test measurements and calculations and Duncan's multiple range test results for pear varieties.

PEAR		ΔD (mm)	F (N)	E (N mm^{-2})	E_A (Nmm)	V_A (mm^3)
Variety	Storage Time (Month)	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$
WILLIAMS	0	^{a} 3.92 ± 0.225 ^{C}	^{a} 59.12 ± 5.534 ^{A}	^{a} 1.678 ± 0.11 ^{A}	^{a} 121.8 ± 15.253 ^{B}	^{a} 197.16 ± 11.32 ^{C}
(VARIETY 1)	1	^{a} 5.63 ± 0.182 ^{A}	^{a} 59.56 ± 4.389 ^{A}	^{a} 1.207 ± 0.088 ^{B}	^{a} 169.15 ± 14.94 ^{A}	^{a} 282.79 ± 9.13 ^{A}
	2	^{a} 4.9 ± 0.281 ^{B}	^{b} 28.96 ± 2.45 ^{B}	^{b} 0.669 ± 0.043 ^{C}	^{a} 73.55 ± 9.804 ^{C}	^{a} 246.25 ± 14.14 ^{B}
	3	^{b} 2.4 ± 0.165 ^{D}	^{b} 10.91 ± 1.327 ^{C}	^{b} 0.511 ± 0.042 ^{C}	^{b} 13.92 ± 2.77 ^{D}	^{b} 120.59 ± 8.29 ^{D}
ANKARA	0	^{a} 3.8 ± 0.135 ^{AB}	^{b} 49.63 ± 2.855 ^{A}	^{b} 1.34 ± 0.07 ^{A}	^{a} 95.01 ± 7.15 ^{AB}	^{a} 191.07 ± 6.76 ^{AB}
(VARIETY 2)	1	^{b} 4.43 ± 0.161 ^{A}	^{b} 49.31 ± 3.089 ^{A}	^{a} 1.137 ± 0.06 ^{AB}	^{b} 110.75 ± 9.51 ^{A}	^{b} 222.53 ± 8.06 ^{A}
	2	^{a} 4.3 ± 0.293 ^{A}	^{a} 47.58 ± 2.272 ^{A}	^{a} 1.155 ± 0.045 ^{AB}	^{a} 105.41 ± 12.00 ^{A}	^{a} 216.15 ± 14.76 ^{A}
	3	^{a} 3.62 ± 0.263 ^{B}	^{a} 36.57 ± 3.58 ^{B}	^{a} 1.037 ± 0.062 ^{B}	^{a} 70.08 ± 12.74 ^{B}	^{a} 182.00 ± 13.2 ^{B}
	4	3.623	28.33	0.809	53.946	182

*There is no significant difference ($P < 0.05$) among storage times with the same capital letter in the same variety (to compare storage times)
There is no significant difference ($P < 0.05$) between varieties with the same small letter in the same storage time (to compare varieties)

Table 5. The mean values and standard errors of impact test measurements and calculations and Duncan's multiple range test results for pear varieties.

