Moisture dependent physical and mechanical properties of Syrjan region wild pistachio nut

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Abstract: the wild pistachio (Pistacia Atlantica Mutika) exists in 2.4 million ha of Iranian forest. In this way the pistachio of Syrjan was chosen as a case study. The objective of this study was to determine physical and mechanical properties of wild pistachio nut of Syrjan rejoin as a function of moisture content. The physical properties including thousand unit mass, length, width, height, arithmetic mean diameter, geometric mean diameter, surface area, true density, bulk density, porosity, repose angle (emptying and filling) and coefficient of friction were determined at four different levels of moisture content. The nut was compressed along the length and thickness at 0.045, 0.069, 0.089 and 0.188 (db) moisture contents to determine required force, deformation, and energy per volume (toughness) at rupture point. The nut average length, width, thickness were 7.31, 6.17, and 4.90 mm respectively at moisture content of 5.5 (%, wb). The greatest true density was 1081 kg cm^{-3}. With increase moisture from 4.84 to 13.65 (%, wb) the bulk density of nut decreased from 658.21 to 636.68 kg m^{-3}, porosity decreased from 37.52 to 32.86%, the emptying angle of repose increased from 32.04 to 34.6 degree, and the filling angle of repose increased from 29.95 to 31.59 degree. The greatest friction coefficient of the nut was obtained on galvanized iron surface and the minimum value on aluminum surface at all moisture content levels. At all levels of moisture content the rupture force, deformation at rupture point, and toughness of the nut were the minimum values along the nut thickness (Z-axis). The minimum values of the rupture force, deformation, and toughness were 175.16 N, 1.03 mm, and 0.49 mJ mm^{-3} respectively.

Keywords: Wild pistachio, nut, moisture content, Syrjan, physical properties, mechanical properties

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1 Introduction

Wild pistachio (Pistacia Atlantica Mutika) has various varieties that grow in altitudes, such as the Zagros Mountains of Iran. The vast of Iranian wild pistachio forests totaled about 2.4 million ha. Wild pistachio is one of the most economically important species for rural people in areas of natural forest. The resin of wild pistachio called Saqez, is used for a variety of industrial and traditional applications, including food and medicine (Pourreza et al., 2008). The wild pistachio fruit has an outer green layer, a wooden nut and a kernel (Figure 1). The fruit of wild pistachio is smaller and not as commercially valuable as those produced in orchards. The wild pistachio nuts are variable in size and color. It may be bright brown, turquoise, or green in color. Wild pistachio kernel is a good source of food and fat (50-60%) and contains unsaturated fatty acids (linoleic, linolenic and oleic acids). The oil extracted from kernel is used for colors, pesticides, glues, essences, papers, mineral oils, and other industrial applications (Nazari-Galedar et al., 2010; Heidarbeigi et al., 2009).

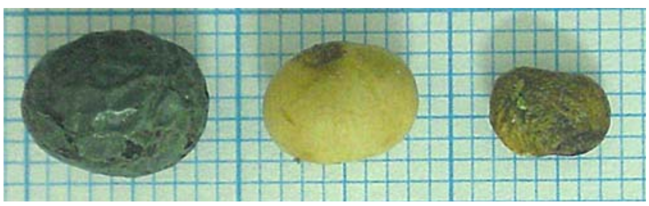

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Figure 1 (a) Wild pistachio fruit with green outer layer, (b) wild pistachio nut, and (c) wild pistachio kernel

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The physical and mechanical properties of agricultural products will be useful parameters in the design of handling and processing equipment. Size and shape of nuts are important for designing the related handling, separating, and sorting machinery, and can be used to determine the lower size limits of conveyors. Porosity affects the resistance to air flow through the bulk material bed and is also necessary factor in the drying process. Bulk density is used in determining the size of the storage bin and true density is necessary parameter in the design of a pneumatic conveyor system. The static friction coefficient on various surfaces affects the maximum inclination angle of conveyor and storage bin. The magnitude of frictional force affects the amount of power required to convey the materials. Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage. Moisture content is useful information in the drying process. Mechanical properties such as rupture force, and energy per volume (toughness) are useful information in designing nut shelling machine. The deformation at rupture point can be used for determining the gap size between the surfaces to compress the fruit or nut for dehulling or shelling (Henderson and Perry, 1976; Mohsenin, 1986; Sirisomboon et al., 2007; Pradhan et al., 2010).

