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Physical properties of almond nut and kernel

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Abstract

Several physical properties of almond nut and kernel were evaluated as functions of moisture content. The average length, width, thickness, the geometric mean diameter, unit mass and volume of nuts were 25.49, 17.03, 13.12, 18.13 mm, 2.64 g and 2.61 cm^3 respectively. Corresponding values for kernel were 21.19, 14.34, 6.38, 11.42 mm, 0.69 g and 0.71 cm^3 respectively. In the moisture range from 2.77 to 24.97 db, studies on re-wetted almond nut showed that the bulk density decreased from 655 to 525 kg/m^3, true density increased from 1015 to 1115 kg/m^3, porosity increased from 35.32% to 53.21%, projected area increased from 3.74 to 3.9 cm^2, and terminal velocity increased from 5.62 to 7.98 m/s. For the kernel, the corresponding values changed from 595 to 475 kg/m^3, 900 to 995 kg/m^3, 34.23% to 50.29%, 1.68 to 2.39 cm^2 and from 5.62 to 7.2 m/s respectively. The rupture strength of almond nut and kernel decreased with increasing moisture content. The highest rupture strength occurred when loaded along the X-axis. In the same moisture range 2.77–24.97 db the static coefficient of friction varied from 0.28 to 0.83 for almond nut and from 0.53 to 0.78 for kernel over different material surfaces.

1. Introduction

Almond (*Amygdalus communis* L.) is perennial plant growing in inner Anatolia, the Mediterranean and the Marmara regions of Turkey. The kernel nut forms an important source of protein in human nutrition. Turkey is a producer country with an annual production of about 37.000 t and its yield ranges between 1789.5 and 2000 kg/ha (SSI, 2001).

At present, the crop is usually planted as main crop in Turkey. Harvesting and handling of the crop are carried out manually. The threshing is usually carried out on a hard floor with a homemade threshing machine. For optimum threshing performance, processes of pneumatic conveying, storing and other processes of almond nut, its physical properties must be known. Almond is an edible, nutlike seed of fruit of a tree, prunus amygdalus, of the rose family, the sweet variety of which is widely used in desserts, candy and cooking.

The kernel form an important source of energy with 6 Kcal/g, protein 15.64% and their oil content changed from 35.27% to 40%. Oil of almond kernel is an important source of oleic acid with 40%.

Kalyoncu (1990) measured the size and rupture strength of almond nuts of 10 almond varieties and determined relationship between rupture strength and the size of the nuts. Viswanathan, Palanisamy, Gothandapani, and Sreenarayanan (1996) found a linear decrease in true density, bulk density and porosity of neem nut with an increase in moisture content in the range 7.6–21% wb. The various physical properties of sunflower seeds including bulk density, porosity, angle of repose, terminal velocity and coefficient of static and dynamic friction were evaluated by Gupta and Das (1997). Limited research has been conducted on the physical properties of almond seeds. Some engineering properties of almond seeds, such as rupture strength, sphericity were reported by Kalyoncu (1990).

The objective of this study was to investigate some moisture dependent physical properties of the almond nut and kernel, namely linear dimensions, unit mass and volume, sphericity, densities, porosity, projected area, terminal velocity, rupture strength and coefficient of static and dynamic friction against three structural surfaces.

2. Materials and methods

2.1. Material

Dried almond (*cv. Taşbadem*) seeds were used for all the experiments in this study. The crop was collected

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Nomenclature

D_p	geometric mean diameter, mm	V_t	terminal velocity, m/s
F_r	rupture force, N	W	width, mm
L	length, mm	w	sample weight, N
M_c	moisture content, % db	Φ	sphericity, %
P_a	projected area, cm^2	ε	porosity, %
q	torque arm, mm	μ_s	dimensionless static coefficient of friction
R^2	determination coefficient	μ_d	dimensionless dynamic coefficient of friction
T	thickness, mm	ρ_b	bulk density, kg/m^3
T_m	measured torque, N mm	ρ_t	true density, kg/m^3

from Konya in Turkey during the spring season in 2001 year. The seeds were cleaned in an air screen cleaner to remove all foreign matter such as dust, dirty, stones and chaff as well immature and broken seeds. The nuts were cracked by hammer on a handle. And than the kernels were separated by hands from hulls.

