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Moisture Dependent Physical and Mechanical Properties of Dent Corn (*Zea mays* var. *indentata* Sturt.) Seeds (Ada-523)

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Abstract: The physical and mechanical properties of dent corn seeds were determined as a function of moisture content in the range of 11.14-24.07% dry basis (d.b.). The average length, width and thickness were 10.890, 8.173 and 4.466 mm, at a moisture content of 11.14% d.b., respectively. In the above moisture range, the arithmetic and geometric mean diameters and sphericity increased from 7.843-8.448 mm, from 7.352-7.943 mm and from 0.675-0.689, respectively, in the moisture range from 11.14-24.07% d.b. Studies on rewetted dent corn seeds showed that the thousand seed mass increased from 430-542 g, the projected area from 54.46-68.90 mm², the true density from 995.09-1100.10 kg m⁻³, the porosity from 29.60-44.51% and the terminal velocity from 6.20-7.50 m sec⁻¹. The bulk density decreased from 700.50-610.50 kg m⁻³ with an increase in the moisture content range of 11.14-24.07% d.b. The static coefficient of friction of dent corn seeds increased the logarithmic against surfaces of six structural materials, namely, rubber (0.42-0.51), aluminum (0.41-0.49), stainless steel (0.31-0.36), galvanized iron (0.31-0.39), glass (0.27-0.33) and MDF (medium density fiberboard) (0.28-0.35) as the moisture content increased from 11.14-24.07% d.b. The shelling resistance of dent corn seeds decreased as the moisture content increased from 116.13-80.44 N.

Key words: Dent corn seeds, physical properties, mechanical properties, moisture content

INTRODUCTION

Dent corns (*Zea mays* var. *indentata* Sturt.) are a cultivated plant grown for fresh and dry consumption and raw material of canned food industry. It contains 9.4 g protein, 4.2 g fat, 72 g total carbohydrates, 9 mg calcium, 2 mg iron, 363 kcal energy per 100 g (dry) (Anonymous, 2006).

Turkey has about 700,000 ha of corn harvesting area, 3,000,000 t of corn production per annual with a yield of 4,286 kg ha⁻¹ of corn and therefore is one of the foremost corn producing countries of the world (SIS, 2005).

In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of dent corn seeds, it is necessary to determine their physical properties as a function of moisture content. However, no published study seems to have been carried out on the physical and mechanical properties of dent corn seeds and their relationship with moisture content. Hence, this study was conducted to investigate some moisture dependent physical and mechanical properties of dent corn seeds namely, seed dimensions, thousand seed mass, surface area, projected area, sphericity, bulk density, true density, porosity, terminal velocity, static coefficient of friction and shelling resistance of dent corn seeds.

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MATERIALS AND METHODS

The dent corn seeds used in the study were obtained from the fields of Agricultural Faculty, Uludag University. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds.

The initial moisture content of the seeds was determined by digital moisture meter (Pfeuffer HE 50, Germany) reading to 0.01%.

The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relation (Coşkun *et al.*, 2006):

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

The samples were then poured into separate polyethylene bags and the bags sealed tightly. The samples were kept at 5°C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantity of the seed was taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h (Singh and Goswami, 1996).

All the physical properties of the seeds were determined at six moisture contents in the range of 11.14-24.07% d.b. with 10 replications at each moisture content. The range of moisture contents for corn seeds recommended for safe module storage as 14.94% d.b. (Isik and Alibaş, 2000).

To determine the average size of the seed, 100 seeds were randomly picked and their three linear dimensions namely, length (L), width (W) and thickness (T) (Fig. 1) were measured using a digital compass (Minolta, Japan) with a accuracy of 0.01 mm.

The average diameter of seed 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 seed were calculated by using the following relationships (Mohsenin, 1970).

$$D_a = (L+W+T)/3 \quad (2)$$

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

The sphericity of seeds ϕ was calculated by using the following relationship (Mohsenin, 1970):

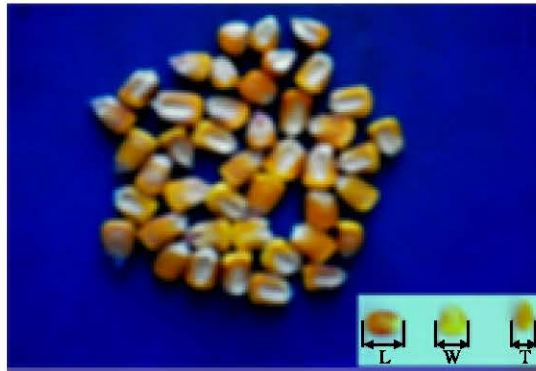


Fig. 1: Three dimensions of dent corns, length (L), width (W) and thickness (T)

$$\phi = \frac{(LWT)^{1/3}}{L} \quad (4)$$

The one thousand seed mass was determined by means of an electronic balance reading to 0.001 g.

