Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Food Engineering 71 (2005) 37–43
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds

Ebubekir Altuntaş *, Engin Özgöz, Ö. Faruk Taşer

Department of Agricultural Machinery, Faculty of Agriculture, University of Gaziosmanpasa, 60240 Tasliciftlik, Tokat, Turkey

Received 3 June 2004; accepted 7 October 2004
Available online 30 November 2004

Abstract

Some physical properties of fenugreek seeds were evaluated as a function of moisture content. The average length, width, thickness, geometric mean diameter and unit mass of the seed ranged from 4.01 to 4.19 mm, 2.35 to 2.61 mm, 1.49 to 1.74 mm, 2.40 to 2.66 mm and 0.0157 to 0.0164 g as the moisture content increased from 8.9% to 20.1% d.b. respectively. In the moisture content range, studies on rewetted fenugreek seed showed that the sphericity increased from 60.79% to 64.06%, the seed volume from 12.58 to 13.83 mm^3, 1000 seed mass from 15.48 to 16.39 g and surface area from 18.09 to 22.18 mm^2. As the moisture content increased from 8.9% to 20.1% d.b., the bulk density, kernel density were found to decrease from 701.16 to 645.81 kg/m^3 and 1240.36 to 1165.25 kg/m^3, whereas angle of repose and porosity were found to increase from 14.34° to 16.88° and 43.47% to 44.58%, respectively. The static and dynamic coefficients of friction on various surfaces, namely, plywood, mild steel and galvanized metal also increased linearly with increase in moisture content. The plywood surface offered the maximum friction followed by mild metal and galvanized metal.

Keywords: Fenugreek; *Trigonella foenum-graceum* L.; Physical properties

1. Introduction

Fenugreek (*Trigonella foenum-graceum* L.) is an annual herb of leguminosea, is being used as spice with its seeds and as vegetable with its leaves. It has a long history as both a culinary and medicinal herb in the ancient world. Fenugreek is known as Greek hay. Its seeds have a strong aroma and somewhat bitter in taste. Fenugreek is native to Southern Europe, the Mediterranean region and Western Asia. It is cultivated from Western Europe to China for the aromatic seeds and is still grown for fodder in parts of Europe and Northern Africa. The seeds are very hard, and difficult to grind. Seed extract is used in imitation vanilla, butterscotch and rum flavoring and is the main flavoring in imitation maple syrup.

Rich in vitamins and minerals, and because it is a seed and a legume, it is high in protein. They are also an important source of diosgenin (Food reference, 2004).

In Turkey, fenugreek is widely cultivated as a spice crop for a long time and is cultivated on 700 hectares with an annual production of 670 tonnes and its yield 957 kg/ha (Anonymous, 2000). It is an important industry and export crop. In Turkey, it is consumed for producing spice and pastirma producing (preserve of dried meat) and garlic-flavoured sausage (called çemen). Çemen is composed of crushed classical fenugreek seeds, garlic and chilli pepper mixed to a paste with some water. The çemen paste covering the slabs of pastirma is both an important factor in the flavour, and protects

* Corresponding author. Tel.: +90 356 252 1616; fax: +90 356 252 1488.
E-mail address: ealtuntas@gop.edu.tr (E. Altuntaş).

0260-8774/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2004.10.015

Nomenclature

A, B	regression coefficients	T	thickness, mm
D_g	geometric mean diameter, mm	V	single seed volume, mm^3
F	measured friction force	W	width, mm
L	length, mm	ρ_k	kernel density, kg/m^3
m	unit mass of the seed, g	ρ_b	bulk density, kg/m^3
m_{1000}	1000 seed mass, g	μ	coefficient of friction
M_c	moisture content, %d.b.	ε	porosity, %
N_f	normal force, N	ϕ	sphericity, %
R^2	determination coefficient	Θ	angle of repose, °
S	surface area, %		

the meat from drying and spoiling by contact with the air (Turkish culture, 2004).

