Some Physico-Mechanical Properties of Apricot Fruit, Pit and Kernel of Ordubad Variety

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ABSTRACT

The physical and mechanical properties of apricot fruit, pit and kernel are the most important parameters for designing and development of harvesting, handling, grading, sizing, processing and packaging equipments. The objective of this study was to determine physical and mechanical properties of apricot fruit, pit and kernel of commercial cultivar of Ordubad. The physical and mechanical properties of the fruit, pit and kernel were determined at 82.29%, 22.12% and 22.65% (w.b.) moisture content, respectively. The pit was compressed along the length, width and thickness at 0.085, 0.20, 0.30 and 0.40 (d.b) moisture contents to determine required force, deformation and energy per volume (toughness) at rupture point. The results showed that average values of length, width, thickness, geometric mean diameter, mass, volume and sphericity for the fruit were 46.64 mm, 44.68 mm, 41.21 mm, 43.93 mm, 48.17 g, 45.84 cm^3 and 94.35%, respectively. The average values of length, width, thickness, geometric mean diameter, mass, volume and sphericity for the pit were 29.74 mm, 20.84 mm, 13.07 mm, 20.01 mm, 2.69 g, 2.59 cm^3 and 67.39%, respectively. The average values of coefficient of friction on different surfaces namely steel, galvanized steel and plywood sheets were determined 0.225 for the fruit, 0.415 for the pit and 0.538 for the kernel, respectively. The hardness at upper, middle and lower parts of the fruit were 3.03 N, 2.23 N and 2.93 N, respectively. The modulus of elasticity was 2.10 MPa for the fruit and 240.70 MPa for the pit. The maximum and minimum rupture forces of the pit were 847.70 N along the length at 0.085 (d.b) and 163.5 N along the width at 0.3 (d.b), respectively.

Keywords: Apricot, fruit, pit, kernel, Ordubad cultivar, physical properties, mechanical properties.

1. INTRODUCTION

Apricot (*Prunus armeniaca L.*) is a cultivated type of zerdali (wild apricot), which is produced by inoculation. Apricot has an important place in human nutrition and can be used as fresh, dried or processed fruit (Vursavus and Ozguven, 2004). Apricot is rich in minerals such as potassium and vitamins such as β-carotene. The β-carotene, which is the pioneer substance of mineral A, is necessary for epithelia tissues covering human bodies and organs, eye-health, bone and teeth development and working of endocrine glades (Haciseferogullari *et al.,* 2007). Moreover, vitamin A plays important role in reproduction and growing functions of our bodies, in increasing body resistance against infections.

Apricot trees can grow all over the world. The annual production of apricot exceeds three million tons and the main apricot producers are Turkey, Iran, Italy, France, Spain, Morocco, Hungary, Tunisia and Australia. Iran with 3113000 apricot trees after Turkey has the second place among the apricot producers with 275580 tons annual production (FAO, 2007). So far, more than 130 apricot varieties have been known in Iran. Some of the most commercial varieties are Ordubad, Ghermez-e-Shahrod, Ghorban-e-maragheh, Nasiri and Naderi (Moghtader, 1989).

Apricot pit consists of shell and kernel. The shell of pit to be formed of sclerenchyma and fiber maters and then is hard and strengthen. The apricot kernels have 40% oil, some protein, sugar, essence and A, C and B17 vitamins and cobalt. The kernels are used as dried nuts and in the production of oils, benzaldehyde, cosmetics, active carbon, and aroma perfume (Guner *et al.*, 1999). The shell obtained from extraction of the kernel from pit traditionally used as fuel in rural areas and in producing Medium Density Fiberboard (MDF) in recent years.

The physical and mechanical properties of agricultural products are the most important parameters for designing and development of handling, sorting, processing and packaging systems. The properties have been determined by previous researchers for many of agricultural products. The physical properties of hazelnuts and almond nut and its kernel were determined by Aydin (2002 and 2003). Some nutritional and technological properties of Turkish wild plum fruits were found by Calisir *et al.* (2004). Some physical properties of Hacıhaliloglu apricot pit and its kernel were determined by Gezer *et al.* (2002). Some physical properties of Shams, Nakhjavan, Jahanghiri, Shahrud-8 and Gheysi-2 apricot fruit were determined by Jannatizadeh *et al.* (2008). Effect of moisture content on physical properties of Sonati-Salmas apricot kernel was studied by Fathollahzadeh *et al.* (2008a). As well, the physical properties of Tabarzeh apricot kernel were investigated by Fathollahzadeh *et al.* (2008b). The physical and mechanical properties of Tabarzeh apricot fruits, pits and kernels were also determined by Ahmadi *et al.* (2008).

In spite of the second place of Iran among the apricot producers, the share of Iran in the world market is not considerable related to the apricot fruits, kernels and their related derivatives. The literature survey showed that there is limited published data concerning physical and mechanical properties of apricot fruit, pit and kernel of commercial cultivars such as Ghermez-e-Shahrod, Ordubad, Ghorban-e-Maragheh and Nassiri cultivars. Therefore, the objective of this research was to determine the physical and mechanical properties of apricot fruit, pit and kernel of Ordubad cultivar. This information can be used to design and development of processing, handling, cracking, separating, sizing and packaging systems.