2.2. Methods

The initial moisture content of Almond seeds was determined by using a standard method (USDA, 1970) and was found to vary between 2.77% and 2.99% db. The almond nut samples of the desired moisture levels were prepared by adding calculating amounts of distilled water, through mixing and then sealing in separate polyethylene bags. The samples were kept at 278 K in a refrigerator for 7 d for the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantities of the seed were allowed to warm up to room temperature (Çarman, 1996; Dehspande, Bal, & Ojha, 1993).

All the physical properties of the fruit were assessed at moisture levels of 2.77%, 9.98%, 18.11% and 24.97% db with five replications at each level.

To determine the average size of the seed, a sample of one hundred seeds was randomly selected. Measurement of the three major perpendicular dimensions of the seed was carried out with a micrometer with an accuracy of 0.01 mm.

The geometric mean diameter (D_p) of the seed was calculated by using the following relationship (Mohsenin, 1970):

$$D_p = (LWT)^{1/3}$$

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

According to Mohsenin (1970), the degree of sphericity (Φ) can be expressed as follows:

$$\Phi = \frac{(LWT)^{1/3}}{L} \times 100$$

This equation was used to calculate the sphericity of almond nut and kernel in the present investigation. To obtain the mass, each seed was weighed by a chemical balance reading to 0.001 g.

The true density of a seed is defined as the ratio of the mass of a sample of a seed to the solid volume occupied by the sample. The nut and kernel volume and their true density were determined using the liquid displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Ögüt, 1998; Sitkei, 1986). The bulk density is the ratio of the mass of a sample of seed to its total volume. The bulk density was determined with a weight per hectolitre tester which was calibrated in kg per hectolitre (Dehspande et al., 1993). The nuts and kernels were poured in the calibrated bucket up to the top from a height of about 15 cm and excess amount was removed by strike off stick. The nuts and kernels were not compacted in any way.

The porosity (ε) of bulk seed was computed from the values of true density and bulk density using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100$$

where ρ_b is the bulk density and ρ_t is the true density.

The projected area of a seed was measured by placing it under a thin transparent paper and using a planimeter equipped with a magnifying glass (Makanjuola, 1972).

The terminal velocities of nut and kernel of different moisture contents were measured in free fall by means of an instrument developed by Keck and Goss (1965). A fruit was allowed to fall from the top of a dropping tube at various heights. The duration of fall was recorded by a timer with a sensitivity of 0.1 ms and was plotted as a function of distance of fall. The linear portion of the curve of the distance versus time indicated the terminal velocity of the almond nut.

To determine the rupture strength of nuts, biological material test device was used. The device was developed by Aydin and Ögüt (1992). This devices has four main components which are upper stable platform and moving bottom platform, a driving unit and the data acquisition system. The nut or kernel was placed on the stable up platform and pressed with moving platform. The rupture force of nut and kernel were measured by the data acquisition system.

The coefficients of frictions of almond nut and kernel different moisture contents were measured using a friction device. The device developed by Tsang-Mui-Chung, Verma, and Wright (1984) and improved by Chung and Verma (1989) has three main components which are a stationary sample container with its support shaft, a driving unit with rotating disc and the data acquisition system. The samples were placed on the rotating surface and the torque necessary to restrain the sample was measured by the data acquisition system. This torque was used to determine the static and dynamic coefficients of friction using the following equation (Chung & Verma, 1989)

$$\mu = T_m/(wq)$$

where μ is the coefficient of friction, T_m the measured torque, q the length of the torque arm and w is the sample weight on the rotating surface. The maximum value of torque obtained as the disc started to rotate was used to calculate the static coefficient of friction and average value of the torque during the rotation of the disc was used to calculate the dynamic coefficient of friction.

3. Results and discussion

3.1. Dimensions and size distribution of almond nut and kernel

Table 1 shows the size distribution of the almond nuts. The frequency distribution curves (Fig. 1) for the mean values of the dimensions show a trend towards a normal distribution. About 80% of the almond nuts have a length ranging from 25.33 to 25.65 mm, about 80% width ranging from 16.89 to 17.16 mm, and about 80% thickness ranging from 13.0 to 13.23 mm.