The physical and mechanical properties have been determined by other researchers for many of agricultural products such as hazelnut and almond nut and its kernel (Aydin, 2002 and 2003), Hacıhaliloglu apricot pit and its kernel (Gezer et al., 2002), Ordubad apricot fruit, pit and kernel (Hassan-Beygi et al., 2009), different varieties of pistachio nut and kernel (Kashaninejad et al., 2006; Razavi et al., 2007a,b,c), wild pistachio nut and kernel (Nazari-Galedar et al., 2010, Razavi et al., 2008). The literature survey showed that there is limited published data concerning physical and mechanical properties of Syrjan wild pistachio nut. The aim of this study was to investigate some physical and mechanical properties of wild pistachio nut as a function of moisture content. The parameters investigated include 1000-unit mass, fruit part fraction, dimensions, geometric mean diameter, sphericity, bulk density, true density, porosity, static friction coefficient on various surfaces, angle of repose (empty and filling), rupture force, deformation at rupture point, and energy used for rupture.

2 Materials and methods

Forty five kilograms of the dried wild pistachio fruit were obtained from a local market in Syrjan, a city of Kerman province in the south east of Iran in 2010. The fruits were peeled and cleaned manually to remove all the foreign materials. The moisture content of samples was determined by air convection oven drying at 130±3℃ for six hours according to ASAE standard (ASAE S 410.1, 2003).

The nuts were divided into four portions labeled A, B, C, and D. The sample A was left at the market stable storage moisture content (about 5%, wb), while B, C and D were soaked in clean water at room temperature for different minutes in order to obtain nuts at different moisture levels (totally four levels). After soaking, the nuts were air dried to eliminate the free water from the sample surface (Oluwole et al., 2007). The sample was packed in sealed polyethylene bags and kept in a refrigerator for 24 h to enable the moisture to distribute uniformly throughout the samples. The moisture content of each sample was determined using air convection oven drying 130±3℃ for 6 h (ASAE S410.1, 2003). The average values of three replications were reported as moisture content for each sample (dry basis for mechanical and wet basis for physical properties). The samples with different moisture content were stored in refrigerator until the test. Before starting each test, the required quantities of sample were allowed to warm up to room temperature.

The three major perpendicular dimensions of each of the sample nuts were measured by using a digital caliper with an accuracy of 0.01 mm (Figure 2). The mass of the each sample nut was measured by a digital balance (AND-GF-600, Japan) with an accuracy of ±0.001 g. The dimensions and mass of 30 nuts were determined for each moisture content levels.

Arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (ϕ) and surface area (S) values were found using the following formula (Equation (1), Equation (2), Equation (3), and Equation (4)) (Mohsenin, 1986):

$$D_a = \frac{L+W+T}{3} \quad (1)$$

$$D_g = \left(LWT\right)^{1/3} \quad (2)$$

$$\phi = \frac{D_g}{L} \quad (3)$$

$$S = 2\pi(\frac{W}{2})^2 + 2\pi\left(\frac{LW}{4e}\right)Arc\sin(e) \quad (4)$$

where, $e=(1-(W/L)^2)^{1/2}$, L is the sample length (mm); W is the sample width (mm) and T is the sample thickness (mm).

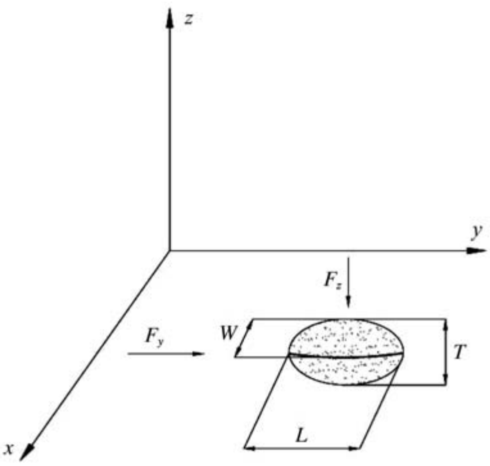

Figure 2 The three axes and three perpendicular dimensions of pistachio nut

The fraction by weight of nut shell in a fruit is the ratio of the mass of shell part to the mass of nut. The 100-unit mass was measured and 1,000-unit mass was calculated by multiplying the 100-unit mass by 10.