The surface area A_s in mm^2 of dent corn seeds was found by analogy with a sphere of same geometric mean diameter, using the following relationship (Dursun and Dursun, 2005).

$$A_s = \pi D_g^2 \quad (5)$$

The projected area A_p was determined from the pictures of dent corn seeds which were taken by a digital camera (Creative DV CAM 316; 6.6 Mpixels), in comparison with the reference area to the sample area by using the Global Lab Image 2-Streamline (trial version) computer program (Işık and Güler, 2003).

The average bulk density of the dent corn seeds was determined using the standard test weight procedure reported by Singh and Goswami (1996) and Gupta and Das (1997) by filling a container of 500 mL with the seed from a height of 150 mm at a constant rate and then weighing the content.

The average true density was determined using the toluene displacement method. The volume of toluene (C_7H_8) displaced was found by immersing a weighed quantity of dent corn seeds in the toluene (Yalçın and Özarslan, 2004). The porosity was calculated from the following relationship (Mohsenin, 1970):

$$\varepsilon = (1 - \frac{\rho_s}{\rho_t})100 \quad (6)$$

The terminal velocities of seed at different moisture contents were measured using a cylindrical air column in which the material was suspended in the air stream (Nimkar and Chattopadhyay, 2001). Relative opening of a regulating valve provided at blower output end was used to control the airflow rate. In the beginning, the blower output was set at minimum. For each experiment, a sample was dropped into the air stream from the top of the air column. Then airflow rate was gradually increased till the seed mass gets suspended in the air stream. The air velocity which kept the seed suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m sec^{-1} (Özdemir and Akıncı, 2004).

The static coefficient of friction of dent corn seeds against six different structural materials, namely rubber, galvanized iron, aluminum, stainless steel, glass and MDF (medium density fiberboard) was determined. A polyvinylchloride cylindrical pipe of 50 mm diameter and 100 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the seed sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt was read from a graduated scale (Unal *et al.*, 2006). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan \alpha \quad (7)$$

where μ is the coefficient of friction and α is the angle of tilt in degrees.

Shelling resistance R_s was determined by forces applied to one axial dimension (length). The shelling resistance of seed was determined under the point load by using a penetrometer (Bosch BS45 tester, Germany).

RESULTS AND DISCUSSION

Seed Dimensions

The mean values and standard errors of the axial dimensions of the dent corn seeds at different moisture contents are presented in Fig. 2. As can be seen in Fig. 2, the three axial dimensions increased with increase in moisture content from 11.14-24.07% d.b. The mean dimensions of 100 seeds measured at a moisture content of 11.14% d.b. are: length 10.890 ± 0.131 mm, width 8.173 ± 0.074 mm and thickness 4.466 ± 0.088 mm.

The average diameter calculated by the arithmetic mean and geometric mean are also presented in Fig. 2. The average diameters increased with the increase in moisture content as axial dimensions. The arithmetic and geometric mean diameter ranged from 7.843-8.448 and 7.352-7.943 mm as the moisture content increased from 11.14-24.07% d.b., respectively.

One Thousand Seeds Mass

The one thousand dent corn seeds mass M_{1000} increased logarithmic from 430-542 g as the moisture content increased from 11.14-24.07% d.b. (Fig. 3).

