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Some physical properties of wild pistachio (*Pistacia vera* L.) nut and kernel as a function of moisture content

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A b s t r a c t. In order to design equipment for improved processing of wild pistachio (*Pistacia vera* L.), some of the engineering properties were determined as a function of moisture content. The average length, width and thickness of wild pistachio nuts at 5.83% moisture content (w.b.) were 13.98, 8.76 and 7.25 mm, while the corresponding values of kernels at 6.03% moisture content (w.b.) were 11.07, 5.92 and 4.83 mm, respectively. The bulk and true densities of wild pistachio nut and kernel increased with increase in moisture content, while porosity decreased. At all moisture contents, the static coefficient of friction was the highest for wild pistachio nut and kernel on rubber and the least for glass. The results of this research indicated that the filling and emptying angle of repose of nuts and kernels increased as the moisture content increased in the range studied.

K e y w o r d s: wild pistachio, nut, kernel, physical properties

INTRODUCTION

Pistachio nut is one of the popular tree nuts. Wild pistachio kernels are a good source of fat (50-60%) and contain unsaturated fatty acids (linoleic, linolenic and oleic acids), essential for human diet (Maskan and Karatas, 1998; Shokraii, 1977). It is consumed in confectionery. Because of the deep green colour of wild pistachio kernels, it is favoured in the ice cream and pastry industries (Woodroof, 1979).

In order to design equipment for harvesting, handling, cleaning, separating, packing, storing, and processing of agricultural products, their physical properties need to be known (Mohsenin, 1980). Aviara *et al*. (1999) noted that the moisture-dependent characteristics of the physical properties of agricultural products have an effect on the adjustment and performance of processing machines. A range of moisture content usually exists, within which optimum performance is achieved. Therefore, the effect of moisture content on the physical properties of wild pistachio nuts and kernels is of importance in the design of handling and processing equipment. The major moisture-dependent physical properties of biological materials are shape, size (dimensions), mean diameters, surface area, sphericity, mass, true density, bulk density, porosity, angle of repose and static friction coefficient against various surfaces (Mohsenin, 1980). Size, shape and physical dimensions of wild pistachio nut and kernel are important in sizing, sorting, sieving and other separation processes. Bulk density determines the capacity of storage and transport systems, while true density is useful for separation equipment; porosity of the mass of seeds determines the resistance to airflow during aeration and drying of nuts and kernels (Vilche, 2003). Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage. Frictional forces affect the amount of power required to convey the material. Static friction between wild pistachio nut and conveyor belt affects the maximum angle with the horizontal which the conveyor can assume when transporting wild pistachio nuts.

Physical properties of numerous nuts and grains have been determined by other researchers. Some of them determined physical properties of different nuts, such as gorgon nut (Jha and Prasad, 1993), neem nut (Visvanathan *et al*., 1996), cashew nut (Balasubramanian, 2001), bambara groundnut (Baryeh, 2001) and arecanut (Kaleemullah and Gunasekar, 2002). Several researchers determined mechanical properties of nuts, such as macadamia nut (Braga *et al*., 1999), shea nut (Olaniyan and Oje, 2002), wheat (Tabatabaeefar, 2003) and walnut (Koyuncu *et al*., 2004).

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However, literature review showed that there is not enough published work on the geometric, gravimetric, frictional properties and mechanical behaviour under compression loading of wild pistachio nut and its kernel relating to moisture content. Hsu *et al.* (1991) studied the physical and thermal properties of Kerman cultivar of pistachio nut. They investigated some of the moisture-dependent gravimetric properties (bulk density and specific gravity) of this variety. Kashaninejad *et al*. (2005) also investigated some moisture-dependent physical properties of dried pistachio nut and its kernel for O'hadi variety. Razavi *et al*. (2007a, b, c) studied the geometric, gravimetric and frictional properties of five Iranian commercial varieties of pistachio nut and its kernel (namely, Akbari, Badami, Kalle-Ghuchi, Momtaz and O'hadi). Therefore, the objective of this study was to determine the geometric properties (length, width, thickness, geometric and arithmetic mean diameter, sphericity and surface area), gravimetric properties (including unit mass, true volume, bulk density, true density, and porosity), frictional properties (angle of repose and static coefficient of friction) and aerodynamic properties (terminal velocity) of wild pistachio nut and its kernel as a function of moisture content. These will be useful parameters in designing handling and processing equipment. The range of moisture content was selected from 5.83 to 31.15% w.b. and 6.03 to 30.73% w.b. for wild pistachio nut and kernel respectively, since all processing operations and storage are performed in this moisture range.