2. MATERIALS AND METHODS

Ordubad apricot fruits, pits and kernels were used in this study. The apricot fruits used in these experiments were supplied from Sahand agricultural research center of Tabriz, Iran on Jun 2007. The apricot fruits were kept at 5 ^{O}C cooled box for experiments. The experiments were done at physical properties laboratory, College of Aboureihan, University of Tehran, Pakdasht, Iran. The samples were cleaned to remove all extra matter and damaged samples. Some pits of fruits extracted from the fruits by hand and then some of the pits were cracked by hammer on a handle. The kernels were separated by hand from shells. The moisture contents of fruits, pits and kernels were determined by using air oven method. The oven temperature was set at 105±3 ^{O}C and the samples weighed every 30 minute until the weight difference in two consecutive weighing was less than 0.2% of initial weight (Ghaebi *et al.,* 2008; Kashaninejad *et al.,* 2006).

To determine the size of the fruits, pits and kernels, three mutually perpendicular axes were defined, Length (L, the longest intercept along of pedicel), width (W, the longest intercept normal to L) and thickness (T, the longest intercept normal to L and W) (Fig. 1). The dimensions of each sample were measured along the axes by a micrometer with an accuracy of ±0.01 mm. The mass of each apricot fruit, pit and kernel were measured by a digital balance with an accuracy of ±0.001 g. The dimensions and mass were measured for 100 samples for the apricot fruit and 50 samples for the apricot pit and kernel.

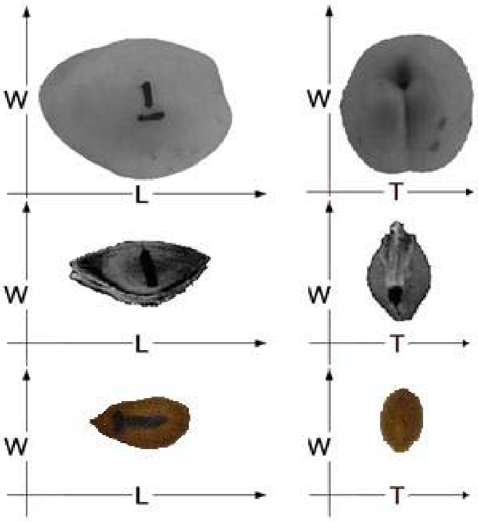

Figure 1. Defined dimensions for apricot fruit, pit and kernel.

The actual volume of fruit, pit and kernel were determined by the water displacement technique (Mohsenin, 1986). The apricot fruit, pit and kernel with known weight were submerged with a metal sponge sinker into a cylinder containing known volume of water and the weight of water displaced by the samples were recorded. The volume of each fruit was calculated by following equation (Mohsenin, 1986). The volumes of 50 samples were determined for fruit, pit and kernel.

$$V_w = \frac{m_w}{\rho_w} \tag{1}$$

where: V_w is volume of displaced water (cm^3), mw is mass of displaced water (g) and ρ_w is density of water (kgm^{-3}). The true density was calculated from measured mass and volume by equation (2) (Mohsenin, 1986):

$$\rho_t = \frac{m}{V_w} \tag{2}$$

where: ρ_t is true density (kgm^{-3}) and m is mass of the samples (g).

The bulk density was determined using the mass and volume relationship by filling an empty container of predetermined volume and weight (Fraser *et al.*, 1978). The apricot fruit, pit and kernel were dropped into the containers with volumes of 3320, 310 and 50 cm3, respectively from a height of 10 cm. The excess samples were removed by sweeping the surface of the container so that the samples were not compressed in any way. The samples bulk density values are mass of the samples within the containers divided to volume of the containers. Porosity of the samples was calculated as (Stroshine and Hamann, 1994; Mohsenin, 1986):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (3)$$

Geometric mean diameter (D_g), sphericity (ϕ) and surface area (S.A.) values were found using the following formula (Jain & Bal, 1997; Mohsenin, 1986):

$$D_g = (LWT)^{0.333} \qquad (4)$$

$$\phi = \frac{D_g}{L} \qquad (5)$$

$$S.A. = \frac{\pi B L^2}{2L - B} \qquad (6)$$

where $B = (WT)^{0.5}$

The coefficient of static friction of the apricot fruit, pit and kernel were determined by using inclined plane method on steel, galvanized steel and plywood sheet surfaces. The end of the friction surface (inclined plane) was attached to an endless screw. The apricot fruit was placed individually on the friction surfaces so that longitudinal axis of fruit was coaxial with length of the surfaces. The apricot pits and kernels arranged in a cylinder with diameter of 80 mm and height of 50 mm and then the cylinder was placed on the surfaces. The cylinder was slowly lifted up to avoid friction between the cylinder and surfaces. The friction surfaces were gradually raised by the screw when the samples started sliding over the surfaces. Both horizontal and vertical height values were measured by a ruler and, using the tangent of that angle, the coefficient of static frication was calculated by following equation (Musa and Hayder, 2004 and Suthar and Das 1996). The experiments were replicated 15 times for fruit and 5 times for pit and kernel.

$$\mu_s = \tan\alpha \qquad (7)$$

where: μ_s is coefficient of static friction, α : is angle that the incline makes with the horizontal when sliding begins.