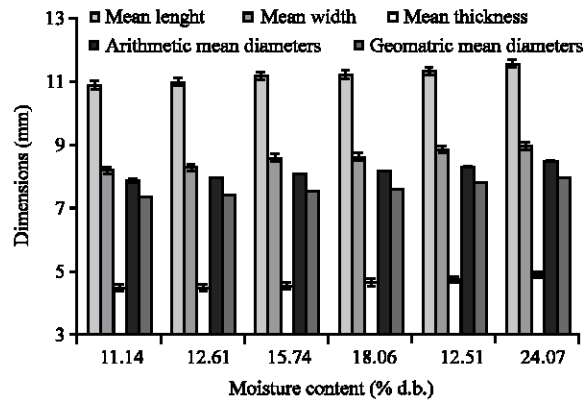


Fig. 2: Dimensions of dent corn seeds

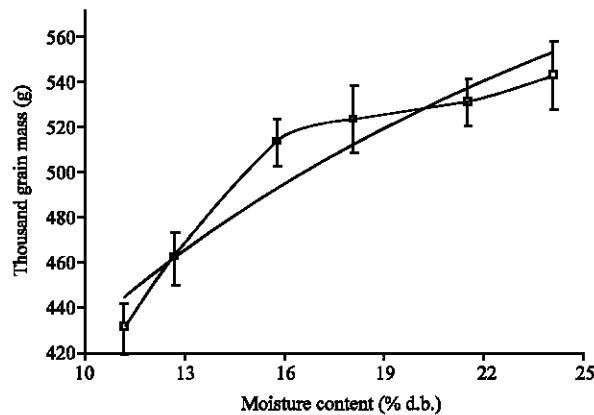


Fig. 3: Effect of moisture content on thousand grains mass of dent corn seeds

An increase of 26.04% in the one thousand seed mass was recorded within the above moisture range. The logarithmic equation for one thousand seed mass can be formulated to be:

$$M_{1000} = 104.88 + 140.62 \ln(M_c) \quad (R^2 = 0.9128) \quad (8)$$

A logarithmic increase in the one thousand dent corn seeds mass as the seed moisture content increases has been noted by Sahoo and Srivastava (2002) for okra seed.

Surface Area of Seed

The variation of the surface area with the dent corn seeds moisture content is plotted in Fig. 4. The figure indicates that the surface area increases linearly with increase in seed moisture content. The surface area of dent corn seeds increased from 169.742-198.127 mm² when the moisture content increased from 11.14-24.07% d.b.

The variation of moisture content and surface area can be expressed mathematically as follows:

$$A_s = 146.12 + 2.1162 M_c \quad (9)$$

with a value for the coefficient of determination R² of 0.9926.

Similar trends have been reported by Öztürk and Keskin (2003) for hemp seed, Dursun and Dursun (2005) for caper seed.

Projected Area of Seed

The projected area of dent corn seeds increased from 56.46 to 68.90 mm², when the moisture content of seed increased from 11.14-24.07% d.b. (Fig. 5).

The variation in projected area with moisture content of dent corn seeds can be represented by the following equation:

$$A_p = 43.941 + 1.029 M_c \quad (R^2 = 0.9797) \quad (10)$$

Similar trends have been reported by Özarslan (2002) for cotton and Konak *et al.* (2002) for chick pea seed.