PEAR			V_z (mm^3)	E_a (Nmm)	C (ml J^{-1})
Variety	Storage Time (Month)	Drop Height (cm)	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$
WILLIAMS (VARIETY 1)	0	10	a 1 C 238.42 ± 32.06	a 1 C 120.87 ± 4.28	a 1 A 1.925 ± 0.248
		15	a 1 B 558.63 ± 86.62	a 1 B 180.4 ± 6.31	a 1 A 3.057 ± 0.446
		20	a 1 A 762.97 ± 110.74	a 1 A 237.8 ± 8.59	a 1 A 3.105 ± 0.397
	1	10	b 1 A 68.43 ± 23.74	b 1 C 112.94 ± 3.88	b 1 A 0.594 ± 0.198
		15	b 1 A 133.86 ± 30.58	b 1 B 174.13 ± 5.99	b 2 A 0.760 ± 0.172
		20	b 2 A 201.46 ± 45.16	b 1 A 232.05 ± 7.99	b 2 A 0.855 ± 0.181
	2	10	b 2 A 15.16 ± 6.7	c 1 C 99.97 ± 4.66	b 2 A 0.147 ± 0.069
		15	b 2 A 92.44 ± 28.98	c 1 B 153.3 ± 6.14	b 2 A 0.589 ± 0.179
		20	b 2 A 115.49 ± 43.6	c 1 A 207.73 ± 7.88	b 2 A 0.547 ± 0.198
	3	10	b 2 A 13.9 ± 9.5	d 1 C 86.78 ± 2.62	b 2 A 0.156 ± 0.11
		15	b 2 A 40.16 ± 26.43	d 2 B 132.14 ± 4.05	b 2 A 0.286 ± 0.172
		20	b 2 A 56.87 ± 38.38	d 2 A 177.05 ± 5.19	b 2 A 0.335 ± 0.226
ANKARA (VARIETY 2)	0	10	ab 1 B 262 ± 50.5	a 2 C 103.64 ± 5.11	b 1 A 2.586 ± 0.549
		15	b 2 B 368.35 ± 69.79	a 2 B 160.21 ± 9.29	b 1 A 2.293 ± 0.43
		20	b 1 A 720.47 ± 103.99	a 2 A 220.23 ± 11.7	b 1 A 3.327 ± 0.444
	1	10	b 1 C 121.52 ± 41.49	d 2 C 78.99 ± 5.68	b 1 B 1.683 ± 0.629
		15	b 1 B 299.40 ± 59.14	d 2 B 124.01 ± 9.33	b 1 AB 2.380 ± 0.436
		20	c 1 A 550.31 ± 94.28	c 2 A 170.84 ± 12.84	b 1 A 3.383 ± 0.569
	2	10	ab 1 B 217.09 ± 27.48	c 2 C 84.54 ± 4.52	b 1 B 2.669 ± 0.371
		15	b 1 B 359.44 ± 69.84	c 2 B 134.49 ± 6.57	b 1 B 2.643 ± 0.438
		20	b 1 A 752.56 ± 71.65	b 2 A 182.52 ± 9.09	b 1 A 4.179 ± 0.382
	3	10	a 1 C 387.1 ± 101.71	b 2 C 84.83 ± 3.62	a 1 A 4.767 ± 1.247
		15	a 1 B 678.54 ± 68.79	b 1 B 137.79 ± 6.66	a 1 A 5.088 ± 0.565
		20	a 1 A 988.98 ± 161.11	b 1 A 182.39 ± 7.41	a 1 A 5.420 ± 0.863
	4	10	384.65	76.063	5.0574
		15	662.75	121.15	5.4703
		20	731.62	166.77	4.387

*There is no significant difference ($P < 0.05$) among drop heights with the same capital letter in the same variety and in the same storage time (to compare drop heights)
There is no significant difference ($P < 0.05$) among storage times with the same small letter in the same variety and in the same drop height (to compare storage times)
There is no significant difference ($P < 0.05$) between varieties with the same number in the same storage time and in the same drop height (to compare varieties)

Table 6. The mean values and standard errors of compression test measurements and calculations and Duncan's multiple range test results for apple varieties.

APPLE		ΔD (mm)	F (N)	E (N mm^{-2})	E_A (Nmm)	V_A (mm^3)
Variety	Storage Time (Month)	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$
		a B	a A	a A	a A	a B
	0	3.39 ± 0.219	44.05 ± 1.554	1.447 ± 0.06	76.29 ± 6.93	170.45 ± 10.99
		a B	a AB	a B	a A	a B
STARKSPUR	1	3.78 ± 0.223	37.57 ± 1.646	1.093 ± 0.047	72.33 ± 7.11	189.85 ± 11.19
GOLDEN		a AB	a AB	b BC	a A	a AB
DELICIOUS	2	4.14 ± 0.220	38.5 ± 1.610	1.014 ± 0.024	81.22 ± 7.52	207.86 ± 11.05
(VARIETY1)		a AB	a B	a BC	a A	a AB
	3	3.98 ± 0.231	35.93 ± 1.957	0.984 ± 0.042	73.41 ± 7.56	200.17 ± 11.64
		a A	a AB	b C	a A	a A
	4	4.7 ± 0.57	37.77 ± 4.03	0.883 ± 0.026	97.76 ± 22.34	236.17 ± 28.6
		a A	a A	a A	a A	a A
	0	3.28 ± 0.168	44.35 ± 2.127	1.507 ± 0.057	74.23 ± 6.24	164.91 ± 8.43
		a A	b B	a B	a B	a A
STARKING	1	2.74 ± 0.193	25.95 ± 1.738	1.074 ± 0.066	36.41 ± 4.72	137.56 ± 9.77
(VARIETY2)		a A	b B	a B	a B	a A
	2	2.54 ± 0.225	27.91 ± 2.884	1.192 ± 0.046	38.79 ± 5.88	127.67 ± 11.29
		a A	b B	a B	a B	a A
	3	3.0 ± 0.362	29.55 ± 3.305	1.111 ± 0.057	49.39 ± 9.97	150.79 ± 18.18
		a A	b B	a B	a B	a A
	4	3.07 ± 0.173	30.43 ± 1.877	1.096 ± 0.039	47.78 ± 4.98	154.17 ± 8.66