MATERIALS AND METHODS

Sample preparation and moisture content determination

The wild pistachio nuts used in this study were collected in the 2007 season from wild pistachio forests of Khajeh-Kalat, located 140 km northeast from the Mashhad township, capital of Khorasan-Razavi province (base on longitude 54°35'–54°49' and latitude 36°54' - 36°64'). The samples were manually cleaned to remove foreign matter and broken and immature nuts. A photograph of wild pistachio nuts in shell and kernels is shown in Fig. 1. The initial moisture content of wild pistachio was determined using the oven method at 103 ± 2°C until a constant weight was reached (Kashaninejad *et al*., 2005). Initial moisture content of nut and kernel was found to be 5.83 and 6.03% w.b., respectively. To obtain higher moisture contents than initial, the samples were prepared by adding a pre-determined quantity of distilled water and sealing in separate polyethylene bags. The samples were kept at 5°C in a refrigerator for one week to enable the moisture to distribute uniformly. Before starting the experiment, the samples were taken out of the refrigerator and allowed to warm up to room temperature for 2 h.

Geometric properties

To determine the average size of the nut and kernel, a sample of 100 nuts was randomly picked and their three major dimensions, namely length, width and thickness (as shown in Fig. 1), were measured using a digital caliper having a resolution of 0.01 mm. The average diameter of these was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter, D_a , and geometric mean diameter, D_g , of the nut and kernel were calculated by using the following relationships (Aydin, 2003; Mohsenin, 1980; Olajide and Igbeka, 2003):

$$D_a = (L+W+T)/3, \quad (1)$$

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

where: D_a – arithmetic mean diameter (mm), D_g – geometric mean diameter (mm), L – length (mm), W – width (mm), T – thickness (mm).

The sphericity, ϕ (%), was calculated by using the following relationship (Mohsenin, 1980):

$$\phi = \frac{(LWT)^{1/3}}{L}. \quad (3)$$

Fig. 1. Wild pistachio nuts (a), wild pistachio kernels (b), and (c) characteristic dimensions of wild pistachio nut and kernel and compression directions; L_n, W_n, T_n are the length, width and thickness of the nut; L_k, W_k, T_k are the equivalent dimensions of the kernel; F_L, F_W, F_T are the forces applied in three directions.

The surface area of wild pistachio and its kernel was found by analogy with a sphere of the same geometric mean diameter. In obtaining the surface area, S (mm^2), of the samples, the equation given by McCabe *et al.* (1986) was used as:

$$S = \pi D_g^2. \tag{4}$$

Gravimetric properties

To obtain the unit mass, each sample was weighed by a precision electronic balance reading to an accuracy of 0.01 g. The true volume, V (cm^3), as a function of moisture content and variety, was determined using the liquid displacement method (Pliestic *et al.*, 2006). Toluene (C_7H_8) was used instead of water because it is absorbed by wild pistachio to a lesser extent. In addition, its surface tension is low, so that it fills even shallow dips in a wild pistachio and its dissolution power is low (Mohsenin, 1980). True density, ρ_t (kg m^{-3}), of samples was also calculated by dividing the unit mass of each sample by its true volume at different moisture content.

In order to determine the bulk density at a given moisture content, a cylindrical container of 0.3 m height and 0.2 m diameter was filled with wild pistachio nut or kernel from a height of 0.15 m from the top surface of the container and the top was levelled. No separate or additional manual compaction was done. The electronic balance was used for weighing, and bulk density, ρ_b (kg m^{-3}), of samples was then defined as the ratio of the mass of bulk sample to the volume of the container. Several researchers, including Baryeh (2002), Deshpande *et al.* (1993), Jain and Bal (1997), Kashaninejad *et al.* (2005), Sharma *et al.* (1985), Suthar and Das (1996) have employed this method for other grains and seeds. According to Mohsenin (1980), the porosity, ε (%), can be expressed as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)100. \tag{5}$$

This equation was used to calculate the porosity of wild pistachio nut and its kernel in this research, as a function of moisture content.