To design equipment for aeration and storage there is a need to know various physical properties as a function of moisture content (Srivastava, Mahoney, & West, 1990). In order to optimize the equipment design for harvesting, handling, storing and other processes of fenugreek seed, its physical properties must be known. The physical properties of fenugreek seeds are to be known; for design and improve of relevant machines and facilities for harvesting, storing, handling and processing. The size and shape are important in designing of separating, harvesting, sizing and grinding machines. Bulk density and porosity affect the structural loads, the angle of repose is important in designing of storage and transporting structures. The coefficient of friction of the seed against the various surface is also necessary in designing of conveying, transporting and storing structures.

In recent years, physical properties have been studied for various crops such as locust bean seed (Ogunjimi, Aviara, & Aregbesola, 2002); millet (Baryeh, 2002); quiona seed (Vilche, Gely, & Santalla, 2003) and almond nut and kernel (Aydin, 2003).

The objective of this study was to investigate some moisture-dependent physical properties of fenugreek seeds, namely, size dimension, sphericity, surface area, volume, 1000 seed mass, bulk density, kernel density, porosity, angle of repose, the static and dynamic coefficients of friction on various surfaces in the moisture content range from 8.9% to 20.1% d.b.

2. Materials and methods

The fenugreek seeds used in this study were obtained from a local market in Tokat city of Turkey. The samples were cleaned manually to remove all foreign matter, dust, dirt, broken and immature seeds. The initial moisture content of the samples was determined by oven drying at 105 ± 1 °C for 24 h (Suthar & Das, 1996). The samples of the desired moisture levels were prepared by adding calculated amounts of distilled water, thorough mixing and then sealing in separate polyethylene bags. The samples were kept at 278 K in a refrigerator for 7 d to allow the moisture to distribute uniformly throughout the sample. Before starting the test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to room temperature (Çarman, 1996; Deshpande, Bal, & Ojha, 1993; Öğüt, 1998; Visvanathan, Palanisamy, Gothandapani, & Sreenarayanan, 1996).The physical properties of the seeds were investigated at three moisture levels in the range of 8.9–20.1% d.b. Ten replications of each test were made at each moisture level. For each moisture content, the length, width, thickness and weight of fenugreek seeds were measured in randomly selected 100 fenugreek seeds. The length, width and thickness of materials were measured by a dial-micrometer to an accuracy of 0.01 mm.

The geometric mean diameter D_g and sphericity ϕ of fenugreek seeds was calculated by using the following relationships (Mohsenin, 1970):

$$D_g = (LWT)^{1/3} \tag{1}$$

$$\phi = \{(LWT)^{1/3}/L\} \times 100 \tag{2}$$

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

To obtain the unit mass of the seed, 1000 seed mass were measured by an electronic balance to an accuracy of 0.001 g. To evaluate 1000 seed mass, 100 randomly selected seeds from the bulk were averaged. The volume V of fenugreek seeds in mm^3 was determined from the following relationship given by Özarslan (2002):

$$V = (m/\rho_k) \times 10^6 \tag{3}$$

where m is the unit mass of the seed in g and ρ_k is the kernel density in kg/m^3.

The surface area of fenugreek was found by analogy with a sphere of same geometric mean diameter, using expression cited by Olajide and Ade-Omowaye (1999) and Sacilik, Öztürk, and Keskin (2003)

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

where S is the surface area in mm^2 and D_g is the geometric mean diameter in mm.

The kernel 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 (Deshpande et al., 1993). The seed volume and its kernel density were determined using the liquid displacement method. Fluids typically used include alcohol, toluene and tetrachloethylene. Ethylene alcohol was used in place of water because it is absorbed by the 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 (Mohsenin, 1970; Sitkei, 1976). The bulk density is the ratio of the mass of a sample of a seed to its total volume and it was determined with a weight per hektolitre tester which was calibrated in kg/m^3 (Deshpande et al., 1993; Mohsenin, 1970).

The porosity ε of bulk seed was calculated from bulk and kernel densities using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = \{(\rho_k - \rho_b)/\rho_k\} \times 100 \tag{5}$$

where ρ_k is the kernel density in kg/m^3 and ρ_b is bulk density in kg/m^3.

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a topless and bottomless cylinder of 300 mm diameter and 500 mm height. The cylinder was placed at the center of a raised circular plate and was filled with fenugreek seeds. The cylinder was raised slowly until it formed a cone on a circular plate. The angle of repose was calculated from the measurement of the height of the cone and the diameter of cone (Kaleemullah & Gunasekar, 2002).