*There is no significant difference ($P < 0.05$) among storage times with the same capital letter in the same variety (to compare storage times)
There is no significant difference ($P < 0.05$) between varieties with the same small letter in the same storage time (to compare varieties)

month in Williams. Furthermore, the differences among the harvest day, and the 1st and the 2nd months for bruise susceptibility were not significant in Ankara variety.

After compression tests, the determined bioyield point force, deformation, modulus of elasticity, deformation energy and deformation volume are shown in Figure 4. The bioyield point force decreased from 59.12 to 10.91 N for Williams and from 49.63 to 28.33 N for Ankara with increasing duration of storage. For the apple varieties these values are almost the same on the harvest day, but after this day, they varied from 44.05 to 37.77 N for Starkspur Golden Delicious and from 44.35 to 30.43 for Starking with an increase in duration of storage. The 2 varieties can be ranked in descending order for modulus of elasticity at harvest as follows: Williams-Ankara and Starking-Starkspur Golden Delicious. The modulus of elasticity of pears and apples in both varieties tended to decrease as the time in cold storage increased. Modulus of elasticities decreased from 1.68 to 0.51 MPa for variety Williams, from 1.34 to 0.8 MPa for variety Ankara, from 1.45 to 0.88 MPa for variety Starkspur Golden Delicious and from 1.51 to 1.1 MPa for Starking with an increase in duration of storage. The modulus of elasticity of the Starkspur Golden Delicious and Starking apple varieties and the Ankara pear variety tended to decrease at about the same rate, whereas that of Williams decreased faster. Deformation energy of Starkspur Golden Delicious was higher than that of Starking during the entire period. For pears, at the initial stage deformation energy of Williams was higher than that of Ankara. However, after the 1st month, deformation energy of Williams decreased very fast and remained under Ankara's values.

Table 7. The mean values and standard errors of impact test measurements and calculations and Duncan's multiple range test results for apple varieties.

APPLE			V_z (mm^3)	E_a (Nmm)	C (ml J^{-1})
Var.	Storage Time (Month)	Drop Height (cm)	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$
STARKSPUR GOLDEN DELICIOUS (VARIETY 1)	0	10	a 1 C 575.74 ± 46.7	b 1 C 96.22 ± 1.75	a 1 A 6.026 ± 0.523
		15	a 1 B 934.53 ± 44.57	b 1 B 147.95 ± 2.18	a 1 A 6.332 ± 0.305
		20	a 1 A 1166.3 ± 62.98	b 1 A 198.87 ± 2.7	a 1 A 5.892 ± 0.348
	1	10	a 2 C 541.31 ± 69.16	a 2 C 97.47 ± 4.23	a 2 A 5.608 ± 0.75
		15	a 2 B 826.72 ± 78.8	a 2 B 154.14 ± 6.99	ab 2 A 5.379 ± 0.544
		20	a 1 A 1108.66 ± 77.29	a 2 A 208.32 ± 9.49	a 1 A 5.359 ± 0.400
	2	10	b 2 C 314.3 ± 25.28	e 2 C 81.82 ± 2.81	b 2 A 3.835 ± 0.282
		15	b 2 B 591.91 ± 67.11	e 2 B 128.81 ± 4.57	b 2 A 4.512 ± 0.412
		20	b 2 A 898.78 ± 84.72	e 2 A 178.65 ± 7.23	a 2 A 4.987 ± 0.349
	3	10	b 2 B 119.91 ± 36.83	d 2 C 84 ± 1.44	c 2 A 1.385 ± 0.412
		15	c 2 AB 286.04 ± 58.99	d 2 B 134.62 ± 2.87	c 2 A 2.085 ± 0.416
		20	c 2 A 463.92 ± 70.8	d 2 A 179.78 ± 3.47	b 2 A 2.548 ± 0.364
	4	10	b 1 B 174.79 ± 71.56	c 2 C 86.81 ± 2.23	c 1 A 2.097 ± 0.887
		15	c 2 B 1.703 ± 0.518	c 2 B 237.86 ± 73.72	c 2 A 136.54 ± 3.36
		20	c 2 A 537.51 ± 115.76	c 2 A 185.85 ± 4.03	b 1 A 2.853 ± 0.599
STARKING (VARIETY 2)	0	10	bc 1 C 487.19 ± 42.71	e 2 C 87.57 ± 2.37	c 1 A 5.608 ± 0.481
		15	a 1 B 908.2 ± 62.89	e 2 B 139.16 ± 4.08	a 1 A 6.555 ± 0.448
		20	a 1 A 1241.2 ± 68.43	e 2 A 189.71 ± 5.49	a 1 A 6.545 ± 0.331
	1	10	a 1 B 909.68 ± 140.65	a 1 C 99.06 ± 3.04	a 1 A 9.072 ± 1.280
		15	a 1 B 1066.82 ± 146.75	a 1 B 162.97 ± 7.44	a 1 A 6.741 ± 0.851