Frictional properties

The static coefficient of friction of wild pistachio nut and its kernel at four moisture content levels was measured for five frictional surfaces, namely glass, fibreglass, rubber, plywood, and galvanized iron sheets. A fibreglass topless and bottomless box of 0.15 m length, 0.1 m width, and 0.04 m height was placed on an adjustable inclined plane, faced with the test surface and filled with the sample. The box was raised slightly (5-10 mm), so as not to touch the surface. The structural surface with the box resting on it was inclined gradually with a screw device until the box just started to slide down over the surface and the angle of tilt (α) was read from a graduated scale. The static coefficient of friction (μ_s) was then calculated from the following equation (Mohsenin, 1980):

$$\mu_s = \tan \alpha. \tag{6}$$

The filling or static angle of repose is the angle with the horizontal at which wild pistachio will stand when piled. This was determined using a topless and bottomless cylinder of 0.15 m diameter and 0.25 m height. The cylinder was placed at the centre of a raised circular plate having a diameter of 0.35 m and was filled with wild pistachio nut or its kernel. The cylinder was raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the filling angle of repose (θ_f) was calculated by the following relationship (Ozguven and Kubilay, 2004):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right), \tag{7}$$

where: H and D are the height and diameter of the cone, respectively. Other researchers have used this method (Fraser *et al.*, 1978; Joshi *et al.*, 1993; Kaleemullah and Gunasekar, 2002; Karababa, 2006; Sacilik *et al.*, 2003).

In order to determine the emptying or dynamic angle of repose, a fibreglass box of 0.2×0.2×0.2 m, having a removable front panel was used. The box was filled with the wild pistachio nut or kernel samples at the moisture content being investigated, and then the front panel was quickly slid upwards, allowing the samples to flow out and assume a natural heap. The emptying angle of repose (θ_e) was obtained from measurements of height of samples at two points (h_1 and h_2) in the sloping wild pistachio heap and the horizontal distance between two points (x_1 and x_2), using the following equation (Bart-Plange and Baryeh, 2003; Jain and Bal, 1997; Paksoy and Aydin, 2004):

$$\theta_e = \tan^{-1}\left[\frac{(h_2 - h_1)}{(x_2 - x_1)}\right]. \tag{8}$$

Statistical analysis

All the physical properties of wild pistachio nut and its kernel were determined at four moisture levels with at least three replications at each level of moisture content. Mean and standard deviations were calculated by Microsoft Excel software (2003). The effect of moisture content on different engineering properties of pistachio nut and its kernel were determined using the analysis of variance (ANOVA) method and significant differences of means were compared using the least significant difference test (LSD) at 5% significance level using MSTATC version 1.4 statistical software program (Michigan State University, East Lansing, MI). The best relationship between moisture content and physical engineering of pistachio nut and its kernel were determined using linear and non linear (NLIN procedure) regression analysis of SAS software (2001) program. Coefficient of determination (R^2), residual mean square (MSE), residual plotting and the mean relative percent error (e) were used to evaluate the fitting of a model to experimental data. The best model was chosen as the one with the highest coefficient of determination and the least residual mean square and the mean relative percent error.

RESULTS AND DISCUSSION

The moisture content, average dimensions, sphericity and surface area of wild pistachio nuts and kernels are given in Table 1. In the sample, about 81% of the nuts had a length in the range of 12-14 mm, about 73% had a width in the range of 8-10 mm, and about 68% had a thickness in the range of 7-8 mm. About 72% of the kernels had a length in the range of 11-12 mm, about 85% had a width in the range of 6-7 mm, and about 78% had a thickness in the range of 4-6 mm. Analysis of va- riance ANOVA results showed that the differences among moisture levels were statistically significant at the level of 0.05 for the three parameters, although Sacilik *et al*. (2003) indicated that differences among moisture contents were statistically insignificant. The average diameters of nuts and kernels calculated by the arithmetic and geometric mean were 9.93 and 7.21, 9.75 and 6.88 mm at moisture contents of 8.62 and 6.03 % w.b., respectively. ANOVA indicated that the differences among the average diameters of wild pistachio nuts and kernels calculated by the two methods were insignificant at a significance level of 0.05. In other words, the average diameter of wild pistachio nuts and kernels calculated by the arithmetic mean and the geometric mean methods in the researched moisture ranges are almost the same (Table 1). Therefore, both the arithmetic mean and the geometric mean method can be used to determine the average diameters of nuts and kernels. Similar results were found by Kaleemullah and Gunasekar (2002) and Razavi *et al*. (2007a), for areca nuts and kernels and pistachio nuts and kernels, respectively.