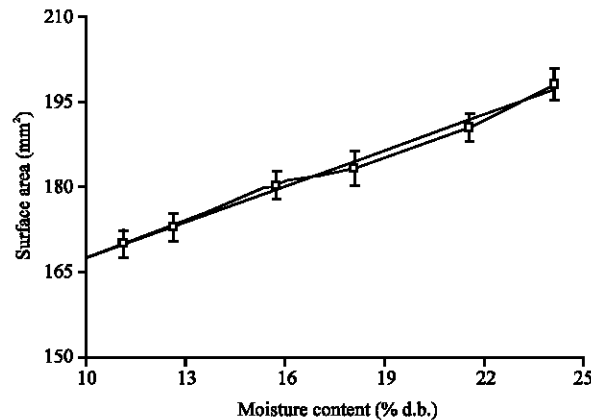


Fig. 4: Effect of moisture content on surface area of dent corn seeds

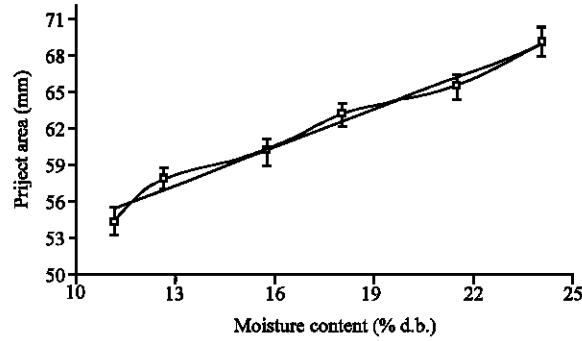


Fig. 5: Effect of moisture content on projected area of dent corn seeds

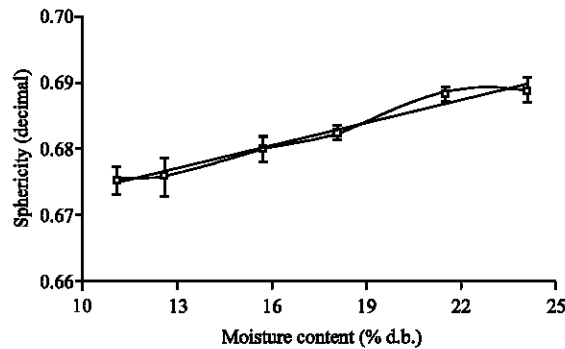


Fig. 6: Effect of moisture content on sphericity of dent corn seeds

Sphericity

The sphericity of dent corn seeds increased from 0.675-0.689 with the increase in moisture content (Fig. 6). The relationship between sphericity and moisture content M_c in % d.b. can be represented by the following equation:

$$\phi = 0.662 + 0.0011M_c \quad (R^2 = 0.9792) \quad (11)$$

Similar trends have been reported by Baryeh and Mangope (2002) for pigeon pea and Saçılık *et al.* (2003) for hemp seed.

Bulk Density

The values of the bulk density for different moisture levels varied from 700.50-610.50 kg m⁻³ (Fig. 7). The bulk density of seeds was found to bear the following relationship with moisture content:

$$\rho_b = 962.91 - 109.83 \ln(M_c) \quad (12)$$

with a value for R^2 of 0.9892.

A different decreasing trend in bulk density has been reported by Nimkar and Chattapadhyay (2001) for green gram, Saçılık *et al.* (2003) for hemp seed and Coşkun, Yalçın and Özarslan (2006) for sweet corn seed.

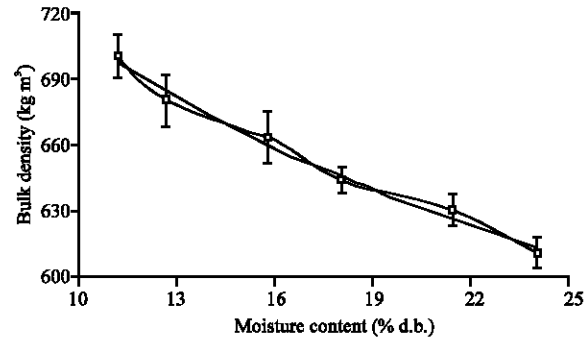


Fig. 7: Effect of moisture content on bulk density of dent corn seeds

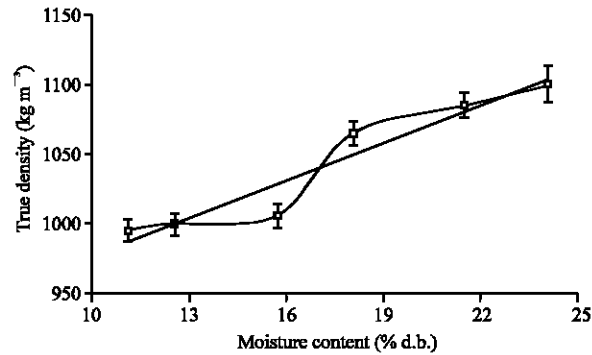


Fig. 8: Effect of moisture content on true density of dent corn seeds

True Density

The true density varied from 995.09-1100.10 kg m⁻³ when the moisture level increased from 11.14-24.07% d.b. (Fig. 8).

The true density and the moisture content of seed can be correlated as follows:

$$\rho_t = 887.62 + 8.9729 M_c \quad (13)$$

with a value for R² of 0.9224.

The results were similar to those reported by Yalçın and Özarslan (2004) for vetch seed, Aviara *et al.* (2005) for *Balanites aegyptiaca* nuts and Coşkun *et al.* (2006) for sweet corn seed.

Porosity

The porosity of dent corn seeds increased from 29.60-44.51% with the increase in moisture content from 11.14-24.07% d.b. (Fig. 9).