The rolling coefficient of apricot fruit was also determined by using inclined plane method on steel, galvanized steel and plywood sheet surfaces. The apricot fruit was placed individually on the friction surfaces so that longitudinal axis of fruit was perpendicular with length of the surfaces. The friction surfaces were gradually raised by the screw when the samples started rolling over the surfaces. The tangent of this angle was calculated and named rolling coefficient

(Ghanbarian *et al.,* 2009; Goyal *et al.,* 2007; Bahnasawy *et al.,* 2004). The experiments were replicated 15 times.

The projected areas (PA) were measured in three perpendicular directions for each sample of apricot fruit, pit and kernel using an apparatus, which works based on digital image processing technique. Images were taken by a digital camera (Canon Ixus 65) in controlled conditions. The captured images were transmitted to a computer and then processed by Matlab and Photoshop softwares. The projected areas were obtained from pixel-area relationship, which was calibrated for known area materials. This method has been used and reported by several researchers (Ghaebi *et al.,* 2008; Khoshnam *et al.,* 2007). The projected areas of 50 samples were determined.

The mechanical properties of the apricot fruit, pit and kernel were determined using a biological material test (BMT) device which was developed by Ghaebi (2008). This device has three main components, which are a stable forced and moving platform, a driving unit (AC electric motor, inverter and reduction unit) and a data acquisition (load cell with resolution of 0.2 N, indicator, PC interface and software).

A probe with 1.5 mm diameter was installed on the load cell of the BMT device for determination of the fruit hardness. The velocity of moving platform was 45 mm/s. The required force for the probe penetration was measured at the upper, middle and lower parts of the fruit. The modulus of elasticity of the fruit and pit were determined by Hertz theory according to the ASAE standard at 6 mm/s velocity of the moving platform (ASAE, 1998). As well, the rupture force of the fruit and kernel were measured at 6 mm/s.

The rupture force, deformation and toughness of apricot pit were determined at different moisture content levels (0.085, 0.2, 0.3 and 0.4 d.b.) and direction of compression loadings (along with length, X, width, Y, and thickness, Z). The apricot pit was placed on the fixed base of the BMT device and pressed with a plate fixed on the load cell at 6 mm/min speed until the pit ruptured. It was assumed that rupture occurred at the bio-yield point that is the point in the force–deformation curve where there is a sudden decrease in force. As soon as the bio-yield point was detected, the compression was stopped. The results from the compression tests should be considered the maximum force and deformation that shell of the apricot pit can withstand prior to rupture. Energy absorbed (E_a) by the sample at rupture was determined by calculating the area under the force–deformation curve from the following equation (Gupta and Das, 2000; Braga *et al.,* 1999; Mohsenin, 1986;).

$$E_a = \frac{1}{2} F_r D_r \tag{8}$$

where F_r is the rupture force and D_r is the deformation at rupture point.

Toughness (P) is expressed as the energy absorbed by the apricot pit up to rupture point per unit volume of the pit. This was calculated using the following formula (Olaniyan and Oje, 2002; Gupta and Das, 2000).

$$p = \frac{E_a}{V} \tag{9}$$

where E_a is the energy absorbed by the apricot pit and V is the volume of the pit, which can be estimated from following formula (Vursavus and Ozguven, 2004).

$$V = \frac{\pi}{6}(LWT) \tag{10}$$

where L is the length, W is the width and T is the thickness of pit.

Spreadsheet softwares of Microsoft EXCEL 2003 and SAS were used to analyze the data. The data was statistically analyzed using the two factor completely randomized design to study the effects of four moisture contents and three compression axes on the rupture force, deformation and toughness of apricot pit under the applied load. Further, Duncan's multiple range tests was used to compare the means. Each experiment was replicated 10 times making a total of 120 apricot pits that were individually measured and tested.

3. RESULTS AND DISCUSSION

Some physical properties of the apricot fruit, pit and kernel of Ordubad cultivar is given in Table 1. These properties were found at moisture contents of 82.29% (w.b.) for fruit, 32.13% (w.b.) for pit and 22.65% (w.b.) for kernel. These moisture content values show that the most of moisture in the apricot concentrate at texture of fruit and pit has the least moisture due to wooden texture.

Table 1. Some physical properties of Ordubad apricot fruit, pit and kernel

Properties	**Fruit**	**Pit**	**Kernel**
Length (mm)	46.62±2.80	29.72±1.25	17.81±0.83
Width (mm)	44.68±3.11	20.82±1.24	12.08±0.55
Thickness (mm)	41.21±2.53	13.07±0.94	8.28±0.89
Geometric mean diameter (mm)	43.93±2.45	20.01±0.88	12.07±0.60
Mass (g)	48.17±7.63	2.69±0.41	0.82±0.11
Volume (cm^3)	45.84±6.96	2.59±0.34	0.77±0.08
Sphericity (%)	94.35±3.31	67.39±2.04	67.85±3.10
Surface area (mm^2)	5850.50±682.56	1067.03±96.00	389.38±40.25
P_A (mm^2)	1878.12±252.97	444.55±50.51	154.84±10.56
P_B (mm^2)	1738.26±205.62	187.43±22.32	79.15±9.75
P_C (mm^2)	1741.67±223.05	246.77±30.57	101.83±11.69
Bulk density (kg/m^3)	533.63±10.89	453.10±10.75	585.00±19.34
True density (kg/m^3)	1033.99±11.44	906.39±186.38	993.64±38.86
Porosity (%)	48.39±0.57	47.30±13.83	41.04±2.33