And Table 2 shows the size distribution of the kernel. The frequency distribution curves (Fig. 2) for the mean values of the dimensions show a trend towards a normal distribution. About 80% of the kernels have a length ranging from 21.09 to 21.29 mm, about 80% width ranging from 10.25 to 12.43 mm, and about 80% thickness ranging from 6.28 to 6.47 mm. The values of mass and volume of a single fruit of almond nut were given in Table 1.

Table 1
Means and standard errors of the almond nut dimensions at 2.77% db

Length, mm	25.49 ± 0.12
Thickness, mm	12.12 ± 0.08
Width, mm	17.03 ± 0.10
Geometric mean diameter, mm	18.13 ± 0.24
Spherically, %	69.59 ± 1.75
Mass, g	2.64 ± 0.10
Volume, cm^3	2.61 ± 0.10
Hull thickness, mm	2.61 ± 0.21
Hull density, g/cm^3	1.18 ± 0.01

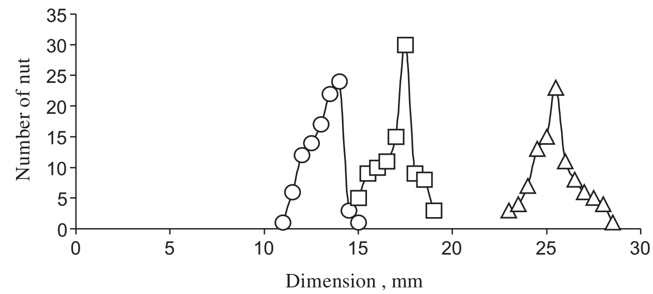

Fig. 1. Frequency distribution curves of almond nut dimensions at 2.77% db. (○), Thickness; (□), width; (△), length.

Table 2
Means and standard errors of the kernel dimensions at 2.87% db

Length, mm	21.19 ± 0.08
Thickness, mm	6.38 ± 0.07
Width, mm	11.34 ± 0.83
Geometric mean diameter, mm	11.42 ± 0.15
Spherically, %	55.17 ± 1.23
Mass, g	0.73 ± 0.02
Volume, cm^3	0.82 ± 0.01

In Table 1, the values of mass and average dimensions almond nut were higher than sunflower seeds (Gupta & Das, 1997). Almond nuts the average values of geometric mean diameter and sphericity were calculated 18.13 mm and 65.59% respectively. Gupta and Das (1997) has reported the sphericity values of sunflower as 57.5% which is close to the results of this investigation.

3.2. Bulk density

The values of bulk density of almond nuts at different moisture levels varied from 655 to 525 kg/m^3. Furthermore the bulk density of kernel at different moisture levels varied from 595 to 475 kg/m^3 (Fig. 3) and indicated a decrease in bulk density with an increase in moisture content. The negative linear relationship of bulk density with moisture content was also observed by Viswanathan et al. (1996) and Gupta and Das (1997) for neem nut and sunflower seed respectively. The relationship between bulk density and moisture content was statistically significant ($p < 0.05$).

3.3. True density

The true density of almond nut at different moisture levels varied from 1015 to 1115 kg/m^3. The effect of moisture content on true density of almond nut showed

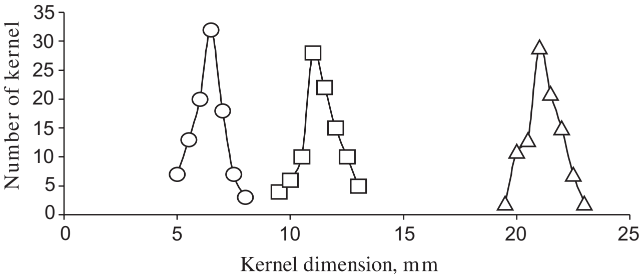

Fig. 2. Frequency distribution curves of kernel dimensions at 2.87% db. (○), Thickness; (□), width; (△), length.