The bulk material of nuts was put into a container with known mass and volume (679 cm^3). The bulk density (ρ_b) is equal to mass of bulk material divided by volume containing the mass. The bulk density was determined for the nuts with different moisture content. The true density (ρ_s) is defined as the mass of individual sample (M_s) divided by the volume of the sample (V_s). The volume of the individual sample was determined by weighing displacement volume of toluene (Equation (5) and Equation (6)) (Mohsenin, 1986).

$$V_s = \frac{M_{TD}}{\rho_T} = \frac{(M_T - M_P)-(M_{PTS} - M_{PS})}{\rho_T} \quad (5)$$

$$\rho_s = \frac{M_s}{V_s} \quad (6)$$

where, M_{TD} is the mass of displacement volume of toluene (kg); ρ_T is the density of toluene (870 kg m^{-3}); M_T is the mass of filled pycnometer with toluene (kg); M_P is the mass of pycnometer (g); M_{PTS} is the mass of pycnometer with toluene and a nut in (g); and M_{PS} is the mass of pycnometer and nut (kg).

Specific surface area (S_s) (cm^2 cm^{-3}) of nut was calculated as Equation (7):

$$S_S = \frac{S \times \rho_b}{m} \quad (7)$$

where, m is mass (g) of one unit of nut.

Porosity in % is the parameter indicating the amount of pores in the bulk material. It is calculated from the following Equation (8):

$$\varepsilon = \left[1 - \frac{\rho_s}{\rho_b}\right] \times 100 \quad (8)$$

The coefficients of static friction of the wild pistachio nuts were determined by using inclined plane method on surfaces of aluminum, galvanized, and colored iron. A topless and bottomless cylinder of 100 mm diameter and 50 mm height was filled with the samples. The cylinder was raised slightly so as not to touch the surfaces. The structural surface with the cylinder resting on it was inclined gradually with a screw device until the cylinder just started to slide down over the surface and the angle of tilt at this juncture, the angle of tilt, in degree was read from a protractor. The coefficient of static friction, μ_s, was calculated from the following Equation (9) (Mohsenin, 1986).

$$\mu_s = \tan(\alpha) \quad (9)$$

The filling and emptying angle of repose of the wild pistachio nuts were measured. The device used in this study consists of two boxes, upper and down box, of dimensions 700 mm length, 400 mm height, and 70 mm width (Figure 3). The upper box was filled with the sample nut. The material of upper box can flow to down through a removable square port, the filling or static angle of repose is the angle of surface with the horizontal at which the nuts will stand when piled on the ground. The emptying or dynamic angle of repose is the angle of surface of residual with horizontal in the upper box.

The height of the nut was measured and the filling angle of repose (θ_F) and emptying angle of repose (θ_E) were calculated by the following relationships (Equation (10) and Equation (11)) (Sirisomboon et al., 2007):

$$\theta_E = \tan^{-1}\frac{H}{A} \tag{10}$$

$$\theta_F = \tan^{-1}\frac{h}{a} \tag{11}$$

where, H and h are the height (mm); and A and a (mm) are horizontal distance.

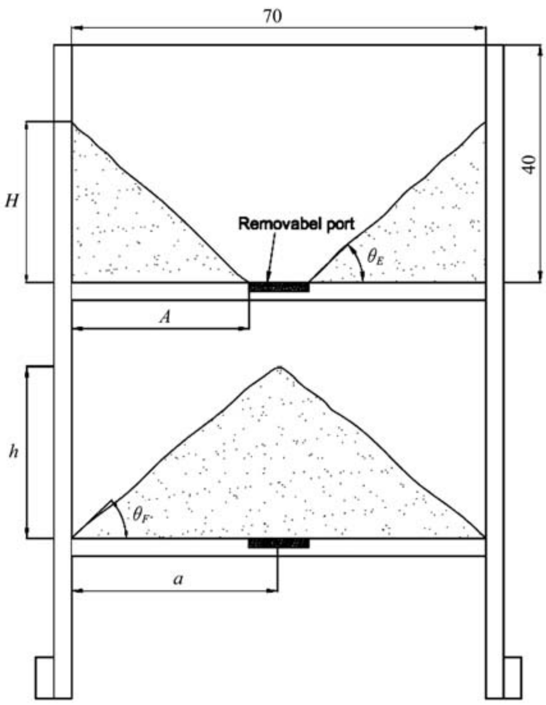

Figure 3 Emptying and filling repose angle

The mechanical properties of the wild pistachio nut were determined using a biological material test (BMT) device which was developed by Ghaebi et al. (2008). This device has three main components, which are a stable forced platform and a moving crosshead, 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).

