Int. Agrophysics, 2008, 22, 239-244

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Physical and mechanical properties of soybean

H. Kibar* and T. Öztürk

Department of Agricultural Structures and Irrigation, Faculty of Agriculture, University of Ondokuz Mayis, 55139, Kurupelit-Samsun, Turkey

Received March 7, 2008; accepted July 3, 2008

A b s t r a c t. The physical and mechanical properties of soybean were determined at 8 to 16% moisture content. In this moisture range, grain length, width, thickness, arithmetic average diameter and geometric average diameter increased from 7.24 to 8.19, 6.79-7.12, 5.78-6.23, 6.60-7.18, 6.57-7.14 mm, respectively. The volume of grain and area of grain surface increased linearly from 130.97 to 160.32 and from 125.46 to 144.39 mm^2, respectively. The sphericity, bulk density, true density and porosity decreased linearly from 0.91 to 0.87, 766.12-719.00, 983.33-905.67 kg m^{-3} and 22.58 to 20.61%, respectively. The angle of internal friction increased linearly from 27.37 to 31.81° with the increase of moisture content. The static coefficient of friction increased from 0.385 to 0.571, 0.304-0.441 and 0.164-0.286 for concrete, wood and galvanized steel surfaces, respectively.

K e y w o r d s: soybean, physical properties, moisture content, angle of internal friction

INTRODUCTION

Nowadays, soybean can be said to be a plant increasingly important for agriculture, because it is one of the main food sources in human and animal nutrition. It is a food source which contains high quality protein and does not contain cholesterol and saturated fatty acids. It is used in food industry for fat products (gliserol, refined soybean oil), complete soybean products and soybean protein products (soybean flour or soybean crust). Soybean is produced at about 195 000 000 tons in the world every year. The largest soybean producer of the world is the USA. That country produces nearly 2/3 of the total world production, followed by Brazil, Argentina and China (Taş, 2003).

In Turkey, soybean cultivation began after the first World War. It was cultivated firstly as a first crop in the Black Sea region and the production reached 10 000-12 000 t. After that it began to be cultivated as a second crop in irrigable areas of the Aegean and Mediterranean regions. Nowadays in Turkey soybean is cultivated predominantly in the Çukurova region. Soybean production increased steadily from 1981 to 1987 in Turkey. Later its production decreased to 50 000 or 60 000 tones. One of the important factors of the decrease lies in the fact that companies responsible for the purchase do not have suuffient storage systems (Anaç and Ertürk, 2003).

Nowadays, engineers greatly complicated systems in the design of storage structures of crops and in the selection of storage equipment. Both structural properties and features of the stored material are important in the design of storage equipment and facilities (Molenda *et al*., 2004).

In recent years, some studies on the physical and mechanical properties which appear to be important in the storage of granular products have been conducted intensively (Karababa, 2006; Baryeh, 2001; Baümler *et al.*, 2004).

The aim of this study was to find out some physical and mechanical properties of grain such as dimensions of grain, sphericity, volume of grain, surface area of grain, bulk density, true density, porosity, angle of internal friction and static coefficient of friction in order to design soybean storage structures.

MATERIALS AND METHODS

Soybean used as research material was provided by the Unity of the Blacksea Agricultural Cooperation which is one of the important agricultural cooperatives in Turkey. Broken, split, spoiled and deformed grains were discarded before samples were prepared for the experiment. The equilibrium moisture content of the samples was determined by drying them at 105±5°C in drying oven during 24 h.

The equilibrium moisture content under laboratory conditions was taken as the reference for the desired moisture content in soybeans. While drying was done to

*Corresponding author's e-mail: hkibar@omu.edu.tr

achieve conditions below the level of balance moisture, Eq. (1) developed by Balasubramanian (2001) was used for the conditions over the level of balance moisture and then this amount was added to the moisture.