The frequency distributions of dimensional characteristics and mass of the Ordubad fruit, pit and kernel are given in Figs. 2–4, respectively. As depicted from Fig. 2, 97% of fruit lengths were between 40.31 to 51.77 mm; 97% of fruit widths were between 38.57 to 51.44 mm; 94% of fruit thicknesses were between 33.94 to 45.22 mm and 91% of fruit mass were between 35.70 to 60.74 g. Jannatizadeh *et al.* (2008) reported the mean values of apricot fruit length, width and thickness of Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8 and Gheysi-2 cultivars were in the range of 40.97 to 46.63 mm, 36.23 to 45.37 mm and 35.26 to 43.97 mm, respectively. The dimensional characteristics and mass of Ordubad cultivar are in the range of the values reported by Hacıseferogullari *et al.* (2007) for Hasanbey variety of Turkey.

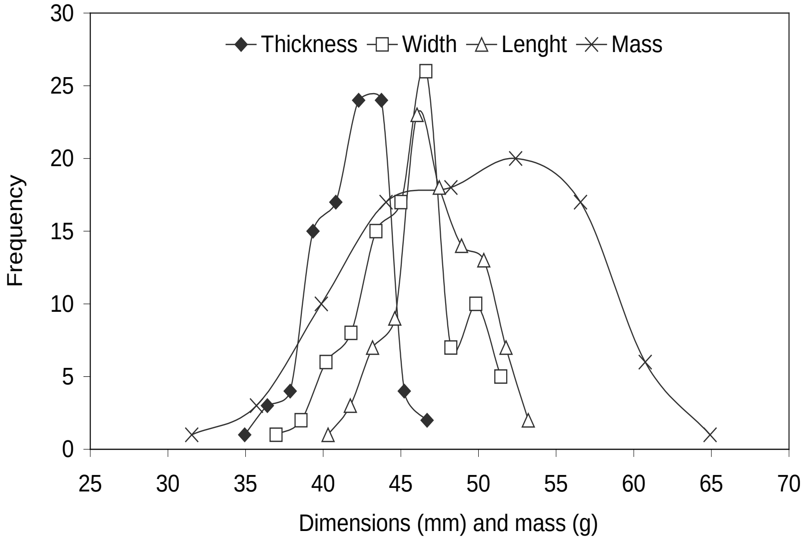

Figure 2. Frequency distribution of dimensions and mass of Ordubad apricot fruit.

It is clear from Fig. 3 that 96% of pit lengths were in the range of 27.79 to 32.32 mm; 92% of pit widths were in the range of 19.06 to 22.94 mm; 92% of pit thicknesses were in the range of 11.19 to 14.72 mm and 96% of pit mass were in the rang of 1.93 to 3.59 g. Ahmadi *et al.* (2008), research work showed that average values of length, width, thickness and mass of Tabarzeh pit were 27.85 mm, 16.33 mm, 10.15 mm and 1.44 g, respectively. These values are less than that of Ordubad pit cultivar, which were contributed to larger dimensions of Ordubad cultivar.

Figure 4 shows that 90% of kernel lengths were in the range of 16.36 to 19.11 mm; 88% of kernel widths were in the range of 11.16 to 12.87 mm; 94% of kernel thicknesses were in the range of 6.73 to 9.88 mm and 92% of kernel mass were in the rang of 0.67 to 1.01 g. Fathollahzadeh *et al.* (2008a,b), reported that average values of length, width, thickness and mass of Tabarzeh and Sonati-Salmas kernels were 15.76 and 15.43 mm for length, 11.06 and 10.49 mm for width, 5.45 and 5.75 mm for thickness, and 0.448 and 0.484 g for mass. The higher average values of Ordubad cultivar were contributed to larger dimensions of this cultivar.

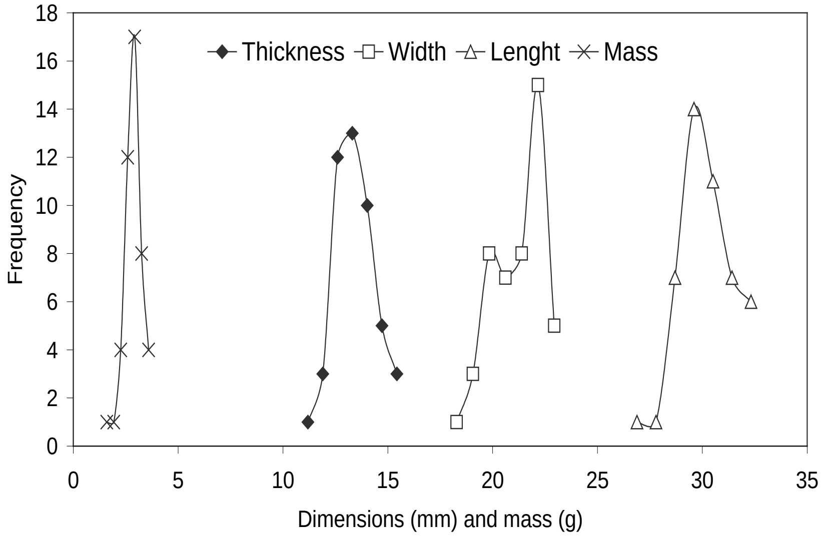

Fig. 3. Frequency distribution of dimensions and mass of Ordubad apricot pit.