The rupture force, deformation, and toughness of the pistachio nut were determined at different moisture content levels (0.045, 0.069, 0.089 and 0.188 db) and direction of compression loadings (along with length, Y, and thickness, Z). The pistachio nut was placed on the fixed platform of the BMT device and pressed with a plate fixed on the load cell at 6 mm min^{-1} speed until the nut ruptured. It was assumed that rupture occurred at the bio-yield point that was the point in the force–deformation curve where there was a sudden decrease in force. As soon as the bio-yield point was detected, the compression was stopped. Energy absorbed (E_a) by the sample at rupture was determined by calculating the area under the force–deformation curve from the following Equation (12) (Hassan-Beygi et al., 2009; Gupta and Das, 2000; Mohsenin, 1986).

$$E_a = \frac{F_r \times D_r}{2} \tag{12}$$

where, F_r is the rupture force (N) and D_r is the deformation at rupture point (mm).

Toughness (P) is the specific energy of nut absorbed by the pistachio up to rupture point (mJ mm^{-3}). This was calculated using the following Equation (13) (Hassan-Beygi et al., 2009; Olaniyan and Oje, 2002).

$$P = \frac{E_a}{V} \tag{13}$$

where, E_a is the energy absorbed by the pistachio nut (mJ) and V is the volume of the nut (mm^3), which can be estimated from following Equation (14) (Vursavus and Ozguven, 2004).

$$V = \frac{\pi L}{16}(W+T)^2 \tag{14}$$

where, L is the length (mm); W is the width (mm) and T is the thickness of nut (mm).

Spreadsheet softwares of Microsoft EXCEL 2003 and SAS were used to analyze the data. The data was statistically analyzed using the two factors completely randomized design to study the effects of four moisture contents and two compression axes on the rupture force, deformation and toughness of pistachio nut under the applied load. Further, Duncan's multiple range tests was used to compare the means. Each experiment was replicated 15 times making a total of 120 pistachio nuts that were individually measured and tested.

3 Results and discussion

Variations of the physical properties of the nut were determined in this study including length, width, thickness, arithmetic mean diameter, geometric mean diameter, unit mass, sphericity, surface area, specific surface area and shell fraction with moisture content are given in Table 1. The length, width, and thickness of the samples were increased linearly with moisture content in the ranges of 7.31 to 7.94 mm, 6.17 to 6.45 mm and 4.90 to 5.19 mm, respectively (Table 1). It is observed that the length of the nuts increased about 8% with moisture content while the width and thickness of nuts were increased only about 5%. The increasing trend in axial dimensions of the nuts with moisture content was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling. This indicates that during the moisture desorption process (such as drying), the wild pistachio nuts will show some decrease in dimensions.

Table 1 Physical properties of the pistachio nut at different moisture content

Moisture content/% wb	Axial dimensions /mm			Average diameters /mm		Unit mass /g	Sphericity (decimal)	Surface area/mm^2	Specific surface area /cm^2 cm^{-3}	Shell fraction /%
	Length, L	Width, W	Thickness, T	Arithmetic mean, D_a	Geometric mean, D_g					
5.5	7.31±0.65	6.17±0.72	4.90±0.53	6.13±0.53	6.04±0.52	0.12±0.03	0.83±0.03	135.84± 6.01	7.35±0.88	0.65±0.04
10.56	7.60±0.81	6.41±0.68	5.03±0.53	6.35±0.56	6.25±0.55	0.13±0.03	0.84±0.03	146.42±26.53	7.48±0.90	0.67±0.04
11.18	7.76±0.88	6.59±0.80	5.03±0.55	6.46±0.65	6.35±0.63	0.14±0.04	0.82±0.04	154.43±35.05	7.28±0.89	0.67±0.04
14.14	7.94±0.77	6.45±0.76	5.19±0.42	6.53±0.49	6.42±0.46	0.14±0.03	0.81±0.04	152.47±30.12	6.93±0.99	0.64±0.09

Note: Data are mean values ± standard deviation.