After desired amount of distillate water in samples was calculated and applied, the samples were placed in polyethylene bags individually and closed. The samples were placed in a refrigerator in order to be uniformly moistured. The samples were removed from the refrigerator and kept at room temperature before the experiment was started. The physical and mechanical proporties of grain were investigated at four moisture levels (8-16% d.b.). At every moisture content, the length (*L*), width (*W*), and thickness (*T*) were measured for 100 soybeans using random sampling method (Fig. 1). Length, width and thickness of the samples were measured using a digital compass with 0.01 mm accuracy:

$$Q = \frac{W_i (M_f - M_i)}{100 - M_f}. \quad (1)$$

where: W_i – dry sample weight (g), M_f – final moisture content of sample (%), M_i – initial moisture content of sample (%).

The geometric average diameter (D_g) of soybean grain was calculated using Eq. (2) as follows;

$$D_g = (LWT)^{0.333}. \quad (2)$$

The sphericity (ϕ), volume of grain (V) and surface area of grain (S) in the samples, depending on the shape of grain, were determined using Eqs (3), (4) and (5) as described by Jain and Bal (1997):

$$\phi = \left[\frac{B(2L - B)}{L^2}\right]^{1/3}, \quad (3)$$

$$V = \frac{\pi B L^2}{6(2L - B)}, \quad (4)$$

$$S = \frac{\pi B L^2}{2L - B}, \quad (5)$$

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

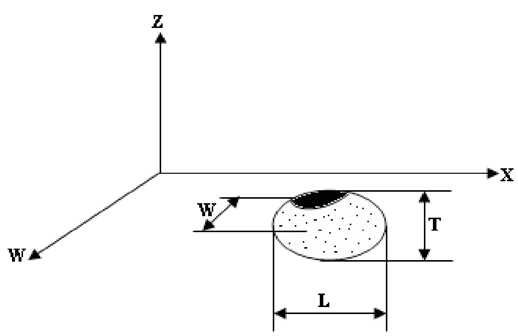

Fig. 1. Characteristic dimensions of soybean.

To determine the bulk density of the experimental samples at different moisture levels, the method defined by Mohsenin (1980) and Singh and Goswami (1996) was used. Weight of a bulk density container of 1 000 ml volume and 108 mm height was used to determine bulk density. The bulk density container was filled up to 5 cm above the top. The soybeans were then allowed to settle into the container and the bulk density was calculated from the following Eq. (6);

$$\gamma = \frac{G_2 - G_1}{V}, \quad (6)$$

where: γ – bulk density (kg m^{-3}), G_1 – free weight of bulk density bucket (kg), G_2 – weight of bulk density bucket with hazelnuts (kg).

The liquid displacement method, as described by Baryeh (2001) and Abalone *et al*. (2004), was used to determine the true density of soybean samples. In this method, toluene (C_7H_8) was used in place of water because it is absorbed to a lesser extent by soybeans and its surface tension is low. To calculate true density, the air dried weight for samples was first determined. The samples were then submerged in toluene and the displacement volume was determined. In the second stage, the true density of samples was calculated by using Eq. (7) as follows:

$$\rho = \frac{m_s + m_w}{V_s + V_w}, \quad (7)$$

where: m_s – weight of liquid (kg), m_w – weight of air dry sample (kg), V_s – volume of liquid (m^3), V_w – volume of sample (m^3).

To determine the angle of internal friction of soybean samples at the different moisture content the direct shear method was used according to Uzuner (1996), Zou and Brusewitz (2001), Molenda *et al*. (2002) and Mani *et al*. (2004). The velocity used during the experiment was 0.7 mm min^{-1} and the angle of internal friction of samples was calculated by using Eqs (8), (9) and (10) as follows:

$$\sigma = \frac{N}{A} 100, \quad (8)$$

where: σ – normal stress (kPa), N – load applied over sample (kg), A – cellular area (cm^2),

$$\tau = \frac{T_s}{A} 100, \quad (9)$$

where: τ – stretch of cutting (kPa), T_s – strength of cutting (kg),

$$\tau = (C + \sigma \, tg \, \phi), \quad (10)$$

where: C – cohesion.