The values of sphericity were calculated individually with Eq. (3) by using the data on geometric mean diameter and the major axis of the wild pistachio nut and kernel, and the results obtained are presented in Table 1. The sphericity of the wild pistachio nut and kernel increased from 69.34 and 62.25 to 72.59 and 65.13% when the moisture content increased from 5.83 and 6.03 to 31.15 and 30.73 % w.b., respectively. The variation of the surface area with the nuts and kernels moisture content is plotted in Table 1. These results indicate that the surface area increases with increase in nut and kernel moisture content. The surface area of the wild pistachio nut and kernel increased from 289.16 and 148.31 to 404.87 and 229.61 mm^2 when the moisture content increased from 5.83 and 6.03 to 31.15 and 30.73% w.b., respectively. Similar trends have been reported by Aviara *et al*. (1999) for guna seed, Sacilik *et al*. (2003) for hemp seed, and Kashaninejad *et al*. (2005) for pistachio nut.

The bulk density of wild pistachio nut and kernel increased from 521 to 543 and from 529 to 548 kg m^{-3}, respectively, as moisture content increased from 5.83 to 31.15 and from 6.03 to 30.73% w.b., respectively (Fig. 2a). This was due to the fact that an increase in mass owing to the moisture gain in nut and kernel was lower than accompanying volumetric expansion (Pliestic *et al.*, 2006). The true density

Table 1. Moisture content, dimensions, sphericity and surface area of wild pistachio nuts and kernels

Parameters	Quantity	Nuts				Kernels			
Moisture content (% w.b.)	3	5.83	9.68	22.48	31.15	6.03	10.37	21.59	30.73
Length (mm)	100	13.98 (1.12)	14.73 (1.23)	15.38 (1.06)	15.93 (1.35)	11.07 (0.95)	11.71 (0.86)	12.31 (1.06)	12.86 (1.22)
Width (mm)	100	8.76 (0.73)	9.31 (0.68)	9.97 (0.79)	10.41 (0.84)	5.92 (0.58)	6.46 (0.46)	6.95 (0.51)	7.51 (0.42)
Thickness (mm)	100	7.25 (0.49)	7.69 (0.58)	8.24 (0.51)	8.63 (0.62)	4.83 (0.35)	5.48 (0.47)	6.04 (0.41)	6.56 (0.55)
Arithmetic mean (mm)	100	9.93 (0.86)	10.63 (0.97)	10.99 (0.83)	11.73 (1.09)	7.21 (0.46)	7.83 (0.58)	8.37 (0.52)	8.94 (0.64)
Geometric mean (mm)	100	9.75 (0.74)	10.05 (0.97)	10.88 (1.18)	11.35 (1.03)	6.88 (0.51)	7.76 (0.42)	8.06 (0.58)	8.52 (0.55)
Sphericity (%)	100	69.34 (4.01)	70.28 (3.49)	68.92 (3.11)	72.59 (2.81)	62.25 (1.84)	68.15 (2.49)	64.58 (3.28)	65.13 (2.95)
Surface area (mm^2)	100	289.16 (26.47)	322.41 (35.18)	365.81 (33.25)	404.87 (37.92)	148.31 (18.59)	193.89 (24.37)	205.01 (22.83)	229.61 (25.72)

Standard deviation values are in parentheses.