The average values of arithmetic and geometric diameters were also linearly increased from 6.13 to 6.53 mm and 6.04 to 6.42 mm, respectively with moisture content increasing in the range of 5.5 to 14.14% (wb). Geometric and arithmetic mean diameters of the wild pistachio nut were smaller than values reported for different varieties of pistachio nut (Kashaninejad et al., 2006; Razavi, 2007a), Jatropha nut (Pradhan et al., 2009), filbert nut (Pliestic et al., 2006) and raw cashew nut (Ogunsina and Bamgboye, 2007).

The product shape can be determined in terms of its sphericity, which affects the flow ability characteristics. The average values of the nut sphericity were ranged from 0.81 to 0.84 for different levels of moisture content (Table 1). Razavi et al. (2008) research work showed that the mean values of wild pistachio sphericity was 0.85 which was close to the results of this investigation.

The surface area, S, of the nuts was calculated by using Equation (4) and given in Table 1. The surface area of the pistachio nuts increased from 135.84 to 154.43 mm^2, when the moisture content increased from 5.50% to 14.14 (%, wb). The increasing trend of the nut surface area with moisture content might be contributed to increasing the dimensions of the nut with increasing of moisture content.

3.1 Thousand unit mass

The mass of 1,000 nut, M_{1000}, increased from 119.4 to 134.6 g as the moisture content, M_C, increases from 4.84% to 13.65 (%, wb) (Figure 4). Similar trends have been reported for other agricultural products (Pradhan et al., 2009; Garnayak et al., 2008).

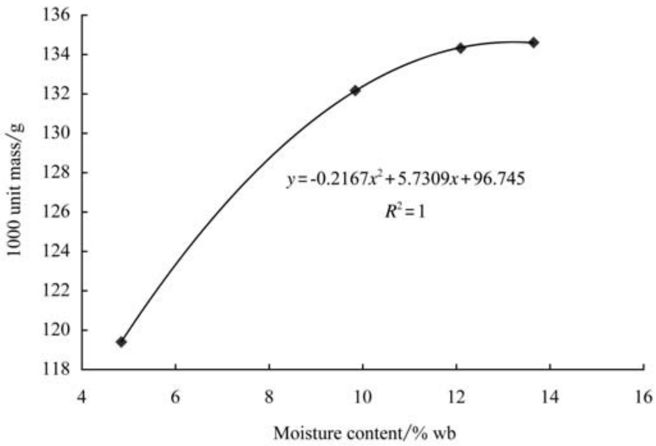

Figure 4 Variation of the 1000 unit mass of the wild pistachio nut with moisture content

3.2 Bulk density

The nut bulk density was decreased from 658 to 636 kg m^{-3} with increasing moisture content as shown in Figure 5. This is due to the fact that mass increased owing to moisture gain in the nut sample, subsequently decreasing the bulk density. The negative linear relationship of bulk density with moisture content is also observed by other researchers (Pradhan et al., 2009; Rezaiefar et al., 2008).

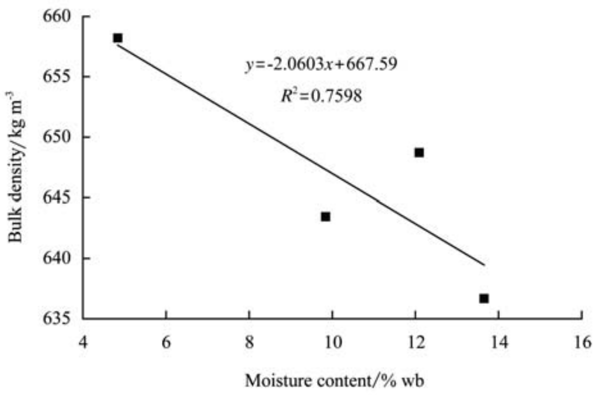

Figure 5 Variation of the bulk density of nut with moisture content

3.3 True density

The true density of the nut was decreased non-linearly from 1081 to 954 kg m^{-3} when moisture content increased in the range of 4.84 to 13.65 (%, wb) (Figure 6). The decreasing trend of the true density with increase in moisture content might be attributed to the relatively higher true volume as compared to the corresponding mass of the fruit attained due to the adsorption of water. The results were in conformity with work reported by Dutta et al. (1988) for gram and by Deshpande et al. (1993) for soybean. The true density of the nuts is greater than the density of water (1000 kg m^{-3}) in the moisture content range of 4.84 to 12.2 (%, wb), therefore the deaf nuts can be separated by sedimentation of nuts in water.