The coefficient of friction of fenugreek seeds was measured using a friction device. The measuring device of friction force is formed by three units. These are metal box, friction surface and electronic units which covers mechanical force unit, electronic variater, load cell, electronic ADC card and PC (Kara, Turgut, Erkmen, & Güler, 1997). Friction force values measured by load cell, were converted by ADC card to digital values and data was recorded in computer.

The static and dynamic coefficients of friction were calculated using the following equation:

$$\mu = F/N_f \tag{6}$$

where μ is the coefficients of friction; F is the measured friction in N and N_f is the normal force in N.

The maximum value of friction force was obtained when box started moving, and this was used to calculate the static coefficients of friction. While the box continued to slide over the friction surface at 0.02 m/s velocity, the dynamic coefficients of friction was measured. The average value of coefficients of friction was used to calculate the dynamic coefficients of friction. The experiment was conducted at different moisture contents of fenugreek seed using friction surfaces of mild steel, galvanized steel and plywood. For each experiment, the sample box was emptied and refilled with a different sample at the same moisture content (Sacilik et al., 2003).

3. Results and discussion

3.1. Seed size

About 76% of the seeds have a length ranging from 3.44 to 4.75 mm, about 80% a width ranging from 2.02 to 2.73 mm, about 77% a thickness ranging from 1.27 to 1.73 mm and about 74% a seed mass ranging from 0.0122 to 0.0197 g at 8.9% moisture content on dry basis (Fig. 1). The average length, width and thickness of fenugreek seeds and single seed mass and geometric mean diameter ranged from 4.01 to 4.19, 2.35 to 2.61, 1.49 to 1.74 mm, 0.0157 to 0.0164 g and 2.40 to 2.66 mm as the moisture content increased from 8.9% to 20.1% d.b., respectively.

3.2. Sphericity

The values of sphericity were calculated with Eq. (2) by using the data on geometric mean diameter of the fenugreek seed and the results obtained are presented in Fig. 2. The sphericity of the fenugreek seed increased from 60.79% to 64.06% as the moisture content increased from 8.9% to 20.1% d.b. (Fig. 2). The relationship between moisture content and sphericity (ϕ) appears linear and can be represented by the regression equation

$$\phi = 59.027 + 1.635M \quad (R^2 = 0.982). \tag{7}$$

Similar trends of increase have been reported by Deshpande et al. (1993) and Sacilik et al. (2003) for soybean and hemp seed, respectively.

3.3. 1000 seed mass

The thousand seed mass of fenugreek m_{1000} increased linearly from 15.48 to 16.39 g as the moisture content increased from 8.9% to 20.1% d.b. (Fig. 2). This relationship between moisture content and 1000 seed mass (m_{1000}) can be represented by the following equation:

$$m_{1000} = 14.993 + 0.455M_c \quad (R^2 = 0.986). \tag{8}$$

Similar trends of increase have been reported by Deshpande et al. (1993) and Baryeh and Mangope (2002) for soybean and QP-38 variety pigeon pea.

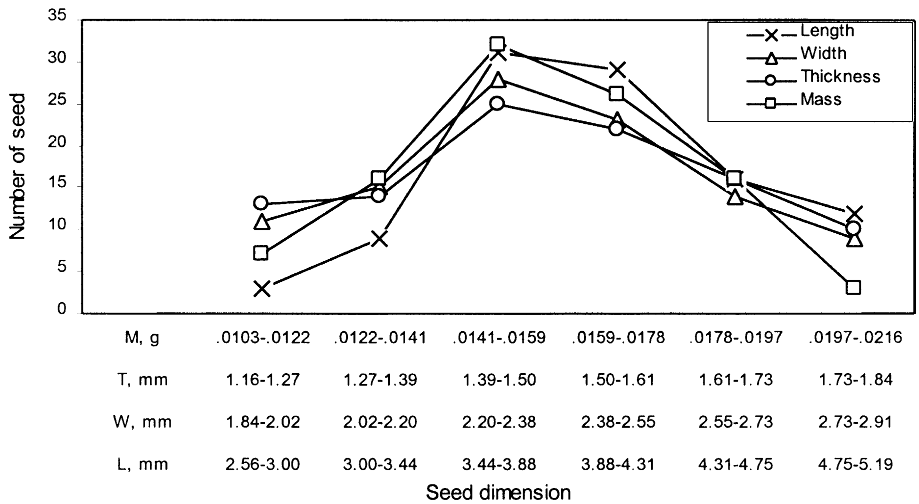

Fig. 1. Frequency distribution curves of fenugreek seed length, width, thickness and unit mass of the seed at 8.9% moisture content (db).