was found to decrease from 809 to 829 kg m^{-3} for nut, and from 812 to 833 kg m^{-3} for kernel (Fig. 2b). The negative linear relation- ship of bulk and true density with moisture content was also observed by Visvanathan *et al*. (1996) for neem nut, Baryeh (2001) for bambara groundnut, Aydin (2002) for hazelnut, and Razavi *et al*. (2007b) for pistachio nut and kernel. The bulk and true density of nuts (*n*) and kernels (*k*) was found to have the following relationship with moisture content (M_C):

$$\rho_{bn}=0.9075\ M_C+515.81 \quad (R^2=0.99), \quad (9)$$

$$\rho_{bk}=0.7393\ M_C+525.30 \quad (R^2=0.99), \quad (10)$$

$$\rho_{tn}=0.7815\ M_C+803.73 \quad (R^2=0.98), \quad (11)$$

$$\rho_{tk}=0.8772\ M_C+807.18 \quad (R^2=0.98). \quad (12)$$

The estimated porosity of both nut and kernel of wild pistachio was found to slightly decrease with increase in their moisture content from 5.83 to 31.15% w.b. and 6.03 to 30.73% w.b., respectively (Fig. 2c). The porosity of nut decreased from 36.65 to 34.79%, while the porosity of kernel decreased from 35.14 to 34.63%. The negative linear relationship of bulk and true density with moisture content was also observed by Shepherd and Bhardwaj (1986) for pigeon pea, Dutta *et al*. (1988) for gram, Aviara *et al*. (1999) for guna seed, and Nimkar and Chattopadhyay (2001) for green gram. The relationship between moisture content and porosity of nuts and kernels appears to be linear and can be represented by the regression equation:

$$\varepsilon_n = -0.0695\ M_C+36.979 \quad (R^2 = 0.99), \quad (13)$$

$$\varepsilon_k = -0.0744\ M_C+35.518 \quad (R^2 = 0.99). \quad (14)$$

Figure 3a, b show the static coefficient of friction for wild pistachio nut and kernel determined with respect to galvanized fibreglass, glass, galvanized iron sheet, plywood and rubber surfaces at different moisture contents. At all moisture contents, the static coefficient of friction was the highest for wild pistachio nut and kernel on rubber, and the least for glass. As the moisture content of wild pistachio nut and kernel increased, the static coefficient of friction increased linearly. The relationships between these coefficients against various surfaces and moisture contents of wild pistachio nut and kernel are shown in Table 2.

The reason for the increased friction coefficient at higher moisture content may be due to the water present in the nut and kernel offering a cohesive force on the surface of contact. As the moisture content of nuts increases, the surface of the samples becomes stickier. Water tends to adhere to surfaces and the water on the moist kernel surface would be attracted to the surface across which the sample is being moved. Other researchers found that as the moisture content