The relationship between porosity and moisture content can be represented by the following equation:

$$\varepsilon = 16.963 + 1.1629 M_c \quad (14)$$

with a value for R² of 0.9756.

Nimkar *et al.* (2005), Aviara *et al.* (2005) and Coşkun *et al.* (2006) reported similar trends in the case of moth gram, *Balanites aegyptiaca* nuts and sweet corn seed, respectively.

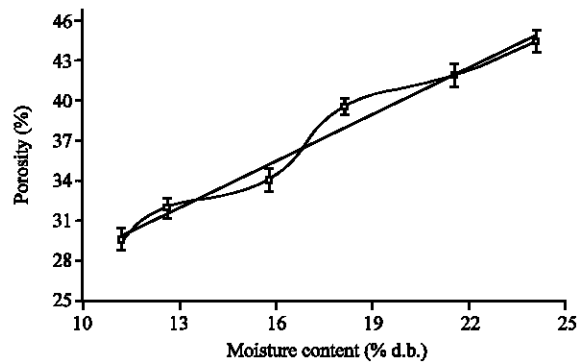


Fig. 9: Effect of moisture content on porosity of dent corn seeds

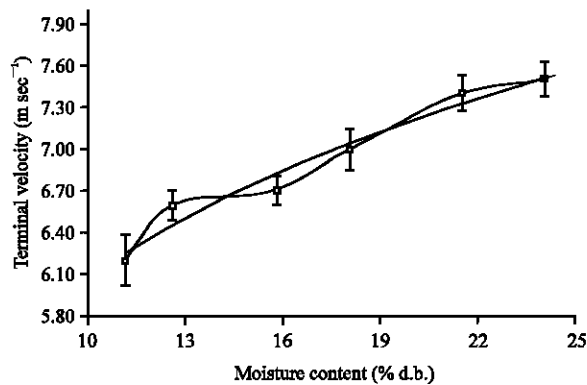


Fig. 10: Effect of moisture content on terminal velocity of dent corn seeds

Terminal Velocity

The experimental results for the terminal velocity of dent corn seeds at various moisture levels are shown in Fig. 10.

The relationship between terminal velocity and moisture content can be represented by the following equation:

$$V_t = 2.3238 + 1.6301 \ln(M_c) \quad (R^2 = 0.9641) \quad (15)$$

The terminal velocity was found to increase logarithmic from 6.20-7.50 m sec⁻¹ as the moisture content increased from 11.14-24.07% d.b. However, linear increase of terminal velocity with increase of moisture content was reported by Joshi *et al.* (1993), Suthar and Das (1996) and Gupta and Das (1997) in the case of pumpkin seeds, sunflower and karingda, respectively.

Static Coefficient of Friction

The static coefficient of friction of dent corn seeds on six surfaces (rubber, stainless steel, aluminum, glass, MDF and galvanized iron) against moisture content in the range 11.14-24.07% d.b. are presented in Fig. 11.

It was observed that the static coefficient of friction increased with increase in moisture content for all the surfaces. This is due to the increased adhesion between the seed and the material surfaces at higher moisture values. Increases of from 0.42-0.51, 0.31-0.36, 0.41-0.49, 0.27-0.33, 0.28-0.35 and

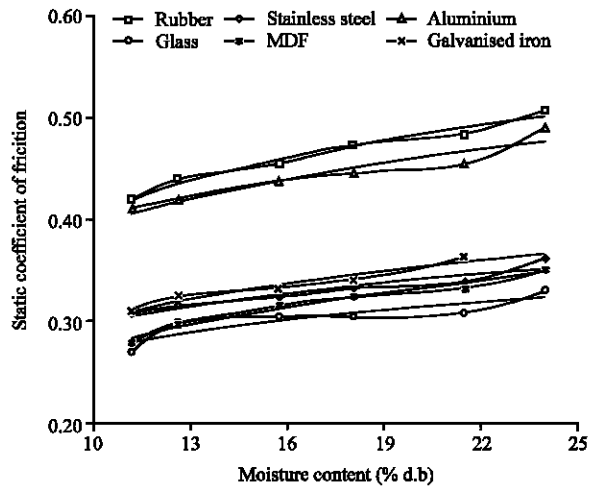


Fig. 11: Effect of moisture content on static coefficient of friction of dent corn seeds against various surface

0.31-0.39 were recorded in the case of rubber, stainless steel, aluminum, glass, MDF and galvanized iron, respectively, as the moisture content increased from 11.14-24.07% d.b.