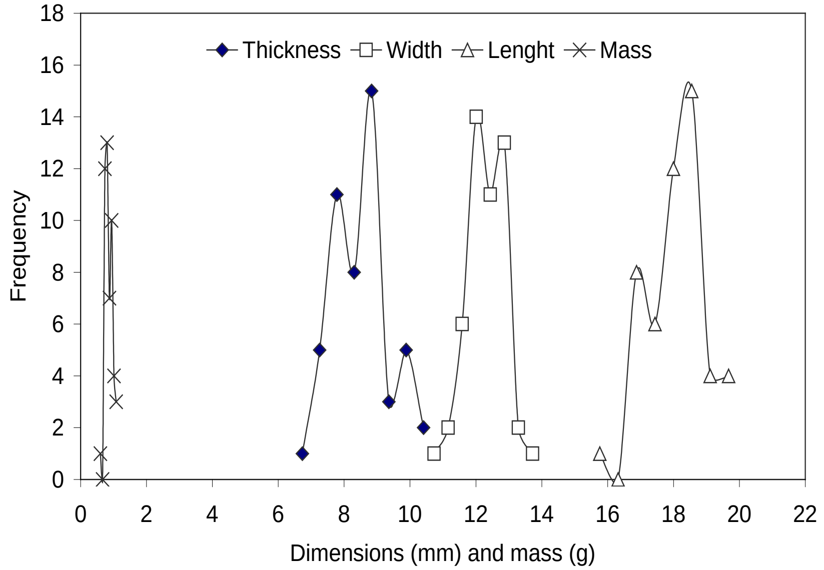

Figure 4. Frequency distribution of dimensions and mass of Ordubad apricot kernel.

Comparing dimensions and mass of Ordubad fruit, pit and kernel (Figs. 2-4) showed that mass of fruit is almost 18-times of mass of pit and mass of pit is almost 3.3-times of mass of kernel. Therefore, nearly 94% of mass of this apricot cultivar is related to texture of fruit and less than 2% of mass of this variety is related to kernel. The average of dimensions of fruit is 2-times of pit and 4-times of kernel. A part of these differences could be contributed to higher moisture content of the fruit texture.

The sphericity of fruit, pit and kernel of Ordubad cultivar were 94.4%, 67.4% and 67.85%, respectively (Table 1). The shape of fruit was nearly spherical and the shape of pit and kernel were nearly elliptical. The sphericity of Turkish apricot fruit cultivars was reported in the range of 87.6 to 99.1% by Hacıseferogullari *et al.* (2007). The sphericity of Hacıhaliloglu apricot pit was reported 65.37% by Gezer *et al.* (2002).

The average value of fruit surface area was found about 5.5-times of pit surface area and about 15-times of kernel surface area. These data showed that the rate of heat and mass transfer from kernel and pit are lower than that of fruit. The larger dimensions of the fruit are the reason of the higher values surface area of fruit than the pit and kernel. The surface areas of Turkish apricot fruit cultivars namely Hacihaliloglu, Hasanbey, Soganoglu and Kabaasi were 4098.97, 5351.69, 4071.39 and 4760.88 mm^2 (Haciseferogullari *et al.*, 2007). The average surface area of Ordubad fruit cultivar was in agreement with surface area of Hasanbey cultivar.

As the results, the projected area which was perpendicular to thickness (P_A) of fruit, pit and kernel was the greatest and that of perpendicular to length (P_B) was the smallest. The differences among the three projected areas in fruit were inconsiderable due to spherical shape of fruit. The difference between P_A and the other projected areas was considerable because of elliptical shape of the pit and kernel. The average of projected areas of the fruit was about 6-times of that of pit and the average of projected areas of pit was about 2.5-times of kernel, which were contributed to the dimensions of the fruit, pit and kernel.

The maximum and minimum values of bulk density were related to the kernel and pit, respectively (Table 1). Therefore, the required space per unit of mass for the kernel was less than that of the fruit and pit. These results would be useful in determining the size of packaging box. Calisir *et al.* (2004) reported that the bulk density of wild plum fruit is 515.12 kg/m^3, which was about the bulk density of Ordubad fruit. The true density of Ordubad fruit was a little higher than that of water and the true density of pit and kernel were a little lower than water. The porosity of the fruit (48.39%) and pit (47.3%) was nearly equal and the porosity of the kernel (41.04%) was lower than the fruit and pit which were indicated that ventilation of the fruit and pit was the same and ventilation of the kernel was lower than that of the fruit and pit.