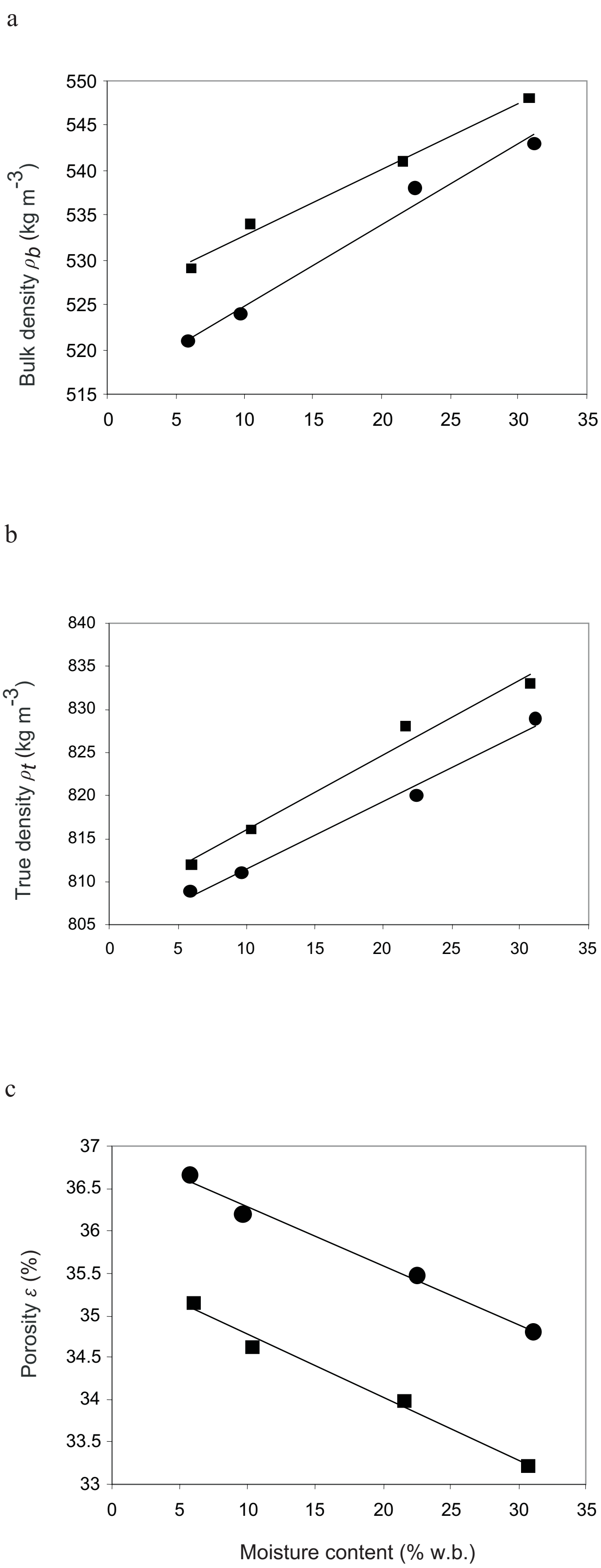

Fig. 2. Effect of moisture content on: a – bulk density, b – true density, and c – porosity of wild pistachio nut (●) and kernel (■).

T a b l e 2. Relationships between static coefficient of friction of wild pistachio nut and kernel and moisture content

Surface	Wild pistachio nut	R^2	Wild pistachio kernel	R^2
Fiberglass	$\mu = 0.0077M_C + 0.4496$	0.967	$\mu = 0.0090M_C + 0.3490$	0.993
Glass	$\mu = 0.0053M_C + 0.3755$	0.983	$\mu = 0.0085M_C + 0.3367$	0.995
Galvanized iron sheet	$\mu = 0.0035M_C + 0.3676$	0.983	$\mu = 0.0069M_C + 0.3097$	0.996
Plywood	$\mu = 0.0037M_C + 0.2862$	0.976	$\mu = 0.0092M_C + 0.2704$	0.987
Rubber	$\mu = 0.0041M_C + 0.2562$	0.980	$\mu = 0.0081M_C + 0.2656$	0.989

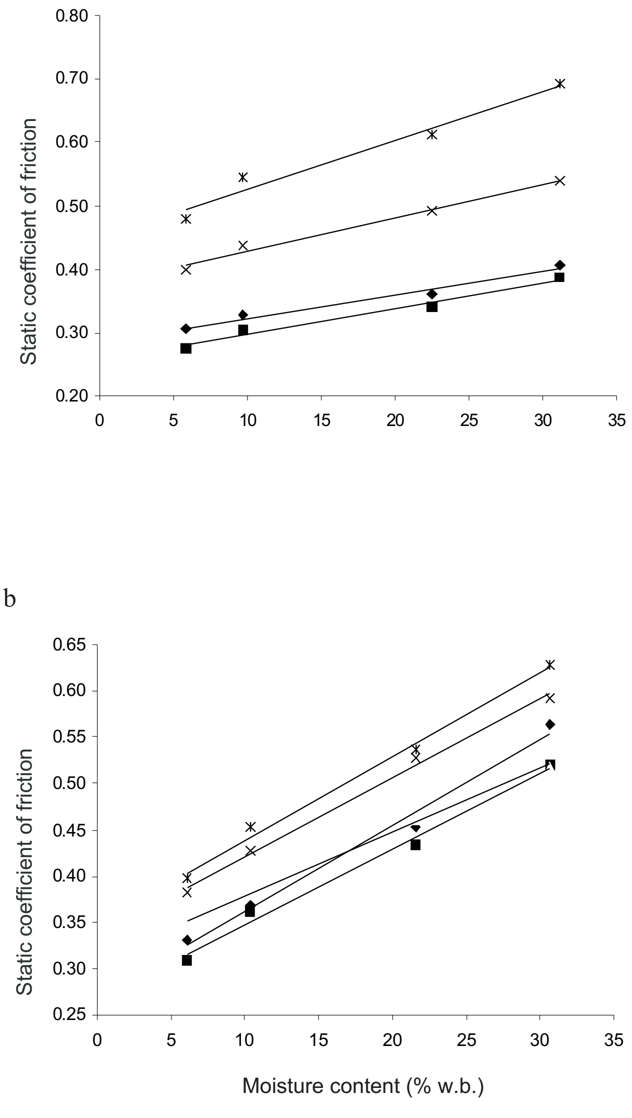

Fig. 3. Effect of moisture content on coefficient of static friction of: a – wild pistachio nuts, b – wild pistachio kernels, against various surfaces: * rubber, × plywood, ◆ fibreglass, ■ glass, and ▲ galvanized iron.

increased, the static coefficient of friction increased also (Carman, 1996; Gezer *et al*., 2002; Gupta and Das, 2000; Joshi *et al*., 1993; Ogut, 1998; Razavi *et al*., 2007c).