Table 7. continued

APPLE			V_z (mm^3)	E_a (Nmm)	C (ml J^{-1})
Var.	Storage Time (Month)	Drop Height (cm)	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$	$\bar{X} \pm S_{\bar{X}}$
STARKING (VARIETY 2)		20	a 1 A 1258.73 ± 188.39	a 1 A 222.91 ± 10.09	ab 1 A 5.810 ± 0.841
	2	10	b 1 C 647.7 ± 65.65	d 1 C 91.53 ± 3.33	b 1 A 7.115 ± 0.664
		15	a 1 B 964.25 ± 86.99	b 1 B 157 ± 5.71	a 1 A 6.129 ± 0.487
		20	a 1 A 1400.07 ± 122.62	c 1 A 202.64 ± 7.74	a 1 A 6.860 ± 0.456
	3	10	c 1 C 393.81 ± 49.74	b 1 C 96.44 ± 2.16	d 1 A 4.074 ± 0.524
		15	b 1 B 672.7 ± 87.59	c 1 B 154.33 ± 3.95	b 1 A 4.315 ± 0.554
		20	b 1 A 1034.06 ± 157.7	b 1 A 212.51 ± 4.83	bc 1 A 4.825 ± 0.726
	4	10	c 1 C 290.57 ± 54.95	c 1 C 93.57 ± 2.57	d 1 A 3.107 ± 0.575
		15	b 1 B 513.3 ± 48.66	d 1 B 141.66 ± 3.94	b 1 A 3.64 ± 0.338
		20	c 1 A 813.68 ± 94.36	d 1 A 201.29 ± 4.78	c 1 A 4.043 ± 0.449

*There is no significant difference ($P < 0.05$) among drop heights with the same capital letter in the same variety and in the same storage time (to compare drop heights)
There is no significant difference ($P < 0.05$) among storage times with the same small letter in the same variety and in the same drop height (to compare storage times)
There is no significant difference ($P < 0.05$) between varieties with the same number in the same storage time and in the same drop height (to compare varieties)

Bruise volume, energy absorbed and bruise susceptibility, determined by dropping pears and apples from 10, 15 and 20 cm heights onto a metal surface are shown in Figures 5 and 6. The absorbed energy of the pear varieties and Starkspur Golden Delicious decreased, whereas that of Starking stayed stable as the storage time increased. Tendency of modulus of elasticity and absorbed energy values in storage time supported each other, as expected. Bruise volumes and bruise susceptibility of both apple varieties and the Williams pear variety tended to decrease as the time in cold storage increased, whereas that of Ankara increased. This means that the Ankara pear variety becomes more susceptible to bruising with time in cold storage, while the others become more resistant. This tendency of both apple varieties and the Williams pear variety can be explained by increasing fruit skin resistance and changing fruit texture during storage. Similar trends have been reported by Hyde and Ingle (1968), Klein (1987), Garcia et al. (1995) and Pasini et al. (2004). Hyde and Ingle (1968), working with 6 apple cultivars, found that bruise size increased with delayed harvest but declined with progressively longer storage periods. With respect to storage, Klein (1987) concluded that bruise volume decreased with storage time. Garcia et al. (1995) noted that the fruit at harvest was more susceptible to bruising than after storage. They explained this change in terms of a decrease in fruit turgidity. Pasini et al. (2004) stated that