At all moisture contents, the least static coefficient of friction were on glass. This may be owing to smoother and more polished surface of the glass sheet than the other materials used. The relationships between static coefficients of friction and moisture content on rubber (μ_{ru}), stainless steel (μ_{ss}), aluminum (μ_a), glass (μ_{gl}), MDF (μ_{mdf}) and galvanized iron (μ_g) can be represented by the following equations:

$$\mu_{ru} = 0.1718 + 0.133 \ln(M_c) \quad (R^2 = 0.9775) \quad (16)$$

$$\mu_a = 0.1924 + 0.089 \ln(M_c) \quad (R^2 = 0.9110) \quad (17)$$

$$\mu_g = 0.1355 + 0.07323 \ln(M_c) \quad (R^2 = 0.9593) \quad (18)$$

$$\mu_{ss} = 0.1551 + 0.0617 \ln(M_c) \quad (R^2 = 0.9132) \quad (19)$$

$$\mu_{mdf} = 0.0849 + 0.0822 \ln(M_c) \quad (R^2 = 0.9772) \quad (20)$$

$$\mu_{gl} = 0.1409 + 0.0573 \ln(M_c) \quad (R^2 = 0.7862) \quad (21)$$

Similar results were found by Sahoo and Srivastava (2002) for okra seed.

Shelling Resistance

The shelling resistance of dent corn seeds was found to decrease with the increase in moisture content (Fig. 12).

The small shelling resistance at higher moisture content might have resulted from the fact that the grain became more sensitive to cracking at high moisture. The variation in

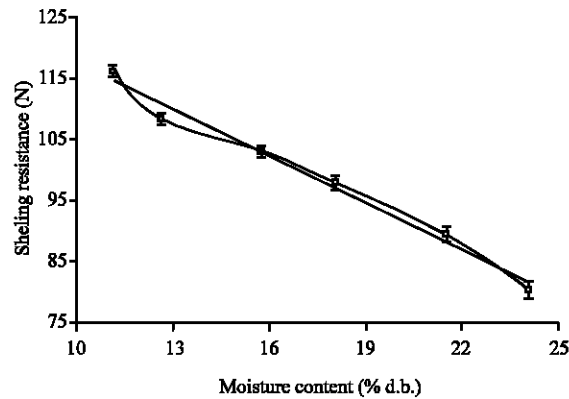


Fig. 12: Effect of moisture content on shelling resistance of dent corn seeds: (□) length

shelling resistance of dent corn seeds R_s in N with moisture content can be represented by the following equation:

$$R_s = 150.9 - 3.5445 M_c \quad (22)$$

with value for R^2 of 0.9804.

Özarslan (2002) and Konak *et al.* (2002) reported as similar decrease in shelling resistance when the moisture content was increased for cotton and chick pea grains, respectively.

CONCLUSIONS

- The average length, width and thickness of seeds ranged from 10.890-11.534, 8.173-8.960 and 4.466-4.850 mm as the moisture content increased from 11.14-24.07% d.b., respectively.
- The arithmetic and geometric mean diameters were found to increase from 7.843-8.448 and 7.352-7.943 mm, respectively.
- The thousand seed mass increased from 430-542 g and the sphericity increased from 0.675-0.689 with the increase in moisture content from 11.14-24.07% d.b.
- The bulk density decreased logarithmic from 700.50-610.50 kg m⁻³, whereas the true density increased from 995.09-1100.10 kg m⁻³.
- The terminal velocity increased logarithmic from 6.20-7.50 m sec⁻¹ as the moisture content increased from 11.14-24.07% d.b.
- The static coefficient of friction of dent corn seeds increased the logarithmic against surfaces of six structural materials, namely, rubber (0.42-0.51), aluminum (0.41-0.49), galvanized iron (0.31-0.39), stainless steel (0.31-0.36), MDF (0.28-0.35) and glass (0.27-0.33) as the moisture content increased from 11.14-24.07% d.b.
- The shelling resistance decreased as the moisture content increased from 116.13-80.44 N.