The static and dynamic coefficients of friction of samples were determined according to the method of Beyhan *et al*. (1994). Wood, concrete (C30) and galvanized steel surfaces were used as friction surfaces. During the experiment, the test surface moved at a low velocity (2.4 cm s^{-1}). The surfaces were driven by a 12V adjustable direct current motor, and the force of friction was measured by using a digital dynamometer. The force of friction was taken into consideration as an important parameter to determine static coefficients of friction. Static coefficient of friction was calculated with constant force of friction read from the digital dynamometer after the friction surface started to move. The static coefficients of friction of the samples were calculated by using Eq. (11) as follows;

$$\mu_s = \frac{F_s}{W_n}, \tag{11}$$

where: μ_s – static coefficient of friction, F_s – strength of friction (N), W_n – normal strength (N).

RESULTS AND DISCUSSIONS

Mean values of the size dimensions of soybean at different moisture contents are presented in Table 1. As also seen in Table 1, all the dimensions increased with increase of moisture content within the moisture range of 8-16% (d.b.). The relationships between the axial dimensions (*L, W, T* and D_g) and moisture content of grain (M_c) can be represented by the regression equations:

$$L = 6.318 + 0.117\, M_c \quad (R^2=0.99), \tag{12}$$

$$W = 6.460 + 0.041\, M_c \quad (R^2=0.99), \tag{13}$$

$$T = 5.360 + 0.055\, M_c \quad (R^2=0.98), \tag{14}$$

$$D_g = 6.020 + 0.070\, M_c \quad (R^2=0.99), \tag{15}$$

by means of which the regression relationship was determined. This results show that there is an important and positive relationship between moisture content of grain and axial dimensions of grain.

The relationship between sphericity and moisture content of grain is shown in Fig. 2a. The sphericity of the samples decreased linearly depending on the increase of moisture content. While the ratio of sphericity was 0.91 at a moisture content of 8%, it was determined as 0.87 at moisture content of 16%. Linearly negative change of sphericity depending on the increase of moisture content can also be observed in some grainy products such as groundnut, peanut (Baryeh, 2001; Baryeh, 2002).

Volumetric change depending on moisture content of grain is shown in Fig. 2b. The volume of grain of samples increased linearly with the increase of moisture content. The volume of grain increased from 130.97 to 160.32 mm^3 when moisture content changed from 8% to 16%. The relationship between moisture content (M_c) and volume (V) can be expressed by the following regression equation;

$$V = 102.45 + 3.64\, M_c \quad (R^2=0.99). \tag{16}$$

The positive relationship between volumetric change and change of moisture content of crops was also found in some grainy products such as groundnut and corn (Baryeh, 2001; Karababa, 2006).

The surface area of grain (S) is shown in Fig. 2c. The surface area of the samples increased with the increase of moisture content. Figure 1 indicates that the surface area of grain increases with increasing moisture content for soybean. The following general expression can be used to describe the relationship between moisture content (M_c) and surface area of grain (S):

$$S = 107.13 + 2.34\, M_c \quad (R^2=0.99). \tag{17}$$

The same results for grainy products are given by Paksoy and Aydın (2004) and Altuntaş *et al.* (2005).

The change of porosity with moisture content is shown in Fig. 2d. The porosity in samples decreased linearly depending on the increase of moisture content. The porosity (ε) and the moisture content of soybean can be correlated as:

$$\varepsilon = 24.75 - 0.25\, M_c \quad (R^2=0.98). \tag{18}$$

T a b l e 1. Axial dimensions of soybean (standard deviation in parentheses)

Moisture content (% d.b.)	Length	Width	Thickness	Arithmetic average diameter	Geometric average diameter
	(mm)				
8	7.32 (0.39)	6.79 (0.41)	5.78 (0.34)	6.60	6.57
10	7.49 (0.41)	6.88 (0.31)	5.92 (0.29)	6.76	6.73
12	7.77 (0.38)	6.97 (0.36)	6.05 (0.30)	6.93	6.89
14	7.93 (0.47)	7.06 (0.26)	6.12 (0.25)	7.04	7.00
16	8.19 (0.51)	7.12 (0.27)	6.23 (0.27)	7.18	7.14