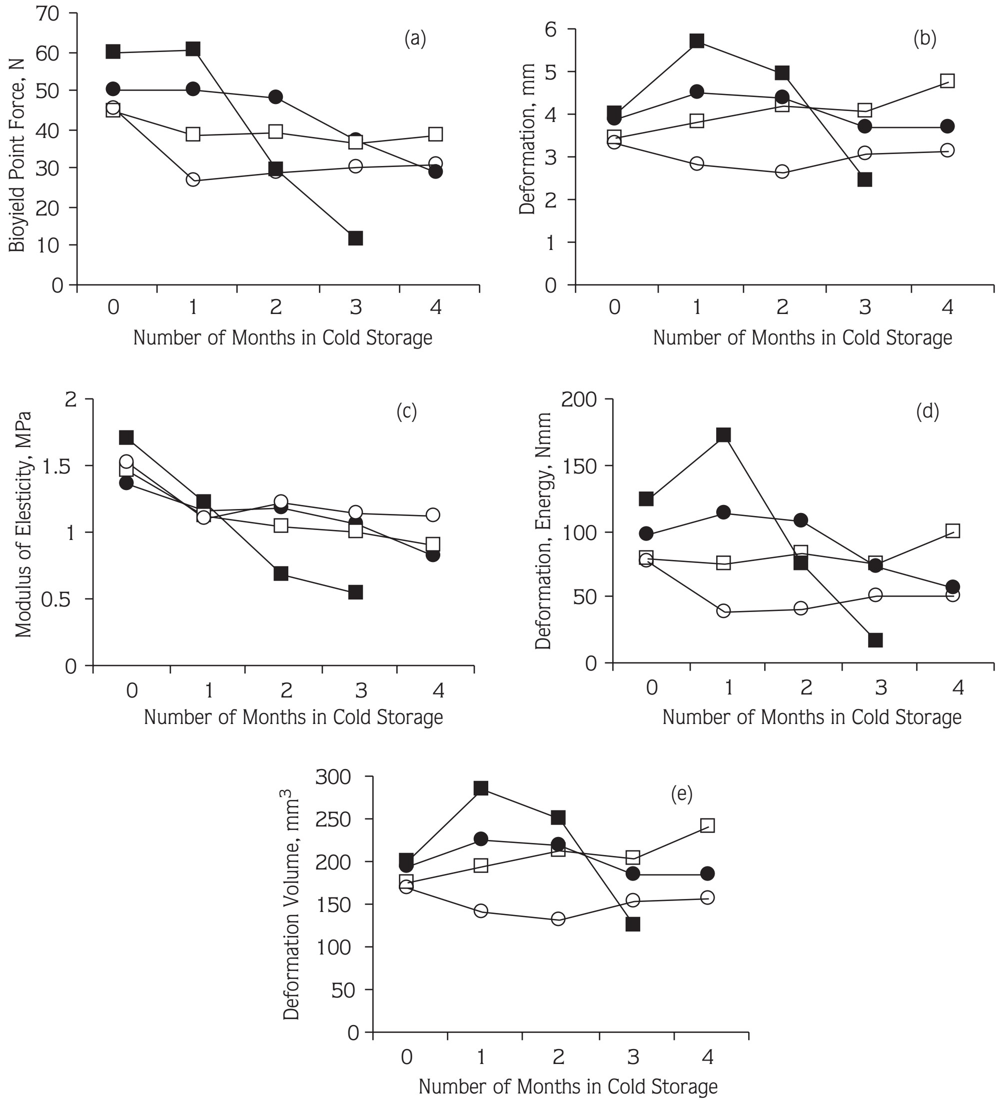

Figure 4. Effects of cold storage time on bioyield point force (a), deformation (b), modulus of elasticity (c), deformation energy (d) and deformation volume (e) of pear and apple varieties: -■- Williams; -●- Ankara; -❑- Starkspur Golden Delicious; -❍- Starking.

long storage can increase resistance to mechanical impact. The test results obtained in this study for the Williams pear variety and the 2 apple varieties were similar to those obtained by the researchers above. The opposite tendency of Ankara pears can be explained by variety and textural properties. The Ankara pear variety and Starking apple variety are also susceptible to impact damage more than Williams pear and Starkspur Golden Delicious apple, respectively. When the drop heights increased, damage in all varieties generally tended to increase. Diener et al. (1979) found similar results and reported that bruise volume in apples was a nearly linear function of drop height over the ranges of height used (10.16, 17.78, 25.40 and 34.29 cm).