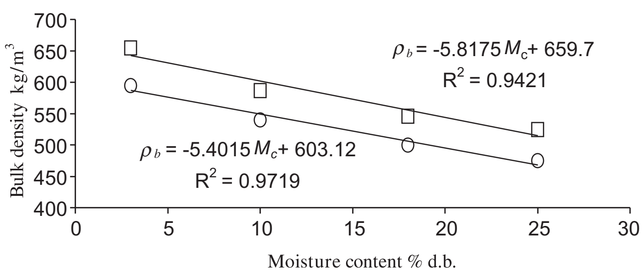

Fig. 3. Variation of bulk density of almond nut and kernel with moisture content (□), almond nut; (○), kernell.

a increase with moisture content. Effect of moisture content on true density of kernel showed a increase with moisture content from 900 to 995 kg/m^3 (Fig. 4). The effect of moisture content on true density of kernel showed a increase with moisture content. Dehspande et al. (1993) also observed the linear increase in kernel density with increase in grain moisture in the range 8.7–25% db for JS-7244 soybean. Gupta and Das (1997) also observed the linear increase in kernel density with increase in seed moisture in the range 4–20% db for sunflower seed.

3.4. Porosity

Since the porosity depends on the bulk as well as true or kernel densities, the magnitude of variation in porosity depends on these factors only. The porosity of almond nut it was found to slightly increase with increase in moisture content from 2.77% to 24.97% db. The porosity of kernel was found to slightly increase with increase in moisture content from 2.77 to 24.97 db. (Fig. 5). The form of the plot is similar to that for sunflower as found by Gupta and Das (1997). The negative linear relationship of porosity with moisture content was also observed by Viswanathan et al. (1996).

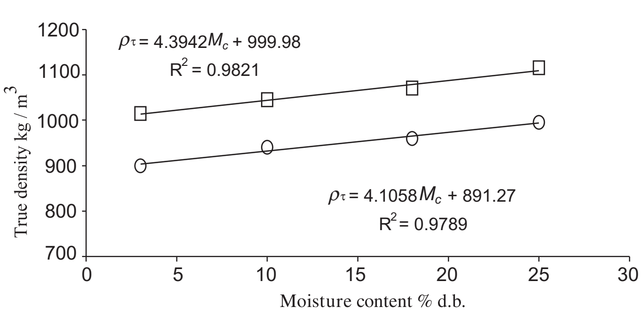

Fig. 4. Variation of true density of almond nut and kernel with moisture content (□), almond nut; (○), kernell.

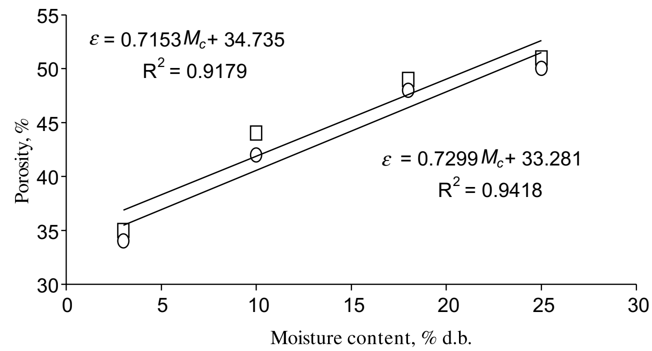

Fig. 5. Variation of porosity of almond nut and kernel with moisture content (□), almond nut; (○), kernell.

3.5. Projected area of nut

The projected area of almond nut (Fig. 6) increased by about 6.56%, while the moisture content of almond nut increased from 2.77% to 24.97% db. Furthermore the projected area of kernel (Fig. 6) increased by about 42.35%, while the moisture content of kernel increased from 2.77% to 24.97% db. Similar trends were reported for many other seeds (Mohsenin, 1970; Sitkei, 1986). Dehspande et al. (1993) found that the surface area of soybean grain increased from 0.813 to 0.952 cm^2, when the moisture content was increased from 8.7% to 25% db. The relationship between projected area and moisture content was found to be significant ($p < 0.05$).

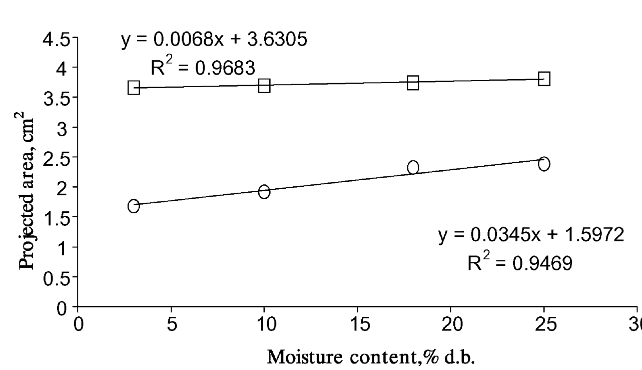

Fig. 6. Variation of projected area of almond nut and kernel with moisture content (□), almond nut; (○), kernell.