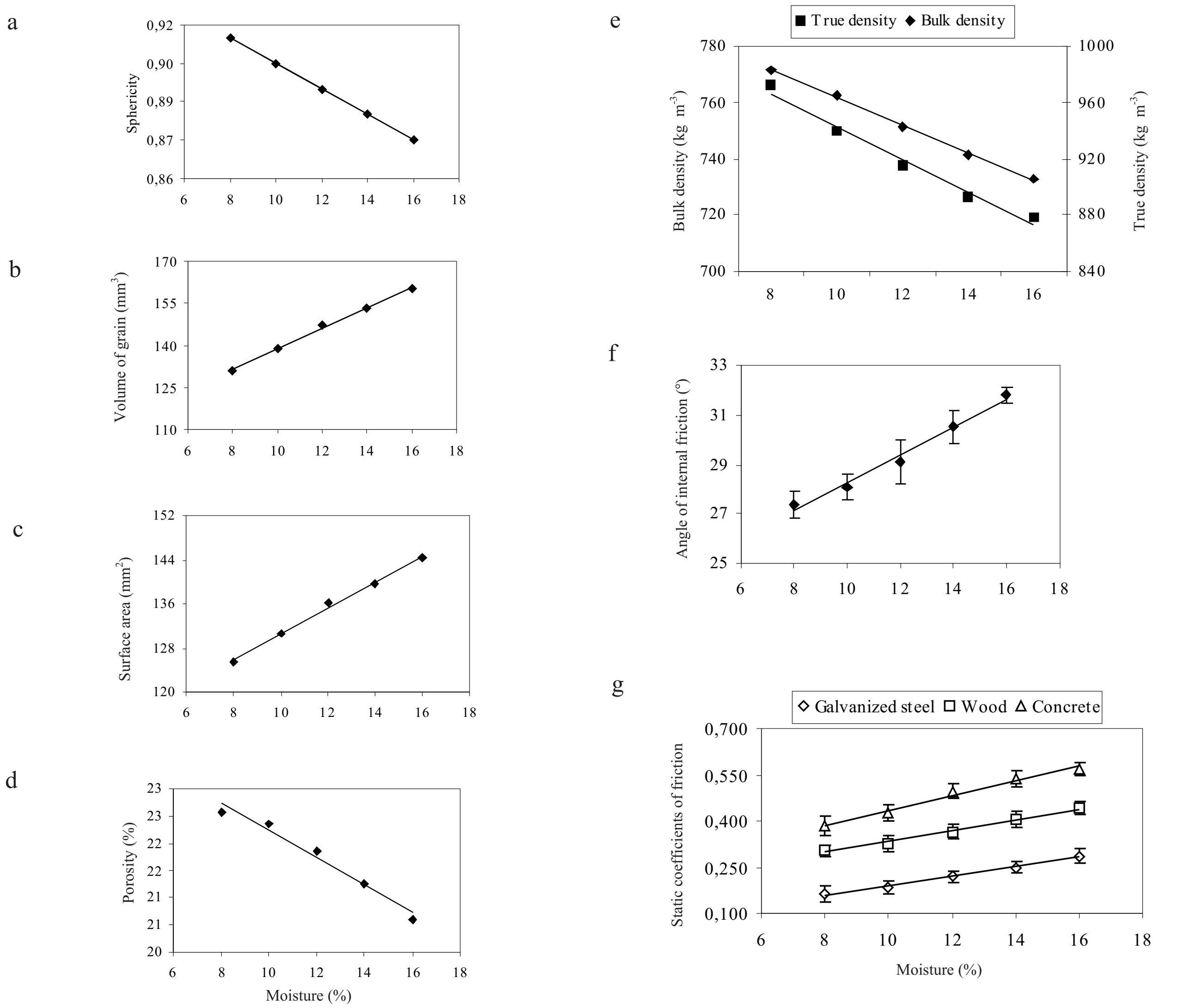

Fig. 2. Effect of moisture content on: a – sphericity, b – volume of grain, c – surface area of grain, d – porosity, e – bulk density and true density, f – angle of internal friction, g – static coefficient of friction.

Similar results were obtained from the studies conducted on the relationship between the moisture content and the porosity in some grainy products (Saçılık *et al.*, 2003; Kabas *et al.*, 2005; Kingsly *et al.*, 2006).