The determined modulus of elasticity in other studies and some of our results are given in Figure 7 for comparison. In this graph, the first 2 columns are our test results. Because of the variety differences, the modulus of elasticity varies. According to the results reported by Öğüt and Aydın (1992), the modulus of

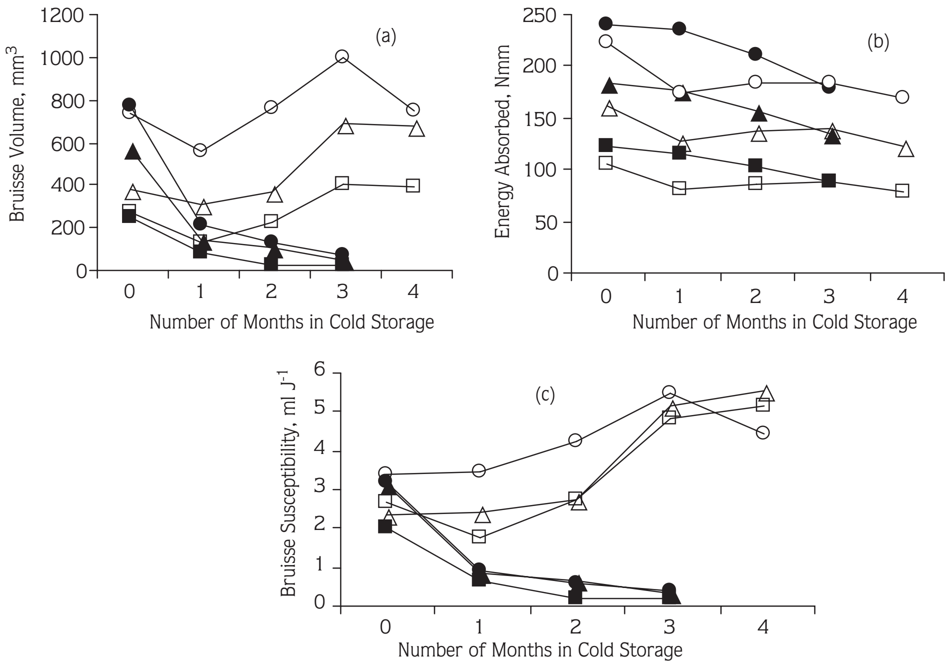

Figure 5. Effects of cold storage time on bruise volume (a), energy absorbed (b) and bruise susceptibility (c) of pear varieties for 10, 15 and 20 cm drop heights: -■- Williams-10 cm; -▲- Williams-15 cm; -●- Williams-20 cm; -❑- Ankara-10 cm; -∆- Ankara-15 cm; -❍- Ankara-20 cm.