3.6. Terminal velocity

The experimental results for the terminal velocity of the almond nut and kernel various moisture levels are plotted in Fig. 7. As moisture content increased, the terminal velocity was found to increase linearly. The results are similar to those reported by Kural and Çarman (1997), but the values were higher than those for pumpkin seeds and cereals (Gorial & Callaghan, 1990). Nimkar and Chattopadyay (2001) found that the terminal velocity of green gram increased from 10.1 to 12 m/s, when the moisture content was increased from 8.39% to 33.4% db. The relationship between terminal velocity and moisture content was found to be significant ($p < 0.05$). The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual fruit per unit frontal area presented to the air stream.

3.7. Rupture strength

The results of the rupture strength tests are presented Figs. 8 and 9. The results show that the rupture strength along any of the three major axis is highly dependent on moisture content for the range moisture content investigated (2.77–24.97% db). For all the curves, greater forces were necessary to rupture the nuts at less moisture content. The highest force was obtained on loading along the X-axis, while on loaded along the Z-axis required the least force to rupture for almond nut. The small rupturing forces at higher moisture content might have resulted from the fact that the kernel tended to be very soft at high moisture content. The relationship between the rupture strengths and moisture content of the almond nut and kernel on three major axis are presented in Figs. 8 and 9. The results are similar to those reported by Viswanathan et al. (1996).

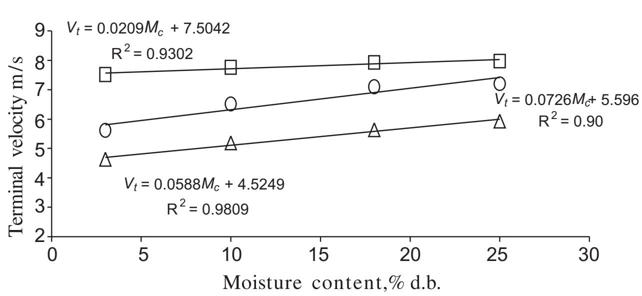

Fig. 7. Variation of terminal velocity of almond with moisture content (□), almond nut; (○), kernell; (△), hull.

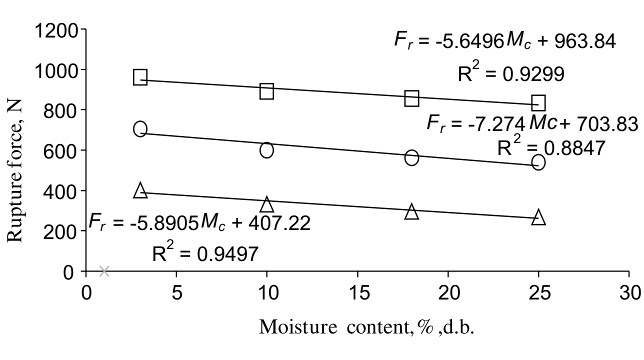

Fig. 8. Variation of rupture force of almond nut with moisture content (□), X-axis; (○), Z-axis; (△), Y-axis.

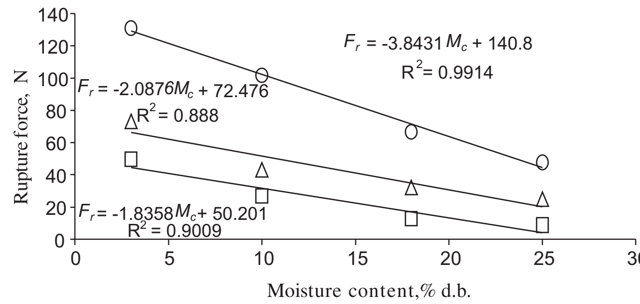

Fig. 9. Variation of rupture force of kernel with moisture content (○), Z-axis; (△), Y-axis; (□), X-axis.