The effect of the friction surface types on static coefficient of friction of the fruit, pit and kernel are shown in Fig. 5. The coefficient of friction of the fruit on the different surface types were nearly the same. The coefficient of friction of the kernel and fruit were the maximum and minimum values, respectively in all surfaces, which could be contributed to less surface roughness of kernel and fruit. Jannatizadeh *et al.* (2008) reported the coefficient of friction of fruits namely Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8 and Gheysi-2 cultivars on steel and galvanized steel sheets were in the range of 0.173 to 0.404 and 0.141 to 0.308, respectively.

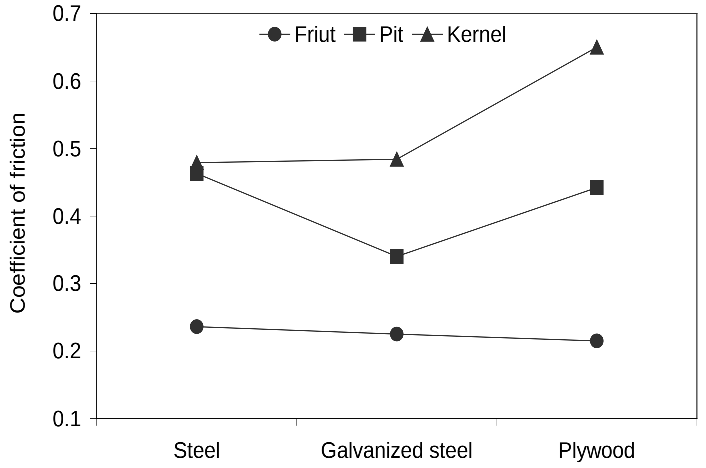

Figure 5. The effect of friction surface types on coefficient of friction of Ordubad apricot fruit, pit and kernel.

Figure 6 shows the effect of the surface types on rolling coefficient of the Ordubad fruit. The rolling coefficients of the fruit on steel and galvanized steel were the same and more than that of plywood. Comparing the Figs. 5 and 6 showed that the coefficient of friction and rolling coefficient of Ordubad fruit were nearly equal, which could be related to spherical shape of the fruit.

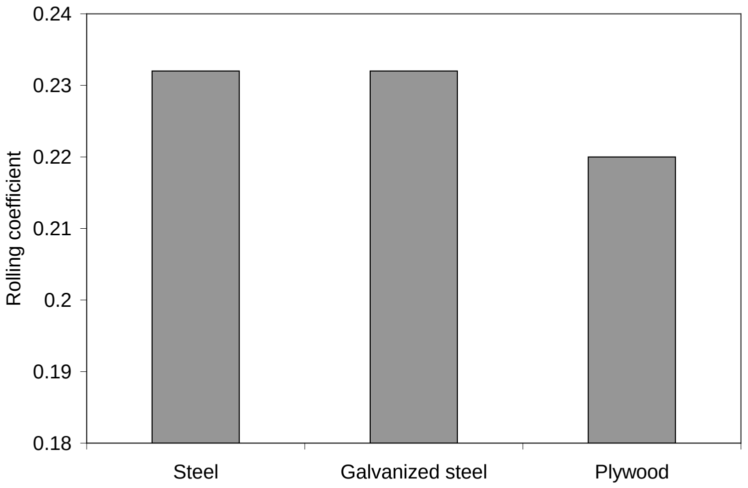

Figure 6. Effect on surface types on rolling coefficient of Ordubad apricot fruit.

The effect of loading position on hardness of the fruit is shown in Fig. 7. The minimum hardness of the fruit is at the middle part and the hardness at upper and lower parts are nearly the same. The average of rupture force of the fruit and kernel were 29.60 N and 135.28 N, respectively. The texture of the fruit was softer than the kernel which could be contributed to higher moisture content of fruit flesh and compositions of the fruit flesh and kernel. The modulus of elasticity of the fruit and pit were 2.10 MPa and 240.70 MPa, respectively. The reason of this difference could be due to the hardness of fiber and sclerenchyme of the pit. Haciseferogullari *et al.* (2007)

reported that the elasticity modulus of six Turkish varieties of apricot fruit are in the range of 2.44 to 4.64 MPa.

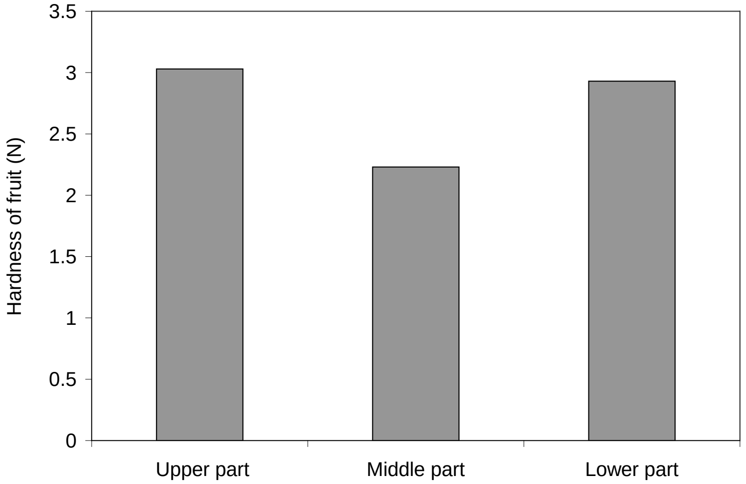

Figure 7. Hardness of Ordubad apricot fruit at upper, middle and lower parts.