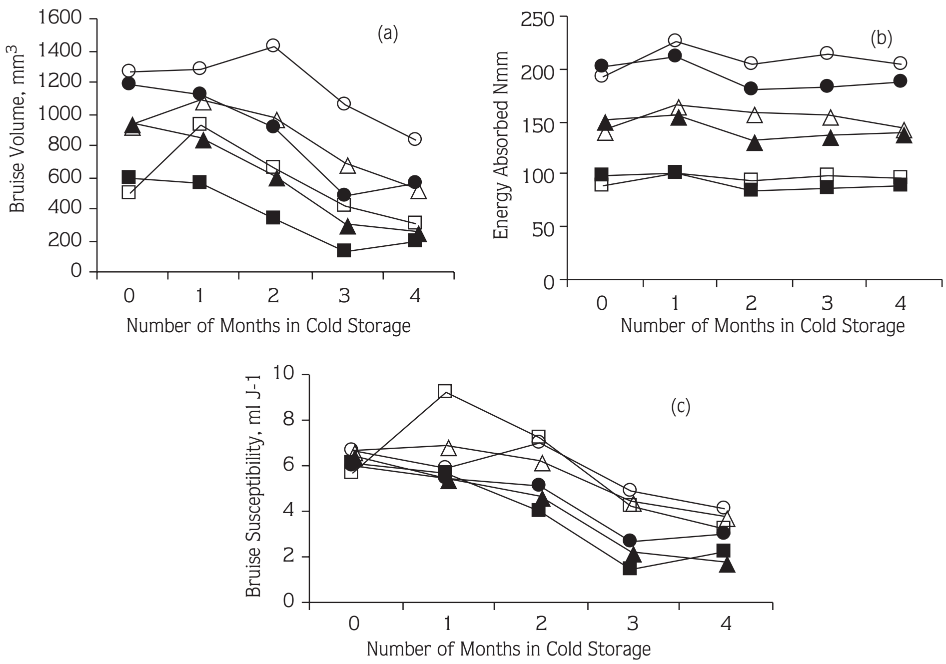

Figure 6. Effects of cold storage time on bruise volume (a), energy absorbed (b) and bruise susceptibility (c) of apple varieties for 10, 15 and 20 cm drop heights: -■- Starkspur Golden Delicious-10 cm; -▲- Starkspur Golden Delicious-15 cm; -●- Starkspur Golden Delicious-20 cm; -❑- Starking-10 cm; -∆- Starking-15 cm; -❍- Starking-20 cm.

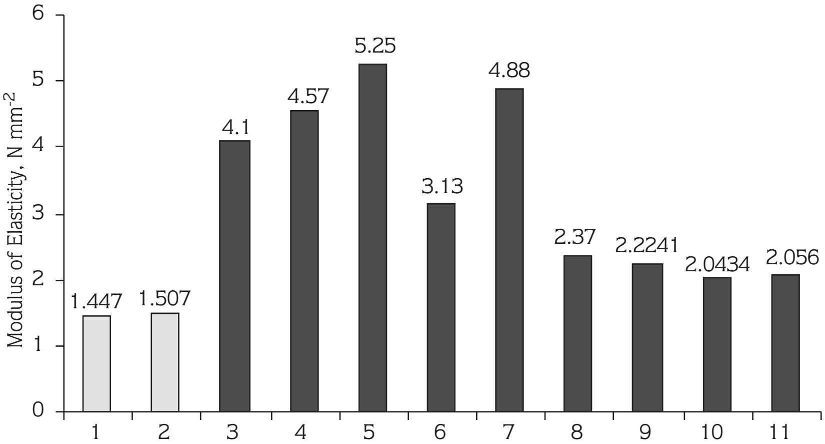

Figure 7. Modulus of elasticity of apples: 1. Starkspur Golden Delicious, at harvest date; 2. Starking, at harvest date; 3., 4. and 5. Delicious, Golden Delicious and Rome Beauty, respectively, 25.4 mm min^{-1} loading rate, Abbott and Lu (1996); 6. Amasya, 62 mm min^{-1} loading rate, Aydın (1989); 7. and 8. Braeburn and Granny Smith respectively, 8 mm diameter probe, 6 mm min^{-1} loading rate, Vursavuş and Özgüven (1999); 9., 10. and 11. Amasya, Golden and Starking, respectively, 2.2 mm diameter cylindrical probe, 62 mm min^{-1} loading rate, Öğüt and Aydın (1992).

elasticity of Starking is 2.056 MPa, whereas our result is 1.507 MPa. This situation in biological materials like apples can be explained by the fact that they are living organisms and their cells are sensitive to influences such as humidity, temperature, oxygen and energy consumption during development and storage. Therefore, their mechanical properties such as modulus of elasticity change according to harvest date, storage time and storage conditions. Consequently, the test conditions, harvest date, storage time and storage conditions must be given in these studies for a suitable comparison.

Conclusions

The results of this study can be summarized as follows:

1. The mechanical properties of the fruits studied in this work are related to storage time. This will determine the behaviour of fruit during harvest and post-harvest processing.
2. Williams-Ankara pears and Starkspur Golden Delicious-Starking apples differed in bioyield point force, modulus of elasticity, susceptibility to impact damage, and response to storage at 0 °C. Drop height affected bruise volume and absorbed energy means, but there was no significant difference in bruise susceptibility among drop heights except in the Ankara variety.
3. Modulus of elasticity of Williams was higher than that of Ankara at the initial stage of cold storage; however, after 1 month, they lost their elasticity and the modulus of elasticity of Ankara became higher than that of Williams. While bruise susceptibility of Ankara increased, it decreased for Williams as the time in cold storage increased. Consequently, extreme care must be exercised when handling Ankara pears to prevent them from becoming bruised but no extreme care is needed to prevent Williams pears from impact, especially after 1 month. It is advisable to do most handling, such as packing, sorting and transportation, within 1 month of harvest for Ankara.
4. Modulus of elasticity and bruise susceptibility of Starking apples were higher than those of Starkspur Golden Delicious apples. Starkspur Golden Delicious and Starking became more resistant to bruising as the time in cold storage increased. This means that extreme care is needed to protect these 2 apple varieties from impact, especially at harvest and during initial storage.