The bulk density of grains varied between 766 and 719 kg m^{-3} and it decreased linearly with the increase of moisture content. The true density of grains varied between 983 and 905 kg m^{-3} and it also decreased linearly with the increase of moisture content (Fig. 2e). The following general expression can be used to describe the relationships among moisture content (M_c), bulk density (γ) and true density (ρ):

$$\gamma = 809.47 - 5.83 M_c \quad (R^2=0.97), \tag{19}$$

$$\rho = 1062.40 - 9.88 M_c \quad (R^2=0.99). \tag{20}$$

The regression equations indicate that the increase of moisture content caused a decline both in bulk density and in true density. It was also observed that the increase of moisture content of grain depending on structure of fibre in grainy products affected bulk density and true density in studies made by Gupta and Das (1997), Baryeh (2001), Sahoo and Srivastava (2002), Aviara *et al.* (2005), Altuntaş *et al.* (2005), Mwithiga and Sifuna (2005) and Yalçın (2006).

The angle of internal friction and standard errors of soybean samples are presented in Fig. 2f. The angle of internal friction increased with the increase of moisture content in the samples. A positive linear relationship between the moisture content and angle of internal friction was determined. Although the highest value for the angle of internal friction (θ = 31.8°) was recorded at 16% moisture content, the lowest value for the angle of internal friction (θ = 27.4°)

was recorded at 8% moisture content. The relationship between moisture content and angle of internal friction of soybean was given by the following equation:

$$\theta = 22.58 + 0.56\, M_c \quad (R^2=0.98), \qquad (21)$$

where: θ – angle of internal friction (°).

Molenda *et al*. (1998) also found in their study that the angle of internal friction increased linearly with increase of moisture content.

The static coefficients of friction and standard errors for soybean depending on moisture content and surface (wood, concrete, steel) are presented in Fig. 2g. It was observed that the static coefficient of friction increased linearly with the increase of the moisture content of grain for all three friction surfaces.

While the highest value for the static coefficient of friction (0.571) with the increase of moisture content of grain was recorded for concrete – at 16% moisture content, the lowest value for static coefficient of friction (0.164) was recorded for galvanized steel surface at 8% moisture content. The regression equations related to the static coefficient of friction in samples and R^2 values are given in Table 2.

T a b l e 2. Regression equations relating to static coefficient of friction of soybean

Surface	Regression equations
Galvanized steel	$\mu = 0.035+0.016\, M_c$ ($R^2 = 0.98$)
Wood	$\mu = 0.156+0.018\, M_c$ ($R^2 = 0.99$)
Concrete (C30)	$\mu = 0.193+0.024\, M_c$ ($R^2 = 0.98$)

Beyhan *et al*. (1994) suggest that the relationship between friction surface and moisture content is important in grainy products on static coefficient of friction. It was also observed in this research that the static coefficient of friction increased linearly with the increase of moisture content of crop for three friction surfaces (wood, concrete, steel) in soybean.

CONCLUSIONS

1. Shape of grain and characteristic dimensional properties such as length, width, thickness, the arithmetic average diameter and the geometric average diameter, increased linearly depending on the increase of moisture content.

2. Sphericity decreased linearly with the increase of moisture content.

3. Volume of grain and surface area of grain increased linearly with the increase of moisture content

4. True density, bulk density and porosity decreased linearly depending on the increase of moisture content.

5. Angle of internal friction increased from 27.4 to 31.8° for grain moisture content increase from 8 to 16%.

6. Static coefficients of friction, depending on friction surface, increased linearly with the increase of moisture content. While the highest value for the static coefficient of friction was recorded for concrete at 16% moisture content, the lowest value for the static coefficient of friction was recorded for galvanized steel surface at 8% moisture content.

REFERENCES

Abalone R., Cassinera A., Gaston A., and Lara M.A., 2004. Some physical properties of amaranth seeds. Biosystems Eng., 89, 109-117.

Altuntaş E., Özgöz E., and Taşer Ö.F., 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J. Food Eng., 71, 37-43.