Figure 8 shows the effect of moisture content and compression axis on force required to initiate pit rupture. The required force to initiate pit rupture along the X-axis decreased significantly from 847.70 to 324.49 N as the moisture content increased from 0.085 to 0.4 d.b because at higher moisture contents, the shell became soft and weak and this was responsible for the initial reduction in rupture force.

The rupture force along the Y–axis decreased significantly from 511.11 to 163.51 N with increase in moisture content from 0.085 to 0.3 d.b and later increased from 163.51 to 210.85 N with increase in moisture content from 0.3 to 0.4 d.b. The trend of rupture force along the Z-axis was similar to Y-axis i.e. the rupture force at first decreased significantly from 591.47 to 249.22 N with increase in moisture content from 0.085 to 0.3 d.b and then the rupture force increased from 249.22 to 339.54 N with increase in moisture content from 0.3 to 0.4 d.b. The reason of this phenomena could be related to the time that the apricot pit samples were compressed along the Y and Z axes and further absorption of water by the pit made kernel inside to swell up and fill the clearance between the kernel and the shell thereby became structurally turgid and this resulted in an increase in rupture force again. Similar trends were also observed by Aydın (2003) for almond nut, by Olaniyan and Oje (2002) for shea nut and Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit.

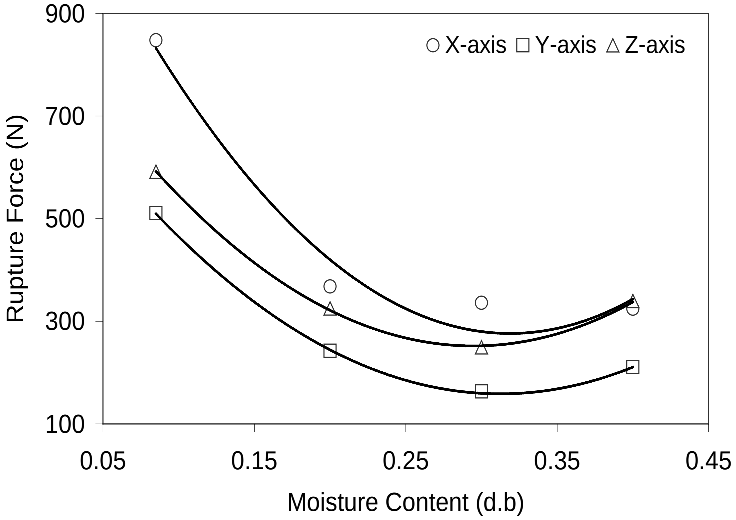

Figure 8. Effect of moisture content and compression axis on rupture force of the apricot pit.

Statistical analysis revealed that the effect of moisture content, compression axis and interaction of moisture content by compression axis on rupture force were significant ($P< 0.01$). There was not significant difference between the rupture forces along the Y and Z axes according to Duncan's multiple range test. Generally, the apricot pit need less compressive force to extract the kernel when loaded along the Y-axis compared to other two compression axes. Therefore, for designing cracking machines the axes should be taken into consideration. Similar results were reported by Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit.

Figure 9 shows the effect of moisture content and compression axis on deformation at rupture. The deformation along the X–axis decreased significantly from 4.19 to 2.68 mm with increase in moisture content from 0.085 to 0.3 d.b and later increased to 3.05 mm with increase in moisture content from 0.3 to 0.4 d.b. The trend of deformation along the Z-axis was similar to X-axis i.e. the deformation at first decreased significantly from 3.09 to 1.51 mm with increase in moisture content from 0.085 to 0.3 d.b and then the rupture force increased to 1.82 mm with increase of moisture from 0.3 to 0.4 d.b. The reason for this trend for compression along the X and Z axes is that at higher moisture content apricot pit behaves like a structurally turgid material because there is not enough clearance between the shell and the kernel. The similar trend for Z-axis was reported by Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit. However, the deformation along the Y-axis decreased significantly from 2.75 to 1.45 mm as the moisture content increased from 0.085 to 0.4 d.b. Generally, the deformation values for apricot pit compressed along the X-axis were always higher than for those compressed along the other two axes. This shows that the pit is more flexible and more resistant to rupturing along the X-axis compared to the other two axes. The trend of the results was in agreement with Vursavus and Ozguven (2004) and Ahmadi *et al.* (2008).

Statistical analysis revealed that the effect of moisture content and compression axis on deformation at rupture was significant ($P<0.01$) but the interaction of moisture content by compression axis on deformation at rupture was not significant. According to Duncan's multiple range test the difference between the deformations at rupture along the Y and Z axes was not significant. Similar results were reported by Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit.