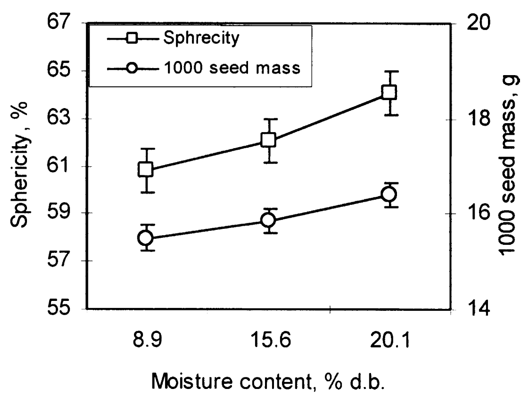

Fig. 2. Effect of moisture content on sphericity and 1000 seed mass.

3.4. Volume

The values of volume were calculated with Eq. (3) by using the data on unit mass of the seed and kernel density of the fenugreek seed, and the results obtained are presented in Fig. 3. The volume of fenugreek seed was observed to increase linearly from 12.58 to 13.83 mm^3 with increase in moisture content from 8.9% to 20.1% d.b. The relationship between moisture content and single seed volume (V) can be represented by following equation:

$$V = 11.89 + 0.625M_c \quad (R^2 = 0.969). \tag{9}$$

Similar trends of increase have been reported by Öğüt (1998) and Baryeh (2002) for white lupin and millet, respectively.

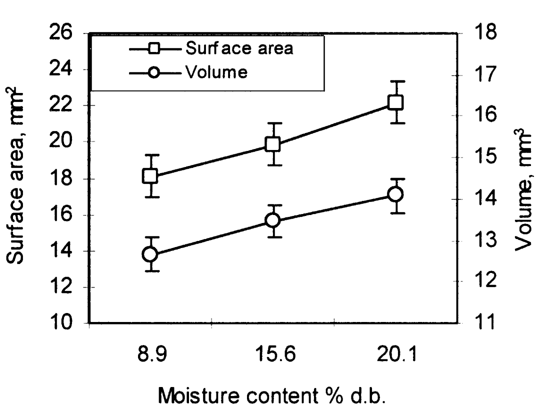

Fig. 3. Effect of moisture content on area and single seed volume.

3.5. Surface area

The values of surface area were calculated with Eq. (4) by using the data on geometric mean diameter and major axis of the fenugreek seed and the results obtained are presented in Fig. 3. The surface area of the fenugreek seed increased from 18.09 to 22.18 mm^2 as the moisture content increased from 8.9% to 20.1% d.b. The relationship between moisture content and surface area (S) appears linear and can be represented by the regression equation:

$$S = 15.953 + 2.045M \quad (R^2 = 0.994). \tag{10}$$

Similar trends of increase have been reported by Sacilik et al. (2003) and Baryeh (2002) for hemp seed and millet, respectively.

3.6. Bulk density

The bulk density of fenugreek seeds at different moisture levels varied from 701.16 to 645.81 kg/m^3 (Fig. 4) and indicated a decrease in bulk density with an increase in moisture content. The relationship between moisture content (M_c) and bulk density (ρ_b) appears linear and can be represented by the regression equation:

$$\rho_b = 726.76 - 27.675M_c \quad (R^2 = 0.983). \tag{11}$$

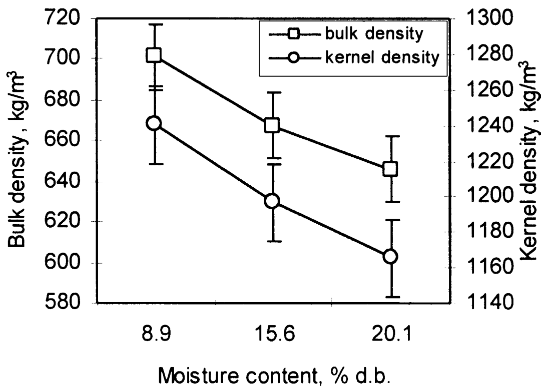

Fig. 4. Effect of moisture content on bulk density and kernel density.