Anaç H. and Ertürk Y.E., 2003. Soybean. Agricultural Economics Research Instıtute, View, 2, 1-4.

Aviara N.A., Maman E., and Umar B., 2005. Some physical properties of *Balanites Aegytiaca* nuts. Biosystems Eng., 92, 325-334.

Balasubramanian D., 2001. Physical properties of raw cashew nut. J. Agric. Eng. Res., 78, 291-297.

Baryeh E.A., 2001. Physical properties of bambara groundnuts. J. Food Eng., 47, 321-326.

Baryeh E.A. and Mangope B.K., 2002. Some physical properties of QP-38 variety pigeon pea. J. Food Eng., 56, 59-65.

Baümler E., Cuniberti A., Nolasco S.M., and Riccobene I.C., 2006. Moisture dependent physical and compression properties of safflower seed. J. Food Eng., 72, 134-140.

Beyhan M.A., Nalbant M., and Tekgüler A., 1994. Determination of coefficient of friction in the grain and husk hazelnuts for different surfaces. Proc. XV Nat. Cong. 'Agricultural Mechanization', September 20-22, Antalya, Turkey, 343-352.

Gupta R.K. and Das S.K., 1997. Physical properties of sunflower seeds. J. Agric. Eng. Res., 66, 1-8.

Jain R.K. and Bal S., 1997. Properties of pearl millet. J. Agric. Eng. Res., 66, 85-91.

Kabas O., Ozmerzi A., and Akıncı I., 2005. Physical properties of cactus pear (*Opuntia ficus india* L.) grown wild in Turkey. J. Food Eng., 73, 198-202.

Karababa E., 2006. Physical properties of popcorn kernels. J. Food Eng., 72, 100-107.

Kingsly A.R.P., Singh D.B., Manikantan M.R., and Jain R.K., 2006. Moisture dependent physical properties of dried pomegranate seeds. J. Food Eng., 75, 492-496.

Mani S., Tabil L.G., and Sokhansanj S., 2004. Mechanical properties of corn stover grind. Transactions of the ASAE, 47, 1983-1990.

Molenda M., Horabik J., and Ross I.J., 1998. Stress and deformation of wheat in direct shear test. Int. Agrophysics, 12, 115-118.

Molenda M., Horabik J., Thompson S.A., and Ross I.J., 2004. Effects of grain properties on loads in model silo. Int. Agrophysics, 18, 329-332.

Molenda M., Montross M.D., Horabik J., and Ross I.J., 2002. Mechanical properties of corn and soybean meal. Transactions of the ASAE, 45, 1929-1936.

Mohsenin N.N., 1980. Structure, physical characteristics and mechanical properties of plant and animal materials. Gordon and Breach Press, New York.

Mwithiga G. and Sifuna M.M., 2005. Effect of moisture content on the physical properties of three varieties of sorghum seeds. J. Food Eng., 75, 480-486.

Paksoy M. and Aydın C., 2004. Some physical of edible sguash (*Cucurbita pepo L.*) seeds. J. Food Eng., 65, 225-231.

Saçılık K., Öztürk R., and Keskin R., 2003. Some physical properties of hemp seed. Biosystems Eng., 86, 191-198.

Sahoo P.K. and Srivastava A.P., 2002. Physical properties of okra seed. Biosystems Eng., 83, 441-448.

Singh K.K. and Goswami T.K., 1996. Physical properties of cumin seed. J. Agric. Eng. Res., 64, 93-98.

Suthar S.H. and Das S.K., 1996. Some physical properties of karingda seeds. J. Agric. Eng. Res., 65, 15-22.

Taş M.T., 2003. Magical Bean: Soybean. DID Press, Ankara, Turkey.

Uzuner B.A., 1996. Soil Mechanics. Technique Press, Ankara, Turkey.

Yalçın I., 2006. Physical properties of cowpea seed. J. Food Eng., 79, 57-62.

Zou Y. and Brusewitz G.H., 2001. Angle of internal friction and cohesion of consolidated ground marigold petals. Transactions of the ASAE, 44, 1255-1259.