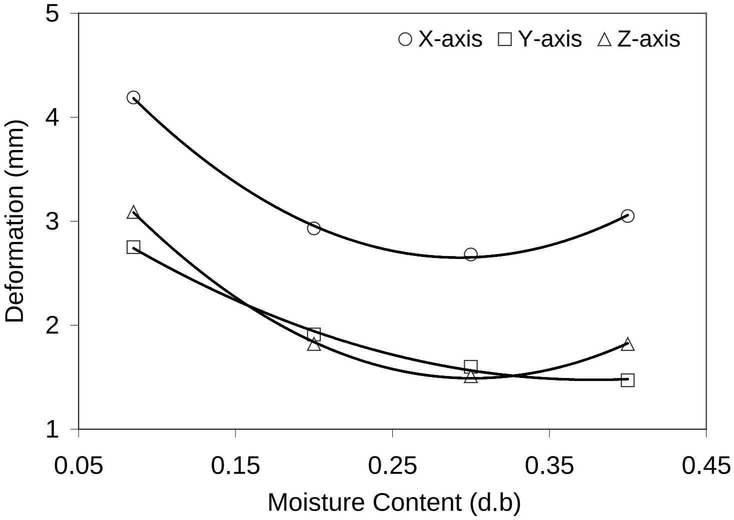

Figure 9. Effect of moisture content and compression axis on deformation of the apricot pit.

The effect of moisture content and compression axis on toughness at rupture is shown in Fig. 10. The deformation along the X–axis decreased significantly from 0.502 to 0.167 mJ/mm^3 with increase in moisture from 0.085 to 0.3 d.b and later increased to 0.209 mJ/mm^3 with increase in moisture content from 0.3 to 0.4 d.b. The reason for this trend of toughness could be attributed to the fact that rupture force of pit decreased progressively with increase of moisture content in the range of 085 to 0.3 d.b, further increase of moisture content to 0.4 d.b causes an increase in the rupture force. Furthermore, volume of the apricot pit increased with increasing of moisture content. Generally the toughness values for apricot pit along the X-axis required more energy for rupture than along the other two axes. The toughness along the Y-axis first decreased from 0.210 to 0.051 mJ/mm^3 and that of Z-axis decreased from 0.231 to 0.076 mJ/mm^3 with increase in moisture content from 0.085 to 0.3 d.b and then the toughness increased to 0.066 mJ/mm^3 and 0.135 mJ/mm^3, respectively with increase in moisture content from 0.3 to 0.4 d.b. The results of pit toughness in this study are in agreement with the findings of Olaniyan and Oje (2002) for shea nut, Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit and Ahmadi *et al.* (2008) for Tabarzeh apricot pit.

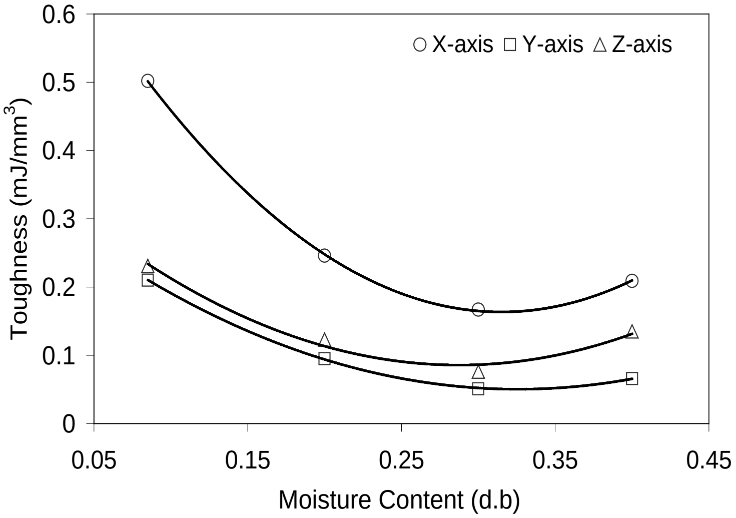

Figure 10. Effect of moisture content and compression axis on toughness of the apricot pit.

Statistical analysis showed that the effect of moisture content, compression axis and moisture by compression axis interaction on the toughness was statistically significant ($P<0.01$). There was no significant difference between the values of toughness along the Y and Z axes, according to Duncan’s multiple range test.

5. CONCLUSIONS

Some physical and mechanical properties of apricot fruit, pit and kernel of Ordubad cultivar were determined. The average values of length, width and thickness of the fruit were around 47, 45 and 41 mm, respectively which means that the Ordubad cultivar is nearly spherical with about 94% sphericity. The pit and kernel of this cultivar were nearly elliptical with sphericity of about 68%. The fruit consist of the major part of the mass and volume of this cultivar. The projected areas were maximum perpendicular to thickness and minimum to the length for fruit, pit and kernel. The maximum and minimum values of bulk density were related to the kernel and pit, respectively. The friction and rolling coefficient were nearly the same for fruit because of its sphericity. The rupture force, deformation and toughness decreased with increasing of moisture content below 0.3 d.b. The average values of rupture force, deformation and toughness of the apricot pit along the X-axis always were more than the two other axes. Therefore, the pit compression along Y or Z axes at 0.30 d.b moisture contents can be recommended for cracking operation with minimum force and energy requirements.

6. ACKNOWLEDGEMENTS

The authors would like to express their appreciation to University of Tehran for full support of the project.

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