The similar decreasing trend in bulk density has been reported by Öğüt (1998), Konak, Çarman, and Aydin (2002), Sacilik et al. (2003) and Özarslan (2002) for white lupin, chickpea, hemp seed and cottonseed, respectively.

3.7. Kernel density

The kernel density of fenugreek seeds at different moisture levels varied from 1240.36 to 1165.25 kgm^{-3} (Fig. 4). The effect of moisture content on kernel of fenugreek seed showed a decrease with increasing moisture content. The relationship existing between moisture content and kernel density (ρ_k) appears linear and can be represented by the regression equation:

$$\rho_k = 1275.8 - 37.555M_c \quad (R^2 = 0.991). \tag{12}$$

This finding is supported by Deshpande et al. (1993), Aydin, Öğüt, and Konak (2002), Kaleemullah and Gunasekar (2002) and Sacilik et al. (2003) for soybean, Turkish mahaleb and arecanut kernels, respectively.

3.8. Porosity

The values of porosity were calculated with Eq. (5) by using the data on bulk and kernel densities of the fenugreek seed and the results obtained are presented in Fig. 5. The porosity of the fenugreek seed decreased from 43.47% to 44.58% as the moisture content increased from 8.9% to 20.1% d.b. (Fig. 5). The relationship existing between moisture content and porosity (ε) appears linear and can be represented by the regression equation:

$$\varepsilon = 42.987 + 0.555M_c \quad (R^2 = 0.952). \tag{13}$$

The results were similar to these reported by Gupta and Das (1997) and Sacilik et al. (2003) for sunflower and hemp seed, respectively.

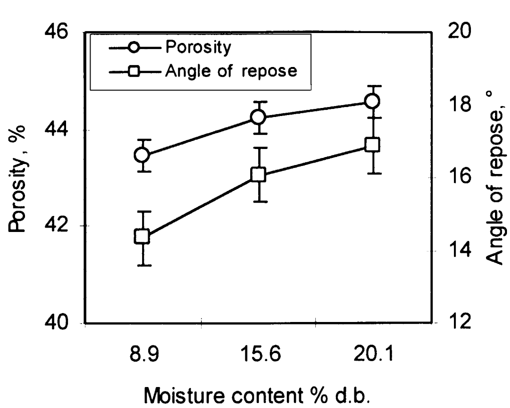

Fig. 5. Effect of moisture content on porosity and angle of repose.

3.9. Angle of repose

The experimental results for angle of repose with respect to moisture content are shown in Fig. 5. and it was observed to increase linearly from 14.34° to 16.88° with increase in moisture content from 8.9% to 20.1% d.b. The relationship between moisture content and angle of repose (Θ) can be represented by the following equation:

$$\Theta = 13.223 + 1.27M_c \quad (R^2 = 0.958). \tag{14}$$

These results were similar to those reported by Joshi, Das, and Mukherjee (1993), Gupta and Das (1997) and Sacilik et al. (2003) for pumpkin seed, sunflower and hemp seed, respectively.

3.10. Static and dynamic coefficient of friction

The effect of moisture of fenugreek seed on the static and dynamic coefficients of friction against the various test surfaces, namely, plywood, mild steel and galvanised metal are given Fig. 6. From these, static coefficients of friction at any moisture content is higher than dynamic coefficients of friction. The static and dynamic coefficients of friction increased also linearly with respect to moisture content for all three surfaces. At all moisture contents, both the static and dynamic coefficients of friction were highest in plywood, followed mild steel and galvanized metal. This may be due to smoother and more polished surface of galvanized metal than other test surfaces.

The linear equations for both static and dynamic coefficients of friction on all three surfaces can be formulated to be:

$$\mu = A + BM_c \tag{15}$$

where μ is the coefficient of friction and A and B are regression coefficients. These values are given in Table 1.