ACKNOWLEDGMENTS

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NOMENCLATURE

A_p	Projected area, mm ²	W	Width of seed, mm
A_s	Surface area, mm ²	W_i	Initial mass of sample, kg
D_a	Arithmetic mean diameter of seed, mm	ϵ	Porosity, %
D_g	Geometric mean diameter of seed, mm	α	Angle of tilt, degree
L	Length of seed, mm	μ	Static coefficient of friction
M_{1000}	Thousand seed mass, g	ρ_b	Bulk density, kg m ⁻³
M_i	Initial moisture content of sample, %d.b.	ρ_t	True density, kg m ⁻³
M_f	Final moisture content of sample, %d.b.	ϕ	Sphericity of seed (decimal)
M_c	Moisture content, % d.b.	Subscripts	
R_s	Shelling resistance, N	al	Aluminum
R^2	Coefficient of determination	gi	Galvanized iron
Q	Mass of water to added, kg	gl	Glass
T	Thickness of seed, mm	mdf	Medium density fiberboard
V_t	Terminal velocity, m sec ⁻¹	ru	Rubber
		ss	Stainless steel

REFERENCES

- Anonymous, 2006. <http://www.yaylabakliyat.com.tr>.
- Aviara, N.A., E. Mamman and B. Umar, 2005. Some physical properties of *Balanites aegyptiaca* nuts. Biosyst. Eng., 92: 325-334.
- Baryeh, E.A. and B.K. Mangope, 2002. Some physical properties of QP-38 variety pigeon pea. J. Food Eng., 56: 341-347.
- Coşkun, M.B., I. Yalçın and C. Özarslan, 2006. Physicaş properties of sweet corn seed (*Zea mays saccharata* Sturt.). J. Food Eng., 74: 523-528.
- Dursun, E. and I. Dursun, 2005. Some physical properties of caper seed. Biosyst. Eng., 92: 237-245.
- Gupta, R.K. and S.K. Das, 1997. Physical properties of sunflower seeds. J. Agric. Eng. Res., 66: 1-8.
- Isik, E. and I. Alibaş, 2000. Drying Systems. Work Book of Uludag University Agricultural Faculty, No. 3. Bursa.
- Isik, E. and T. Güler, 2003. Determination of surface area for apples with image analysis technique. J. Uludag University Agric. Facul., 17: 59-64.
- Joshi, D.C., S.K. Das and R.K. Mukherjee, 1993. Physical properties of pumpkin seeds. J. Agric. Eng. Res., 54: 219-229.
- Konak, M., K. Carman and C. Aydin, 2002. Physical properties of chick pea seeds. Biosyst. Eng., 82: 73-78.
- Mohsenin, N.N., 1970. Physical Properties of Plant and Animal Materials. New York: Gordon and Breach Science Publishers.
- Nimkar, P.M. and P.K. Chattopadhyay, 2001. Some physical properties of green gram. J. Agric. Eng. Res., 80: 183-189.
- Nimkar, P.M., D.S. Mandwe and R.M. Dudhe, 2005. Physical properties of moth gram. Biosyst. Eng., 91: 183-189.
- Özarslan, C., 2002. Physical properties of cotton seed. Biosyst. Eng., 83: 169-174.
- Özdemir, F. and I. Akıncı, 2004. Physical and nutritional properties of four major commercial Turkish hazelnut varieties. J. Food Eng., 63: 341-347.

- Saçılık, K., R. Öztürk and R. Keskin, 2003. Some physical properties of hemp seed. *Biosyst. Eng.*, 86: 191-198.
- Sahoo, P.K. and A.P. Srivastava, 2002. Physical properties of okra seed. *Biosyst. Eng.*, 83: 441-448.
- SIS, 2005. Agricultural Statistic, Ankara, Turkey.
- Singh, K.K. and T.K. Goswami, 1996. Physical properties of cumin seed. *J. Agric. Eng. Res.*, 64: 93-98.
- Suthar, S.H. and S.K. Das, 1996. Some physical properties of karingda [*Citrullus lanatus* (thumb) mansf] seeds. *J. Agric. Eng. Res.*, 65: 15-22.
- Unal, H., E. Isik and H.C. Alpsoy, 2006. Physical Properties of Black-eyed Pea. *Pak. J. Biolog. Sci.*, 9: 1799-1806.
- Yalçın, I. and C. Özarslan, 2004. Physical properties of vetch seed. *Biosyst. Eng.*, 88: 507-512.