3.8. Static and dynamic coefficients of friction

The static and dynamic coefficients of friction for almond nut and kernel determined with respect to rubber, plywood and galvanised sheet metal surfaces are presented in Figs. 10–13. At all moisture contents, both the static and dynamic coefficients of friction were greatest for almond nut and kernel, against plywood

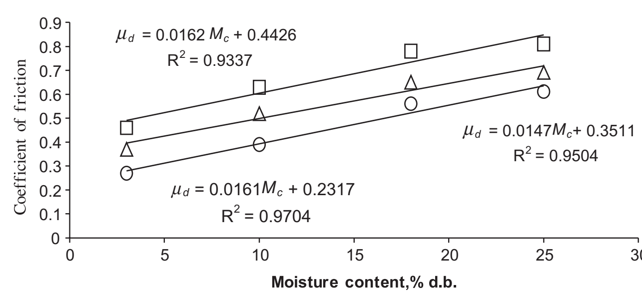

Fig. 10. Effect of moisture content on dynamic coefficient of friction of kernel with (□), plywood; (△), rubber; (○), galvanised metal.

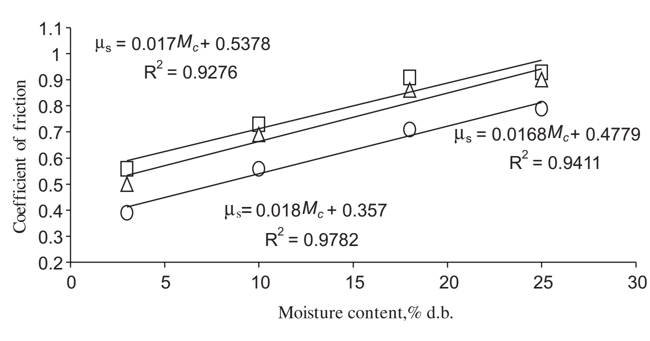

Fig. 11. Effect of moisture content on static coefficient of friction of kernel with (□), plywood; (△), rubber; (○), galvanised metal.

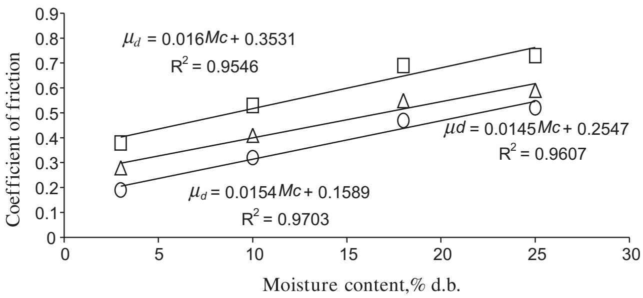

Fig. 12. Effect of moisture content on dynamic coefficient of friction of almond nut with (□), plywood; (△), rubber; (○), galvanised metal.

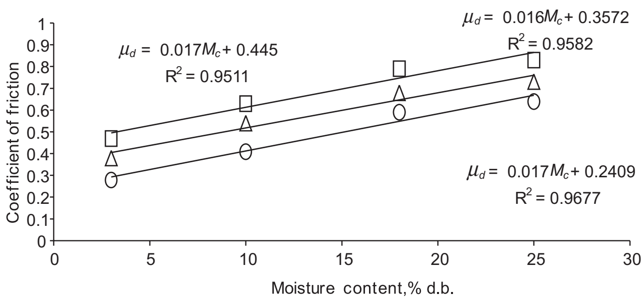

Fig. 13. Effect of moisture content on static coefficient of friction of almond nut with (□), plywood; (△), rubber; (○), galvanised metal.

and least for galvanised sheet metal, with rubber in between. As the moisture content of the nut increased, the static and dynamic coefficients increased significantly. Gupta and Das (1997) reported a similar result. It was observed that material surface had a more significant effect than the moisture content on the dynamic coefficient of friction. When compared with other seeds, the coefficient of friction for almond nut was higher than that of sunflower seed, lentil seed, white lupin, green gram and neem nut (Çarman, 1996; Gupta & Das, 1997; Nimkar & Chattopadyay, 2001; Ögüt, 1998; Viswanathan et al., 1996). The relationship between the coefficients of friction and moisture content of the nut on three different surfaces is presented in Figs. 10–13.

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