References

Abbott, J.A. and R. Lu. 1996. Anisotropic mechanical properties of apples. Transactions of the ASAE, 39: 1451-1459.

Agricultural Engineers Yearbook. 1994. Compression test of food materials of convex shape., ASAE Standard: ASAE S368.2, p. 472-475, St. Joseph, Michigan.

Aydın, C. 1989. Amasya Elma Çeşidinin Tarım Tekniği Yönünden Önemli Fiziko-Mekanik Özelliklerinin Belirlenmesi. Yüksek Lisans Tezi. Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, p. 66.

Aydın, C. and K. Çarman. 1998. Elmalar arasında çarpışma enerjisine bağlı olarak zedelenmenin saptanması. Tarımsal Mekanizasyon 18. Ulusal Kongresi, Tekirdağ, pp. 773-778.

Chen, P., M. Ruiz, F. Lu and A.A. Kader. 1987. Study of impact and compression damage on Asian pears. Transaction of the ASAE 30: 1193-1197.

Diener, R.G., K.C. Elliott, P.E. Nesselroad, M. Ingle, R.E. Adams and S.H. Blizzard. 1979. Bruise energy of peaches and apples. Transactions of the ASAE, 287-290.

Garcia, J.L., M. Ruiz-Altisent and P. Barreiro. 1995. Factors influencing mechanical properties and bruise susceptibility of apples and pears. J. Agric. Engng. Res., 61: 11-17.

Hyde, J.E. and M. Ingle. 1968. Size of apple bruises as affected by cultivar, maturity and time in storage. Proc. Am. Soc. Hort. Sci., 92: 733-738.

Klein, J.D. 1987. Relationship of harvest date, storage conditions, and fruit characteristics to bruise susceptibility of apple. J. Amer. Soc. Hort. Sci., 112(1): 113-118.

Mohsenin, N.M. 1980. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York.

Öğüt, H. and C. Aydın. 1992. Konya ekolojik şartlarında yetiştirilen bazı elma çeşitlerinin Poisson oranı ve elastikiyet modüllerinin belirlenmesi. Selçuk Üniversitesi Ziraat Fakültesi Dergisi, 2: 39-53, Konya.

Özbek, S. 1978. Özel Meyvecilik (Kışın Yaprağını Döken Meyve Türleri). Çukurova Üniversitesi Yayın No: 128, Ders Kitabı No: 11, Adana.

Parke, D. 1963. The resistance of potatoes to mechanical damage caused by impact loading. J. Agric. Engng. Res., 8: 173-177.

Pasini, L., L. Ragni, A.D. Rombola, A. Berardinelli, A. Guarnieri and B. Marangoni. 2004. Influence of the fertilization system on the mechanical damage of apples. Biosystems Engineering, 88: 441-452.

Schoorl, D. and J.E. Holt. 1978. The effects of storage time and temperature on the bruising of Jonathan, Delicious and Granny Smith apples. J. Texture Studies, 8: 409-416.

Schoorl, D. and J.E. Holt. 1980. Bruise resistance measurements in apples. J. Texture Studies, 11: 389-394.

Tarımsal Yapı (Üretim, Fiyat, Değer). 2000. Türkiye Cumhuriyeti Başbakanlık Devlet İstatistik Enstitüsü, Ankara.

Topping, A.J. and M.T. Luton. 1986. Cultivar differences in the bruising of English apples. Journal of Horticultural Science, 61: 9-13.

Türkiye Cumhuriyeti Tarım ve Köyişleri Bakanlığı Elma Çeşit Katalogu. 1991. Ankara.

Türkiye Cumhuriyeti Tarım ve Köyişleri Bakanlığı Armut Çeşit Katalogu. 1993. Ankara.

Vursavuş, K. and F. Özgüven. 1999. Determination of the some mechanical properties and susceptibility to bruising damage of apples. 7th International Congress on Agricultural Mechanization and Energy, Adana, Turkey, pp. 570-575.

Vursavuş, K. and F. Özgüven. 2000. Çarpma durumunda elmanın fiziko-geometrik özelliklerinin mekanik zedelenme üzerindeki etkisinin araştırılması. Tarımsal Mekanizasyon 19. Ulusal Kongresi, Erzurum, pp. 489-494.