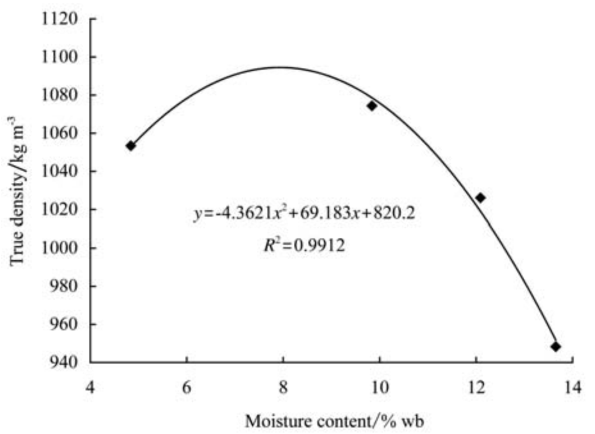

Figure 6 Effect of moisture content on the nut bulk density

3.4 Porosity

Porosity was evaluated using the bulk density and true density by Equation (8). The variation of the wild nut porosity was dependent on moisture content as was shown in Figure 7. The porosity was found to vary from 40.10% to 32.86% in the specified moisture levels. The porosity value is often needed in air flow and heat flow studies. As was depicted from this figure with increasing moisture content from 5% to about 8%, resistance to air flow was reduced and then the air flow resistance was increased with increasing the nut moisture content.

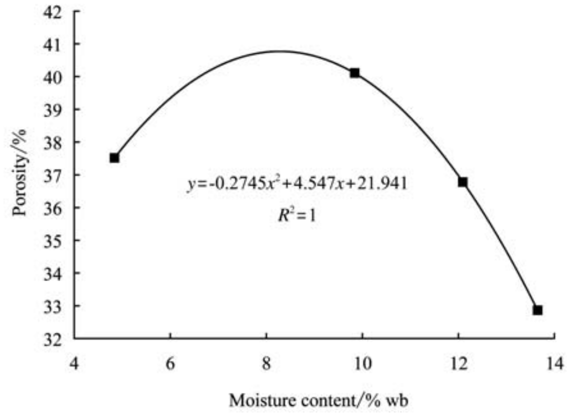

Figure 7 Effect of moisture content on the nut porosity

3.5 Angle of repose

The experimental results for the angle of repose with respect to moisture content are shown in Figure 8. The values are found to increase from 29.4 to 31.6 degree, and 32.0 to 34.6 degree for filling and emptying repose of angle in the moisture range of 4.84 - 13.65 (%, wb), respectively. These values implied the lowest flow ability of the nuts compared to the dried nuts. The variation of angle of repose with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of nuts together by the

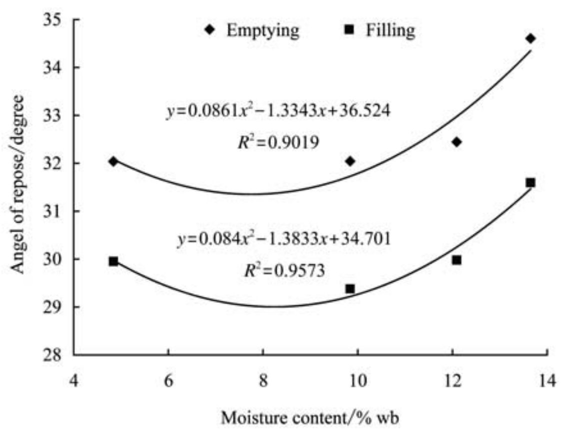

Figure 8 Effect of moisture content on the nut angle of repose (emptying and filling)

surface tension. Furthermore, the viscous surface of nut with higher moisture content lead to the greater cohesion among the nuts and therefore the angle of repose might be increased with moisture content. The angle of repose obtained from emptying method was greater than that of filling method because adhesion between container wall and the nut affected the value of angle of repose.