The results of the filling and emptying angle of repose of wild pistachio nuts and kernels at different moisture levels are shown in Fig. 4. The filling angle of repose of wild pistachio nut and kernel increased from 15.64 to 18.57° and from 24.90 to 26.93°, respectively, as moisture content increased from 5.83 to 31.15% w.b. and 6.03 to 30.73% w.b. The emptying angle of repose was found to increase from 24.17 to 27.33° for nut, and from 25.58 to 27.83° for kernel. The results of this research indicated that the filling angle of repose of nuts and kernels increased as the moisture content increased in the range studied. It can be also found that the emptying angle of repose with wild pistachio nuts and kernels varieties increased as the moisture content increased. It seems that it is due to the higher moisture contents and therefore higher stickiness of the surface of the wild pistachio nuts and kernels that confines the easiness of sliding nuts on each other. The equations representing the relationship between filling and emptying angle of repose of wild

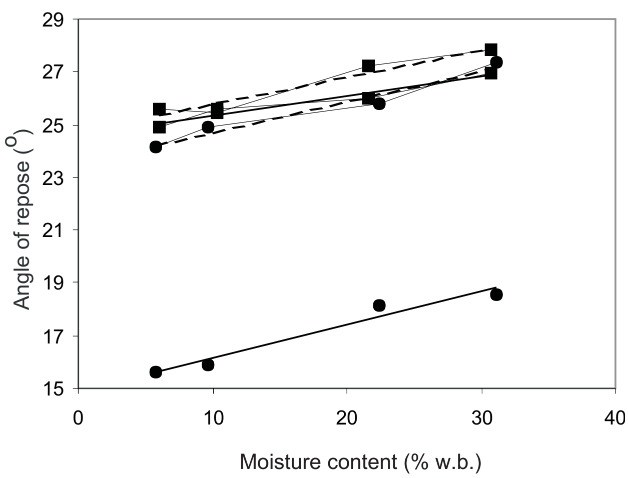

Fig. 4. Effect of moisture content on filling (—) and emptying (– –) angle of repose of porosity of wild pistachio nut (●) and kernel (■).

pistachio nuts and kernels and moisture content and their coefficient of determination (R^2) are presented as follows. As it can be found, there was a linear relationships with very high correlation between filling emptying angle of repose and moisture content for wild pistachio nut and kernel.

$$\theta_{fn}=0.1273\ M_C+14.857, \quad (R^2=0.96), \quad (15)$$

$$\theta_{fk}=0.0740\ M_C+24.590, \quad (R^2=0.95), \quad (16)$$

$$\theta_{en}=0.1152\ M_C+23.563, \quad (R^2=0.97), \quad (17)$$

$$\theta_{ek}=0.1032\ M_C+24760, \quad (R^2=0.94). \quad (18)$$

CONCLUSIONS

The following conclusions are drawn from the investigation on physical and mechanical properties of wild pistachio nuts and kernels for four moisture content ranges of 5.83 to 31.15 and 6.03 to 30.73% w.b., respectively:

1. The average length, width and thickness, arithmetic and geometric mean diameter of wild pistachio nuts at 5.83% moisture content (w.b.) were 13.98, 8.76, 7.25, 9.93 and 9.75 mm, while the corresponding values of kernels at 6.03% moisture content were 11.07, 5.92, 4.83, 7.21 and 6.88 mm, respectively.
2. The bulk and true densities of wild pistachio nut and kernel increased with increase in moisture content, while porosity decreased.
3. At all moisture contents, the static coefficient of friction was the highest for wild pistachio nut and kernel on rubber and the least for glass.
4. The results of this research indicated that the filling and emptying angle of repose of nuts and kernels increased as the moisture content increased in the range studied.

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