The static and dynamic coefficients of friction ranged from 0.464 to 0.567 and 0. 385 to 0.475, respectively for plywood; 0.446–0.554 and 0.370–0.458, respectively for mild steel and 0.420–0.501 and 0.343–0.402, respectively for galvanized metal as the moisture content increased from 8.9% to 20.1% d.b., respectively (Fig. 6). The

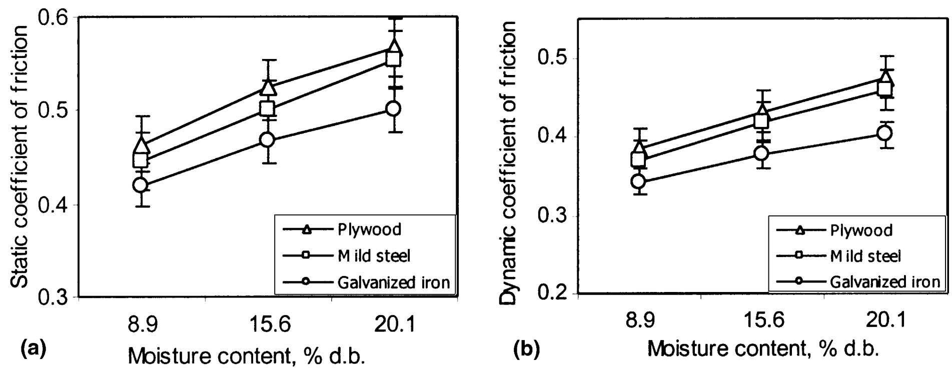

Fig. 6. Effect of moisture content on static and dynamic coefficient friction of fenugreek seeds against various surfaces: plywood, mild steel, galvanized metal.

Table 1
Regression coefficients and coefficients determination of Eq. (7) for static and dynamic coefficients of friction on various friction surfaces

Surface	Regression coefficient		Coefficient of determination (R^2)
	A	B	
Static coefficient of friction			
Plywood	0.415	0.052	0.991
Mild metal	0.392	0.054	0.999
Galvanized metal	0.382	0.041	0.992
Dynamic coefficient of friction			
Plywood	0.341	0.045	0.999
Mild metal	0.327	0.044	0.997
Galvanized metal	0.315	0.030	0.989

plywood as a surface for sliding offered the maximum friction followed by mild metal and galvanized metal. Similar results were found by other researchers (Amin, Hossain, & Roy, 2004; Baryeh, 2002; Çarman, 1996; Gupta & Das, 1997; Öğüt, 1998).

4. Conclusion

The following conclusions are drawn from the investigation on physical properties of fenugreek seeds for moisture content range of 8.9–20.1% d.b.

1. The average length, width, thickness, geometric mean diameter and unit mass of the fenugreek seed ranged from 4.01 to 4.19 mm, 2.35 to 2.61 mm, 1.49 to 1.74 mm, 2.40 to 2.66 mm and 0.0157 to 0.0164 g as the moisture content increased from 8.9% to 20.1% d.b., respectively.
2. As moisture content increased from 8.9% to 20.1% d.b., sphericity, 1000 seed mass, volume, surface area, porosity and angle of repose of fenugreek seed were varied from 60.79% to 64.06%, 15.48 to 16.39 g, 12.58 to 13.83 mm^3, 18.09 to 22.18 mm^2, 43.47% to 44.58% and 14.34° to 16.88°, respectively. As the moisture content increased from 8.9% to 20.1% d.b., the bulk density and kernel density were found to decrease from 701.16 to 645.81 kg/m^3 and 1240.36 to 1165.25 kg/m^3, respectively.
3. The static and dynamic coefficients of friction on various surfaces increased linearly with increase in moisture content. At all moisture contents, the static coefficient of friction ranged from 0.464 to 0.567, 0.446 to 0.554 and 0.420 to 0.501 for plywood, mild steel and galvanized metal, respectively. Corresponding values of dynamic coefficient of friction were found to vary from 0.385 to 0.475, 0.370 to 0.458 and 0.343 to 0.402 for plywood, mild steel and galvanized metal, respectively. The plywood as a surface for sliding offered the maximum friction followed by mild metal and galvanized metal.

References

Amin, M. N., Hossain, M. A., & Roy, K. C. (2004). Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering, 65*, 83–87.