3.6 Friction

Variations of the wild pistachio nut coefficient of friction with moisture content for different surfaces were shown in Figure 9. As was depicted from this picture, the static coefficient of friction of nuts on aluminum, galvanized iron and colored iron sheets were increased with moisture content in the range of 0.24 to 0.33, 0.35 to 0.49 and 0.32 to 0.48, respectively. The increasing trend of friction coefficient with moisture might be contributed to increase in adhesive force and decrease of sphericity that made it difficult to move on any surfaces (Table 1). However, the coefficient of friction of the nuts was the minimum at about 10% moisture content on all the surfaces, which might be related to surface conditions of the nuts at this moisture content. Other researchers have found similar trend for increasing static coefficient of friction with moisture content (Gezer et al., 2002; Gupta and Das, 2000; Razavi et al., 2007c). The static coefficient of friction of nuts on the galvanized iron was greater than that of other surfaces due to more adhesiveness of this surface.

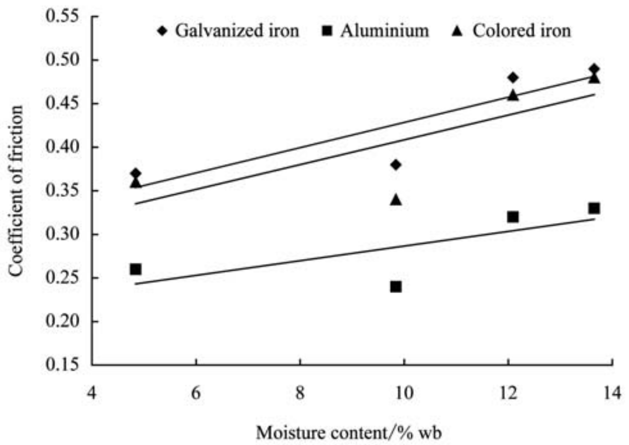

Figure 9 Effect of moisture content on the nut coefficient of friction for different surfaces

3.7 Rupture force

Statistical analysis (ANOVA) revealed that the effects of moisture content, compression axis and the interaction of moisture content by compression axis were significant ($P<0.01$) on the wild pistachio nut rupture force. Similar results were reported by Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit and Hassan-Beygi et al. (2009) for Ordubad apricot pit and Ghaebi et al. (2010) for Ghermez-Shahrood apricot pit. The effect of moisture content and compression axis on the nut rupture force is shown in Figure 10. The required force to initiate nut rupture along the length (Y-axis) decreased significantly from 370.46 to 222.15 N as the moisture content increased from 0.045 to 0.188 (db) because at higher moisture contents, the shell became soft and weak, and this was responsible for the reduction of rupture force. The required force to initiate nut rupture along the width (Z-axis) was not significantly variation with the moisture content. As was shown in Figure 10, the nut rupture force was greater significantly ($P<0.01$) along Y-axis than Z-axis for all of the moisture content levels except for 0.188 (db) moisture level. The nut shell is essentially fragile and strength to compressive stress which existed in Y direction. Generally, the wild pistachio nut need less compressive force to extract the kernel when loaded along the Z-axis compared to other compression axis which should be considered in the design of cracking machine. Similar results were reported by Vursavus and Ozguven (2004) for Hacıhaliloglu apricot pit, Hassan-Beygi et al. (2009) for Ordubad apricot pit and Ghaebi et al. (2010) for Ghermez-Shahrood apricot pit.

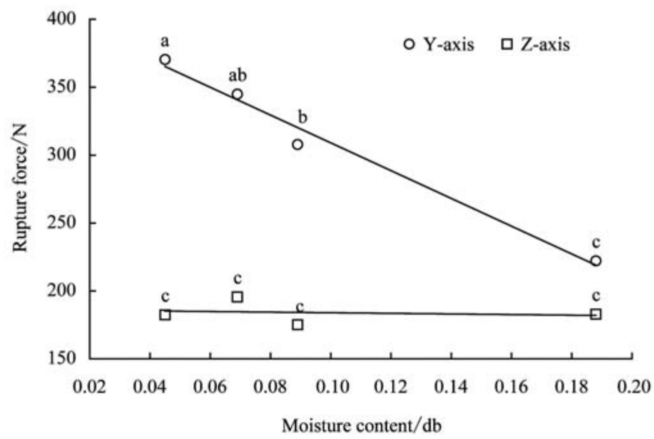

Figure 10 Effect of moisture content and compression axis on the nut rupture force

3.8 Deformation at rupture

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. Similar results were reported by others (Vursavus and Ozguven, 2004; Hassan-Beygi et al., 2009; Ghaebi et al., 2010). Figure 11 shows the effect of moisture content and compression axis on deformation at rupture. The deformation variations were not significant along the length of nut (Y–axis) with increase in moisture content from 0.045 to 0.188 (db). The trend of deformation along the thickness of the nut (Z-axis) was similar to Y-axis. Generally, the deformation values for the nut compressed along the Y-axis were always higher than for that compressed along the other axis. This showed that the nut was more flexible and more resistant to rupturing along the Y-axis compared to Z-axis. The trend of the results was in agreement with Vursavus and Ozguven (2004) and Hassan-Beygi et al. (2009).

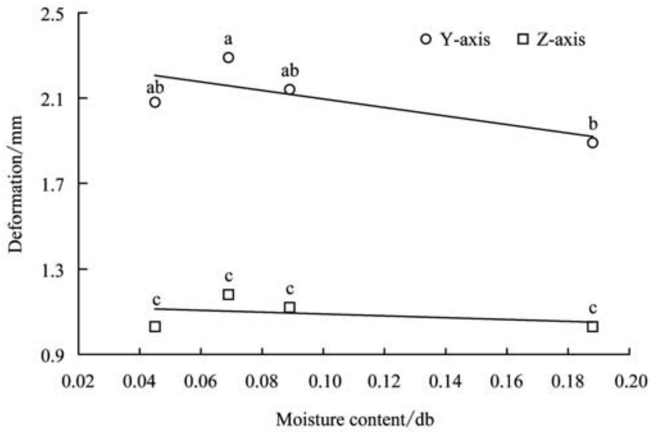

Figure 11 Effect of moisture content and compression axis on deformation of the nut

3.9 Toughness

Statistical analysis showed that the effects of moisture content, compression axis and the interaction of moisture content by compression axis were significant on the wild pistachio nut toughness (P<0.01). The effect of moisture content and compression axis on the nut toughness at rupture is shown in Figure 12. According to Duncan's multiple range test the toughness of nut along the length (Y–axis) decreased significantly from 2.27 to 1.13 mJ mm^{-3} with increase in moisture from 0.045 to 0.188 (db). The reason for this trend of toughness could be attributed to the facts that rupture force of the nut decreased with increase of moisture content. The toughness variations were not significant along the thickness of nut (Z–axis) with increase in moisture content from 0.045 to 0.188 (db). However, the toughness values for the nut compressed along the Y-axis were significantly greater than for that compressed along the other axis (P<0.01). This showed that the nut required more energy for rupture along the Y-axis compared to Z-axis. The results of nut toughness in this study are in agreement with the findings of Olaniyan and Oje (2002) for shea nut, Hassan-Beygi et al. (2009) for Ordubad apricot pit and Ghaebi et al. (2010) for Ghermez-Shahrood apricot pit.

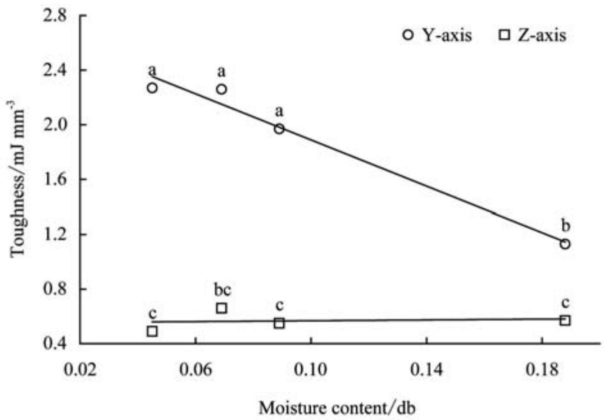

Figure 12 Effect of moisture content and compression axis on the nut toughness

4 Conclusions

Some physical and mechanical properties of wild pistachio nut of Syrjan region were determined as function of moisture content. The average values of length, width and thickness of the nut were ranged from 7.31-7.94 mm, 6.17-6.45 mm and 4.90-5.19 mm respectively, which means that the nut was elliptical shape with about 82% sphericity. The nut bulk density, true density and porosity had decreasing trend with moisture content. The nut emptying and filling angle of repose were increased with moisture content non-linearly. The nut coefficient of friction was increased with moisture content on all the studied surfaces. The rupture force, deformation and toughness decreased with increasing of moisture content along the nut length

(Y-axis). The average values of rupture force, deformation and toughness of the nut along the Y-axis always were more than the Z-axis. Therefore, the nut compression along Z-axis can be recommended for cracking operation with minimum force and energy requirements.

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