Anonymous (2000). *Agricultural structure, production, price and value*. State Institute of Statistics, Prime Ministry Republic of Turkey. Ankara, Turkey.

Aydin, C. (2003). Physical properties of almond nut and kernel. *Journal of Food Engineering, 60*, 315–320.

Aydin, C., Öğüt, H., & Konak, M. (2002). Some physical properties of Turkish Mahaleb. *Biosystem Engineering*. doi 10.1016/beng.2002.0062.

Baryeh, E. A. (2002). Physical properties of millet. *Journal of Food Engineering, 51*, 39–46.

Baryeh, E. A., & Mangope, B. K. (2002). Some physical properties of QP-38 variety pigeon pea. *Journal of Food Engineering, 56*, 59–65.

Çarman, K. (1996). Some physical properties of lentil seeds. *Journal of Agricultural Engineering Research, 63*(2), 87–92.

Deshpande, S. D., Bal, S., & Ojha, T. P. (1993). Physical properties of soybean seeds. *Journal of Agricultural Engineering Research, 56*, 89–92.

Food reference (2004). *Food history, herbs: fenugreek*. Food reference website, www.foodreference.com.

Gupta, R. K., & Das, S. K. (1997). Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research, 66*, 1–8.

Joshi, D. C., Das, S. K., & Mukherjee, R. K. (1993). Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research, 54*(3), 219–229. doi: 10.1016/jaer.1993.1016.

Kaleemullah, S., & Gunasekar, J. J. (2002). Moisture-dependent physical properties of arecanut kernels. *Biosystem Engineering, 82*(3), 331–338.

Kara, M., Turgut, N., Erkmen, Y., & Güler, I. E. (1997). Determination of coefficient of friction of some granules. *17th National Symposium on Mechanization in Agriculture*. (pp. 609–614). Tokat. Turkey (in Turkish).

Konak, M., Çarman, K., & Aydin, C. (2002). Physical properties of chickpea seeds. *Biosystems Engineering, 82*(1), 73–78. doi: 10.1006/bioe.2002.0053.

Mohsenin, N. N. (1970). *Physical properties of plant and animal materials*. New York: Gordon and Breach Science Publishers.

Ogunjimi, L. A. O., Aviara, N. A., & Aregbesola, O. A. (2002). Some engineering properties of locust bean seed. *Journal of Food Engineering, 55*, 95–99.

Öğüt, H. (1998). Some physical properties of white lupin. *Journal of Agricultural Engineering Research, 69*(3), 273–277. doi: 10.1006/jaer.1997.0252.

Olajide, J. D., & Ade-Omowaye, B. I. O. (1999). Some physical properties of locust bean seed. *Journal of Agricultural Engineering Research, 74*(2), 213–215. doi: 10.1006/jaer.1997.0243.

Özarslan, C. (2002). Some physical properties of cotton seed. *Biosystems Engineering, 83*(2), 169–174.

Sacilik, K., Öztürk, R., & Keskin, R. (2003). Some physical properties of hemp seed. *Biosystems Engineering, 86*(2), 213–215. doi: 10.1006/S1537-5110(03)00130-2.

Sitkei, G. (1976). *Mechanic of agricultural materials*. Budapest: Akademia Kiado.

Srivastava, A. K., Mahoney, W. T., & West, N. L. (1990). *The effect of crop properties on combine performance*. ASAE Paper No. 63–67.

Suthar, S. H., & Das, S. K. (1996). Some physical properties of karingda [*Citrus lanatus (thumb) mansf*] seeds. *Journal of Agricultural Engineering Research, 65*(1), 15–22. doi: 10.1006/jaer.1996.090015.

Turkish culture (2004). *Turkish Cultural Foundation, culinary_arts, pastirma*. Turkishculture website www.turkishcoulture.org/culinaryarts/pastirma.html.

Vilche, C., Gely, M., & Santalla, E. (2003). Physical properties of quinoa seeds. *Biosystems Engineering, 86*(1), 59–65.

Visvanathan, R., Palanisamy, P. T., Gothandapani, L., & Sreenarayanan, V. V. (1996). Physical properties of neem nut. *Journal of Agricultural Engineering Research, 63*(1), 19–25. doi: 10.1006/jaer.1996.0003.