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Physical and Mechanical Properties of Turkish Göynük Bombay Beans (*Phaseolus vulgaris* L.)

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Abstract: The physical properties of Turkish Göynük Bombay bean grains were determined as a function of moisture content in the range of 10.25-25.6% dry basis (d.b.). The average length, width and thickness were 22.60, 13.57 and 10.25 mm, at a moisture content of 10.25% d.b., respectively. In the above moisture range, the arithmetic and geometric mean diameters increased from 15.477 to 16.283 mm and from 14.617 to 14.825 mm, respectively, while the sphericity decreased from 0.734 to 0.599. In the moisture range from 10.25 to 25.6% d.b., Studies on rewetted Turkish Göynük Bombay bean grains showed that the thousand grain mass increased from 1700 to 2170 g, the projected area from 185.80 to 225.44 mm^2, the true density from 1301.60 to 1452.80 kg m^{-3}, the porosity from 46.287 to 63.047% and the terminal velocity from 6.20 to 6.98 m sec^{-1}. The bulk density decreased from 664.95 to 536.19 kg m^{-3} with an increase in the moisture content range of 10.25-25.6% d.b. The static coefficient of friction of Turkish Gunk Bombay bean grains increased the linearly against surfaces of six structural materials, namely, rubber (0.41–0.60), aluminum (0.33-0.48), stainless steel (0.29-0.40), galvanized iron (0.32-0.43), glass (0.28-0.40) and mdf (medium density fiberboard) (0.24-0.36) as the moisture content increased from 10.25 to 25.6% d.b. The shelling resistance of Turkish Göynük Bombay beans grain decreased as the moisture content increased from 100.76 to 59.01 N.

Key words: Turkish Göynük Bombay bean grains, physical properties, Moisture content

INTRODUCTION

Turkish Göynük Bombay beans (*Phaseolus vulgaris* L.) are a cultivated plant grown for fresh and dry consumption and raw material of canned food industry. It contains 23.1 g protein, 1.7 g fat, 59.4 g total carbohydrates, 163 mg calcium, 6.9 mg iron, 336 cal, 437 mg phosphorus per 100 g (dry).

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

MATERIALS AND METHODS

The Turkish Göynük Bombay bean grains used in the study were obtained from a local market. The grains were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken grains. The initial moisture content of the grains 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 (Saçılık *et al*., 2003; Coskun *et al*., 2006):

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

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 grain was taken out of the refrigerator and allowed

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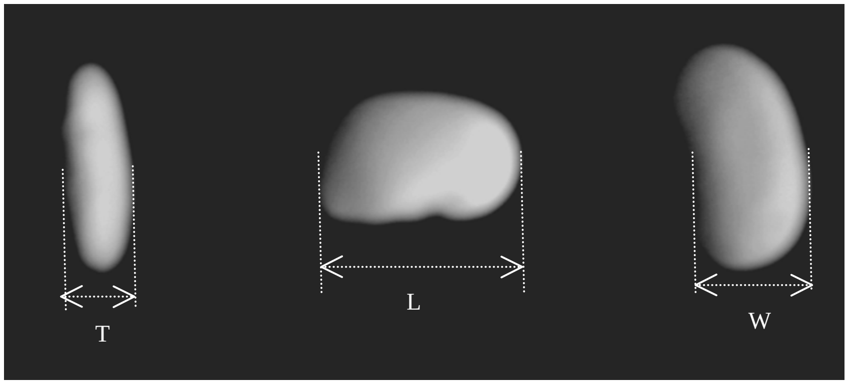

Fig. 1: Three dimensions of Turkish Göynük Bombay beans, Length (L), Width (W) and Thickness (T)

to equilibrate to the room temperature for about 2 h (Singh and Goswami, 1996; Yalcin and Ozarslan, 2004; Coskun *et al*., 2006).

All the physical properties of the grains were determined at seven moisture contents in the range of 10.25-25.6% d.b. with 10 replications at each moisture content. The range of moisture contents for bean grains recommended for safe module storage as 12.35% d.b. on 5°C (Isik and Yuksel, 1997).

To determine the average size of the grain, 100 grains 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 grain 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 grain were calculated by using the following relationships (Mohsenin, 1970; Dursun and Dursun, 2005).

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

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

The sphericity of grains ϕ was calculated by using the following relationship (Mohsenin, 1970; Nimkar and Chattopadhyay, 2001):

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

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

The surface area A_s in mm^2 of Turkish Göynük Bombay bean grains was found by analogy with a sphere of same geometric mean diameter, using the following relationship (Olajide and Ade-Omewaye, 1999; Baryeh and Mangope, 2002; Tunde-Akintunde and Akintunde, 2004; Dursun and Dursun, 2005).

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

The projected area A_p was determined from the pictures of Turkish Göynük Bombay bean grains 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 (Isik and Guler, 2003).

The average bulk density of the Turkish Göynük Bombay bean grains 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 grain 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 Turkish Göynük Bombay bean grains in the toluene (Ogut, 1998; Singh and Goswami, 1996; Yalcin and Ozarslan, 2004; Coskun *et al*., 2006). The porosity was calculated from the following relationship (Mohsenin, 1970; Singh and Goswami, 1996; Gupta and Das, 1997; Yalcin and Ozarslan, 2004):

$$P_f = (1 - \frac{\rho_b}{\rho_t})100 \qquad (6)$$

where P_f is the porosity in %; ρ_b is the bulk density in kg m^{-3}; and ρ_t is the true density in kg m^{-3}.

The terminal velocities of grain 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). The air column was 28 mm in diameter. 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 grain mass gets suspended in the air stream. The air velocity which kept the grain suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m s^{-1} (Özdemir and Akıncı, 2004).

The static coefficient of friction of Turkish Göynük Bombay bean grains against six different structural materials, namely rubber, galvanized iron, aluminum, stainless steel, glass and mdf 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 grain 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 (Singh and Goswami, 1996; Gupta and Das, 1997; Nimkar and Chattopadhyay, 2001; Yalcin and Ozarslan, 2004). The coefficient of friction was calculated from the following relationship:

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

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 (thickness). The shelling resistance of grain was determined under the point load by using a penetrometer (Bosch BS45 tester, Germany).

RESULTS AND DISCUSSION

Grain dimensions: The mean values and standard errors of the axial dimensions of the Turkish Göynük Bombay bean grains at different moisture contents are presented in Table 1. As can be seen in Table 1, the three axial dimensions increased with increase in moisture content from 1 0.25-25.63% d.b. The mean dimensions of 100 grains measured at a moisture content of 10.25% d.b. are: length 22.60±0.160 mm, width 13.57±0.091 mm and thickness 10.25±0.1234 mm.

The average diameter calculated by the arithmetic mean and geometric mean are also presented in Table 1. The average diameters increased with the increase in moisture content as axial dimensions. The arithmetic and geometric mean diameter ranged from 15.477 to 16.283 mm and 14.617 to 14.825 mm as the moisture content increased from 10.25-25.63% d.b., respectively.

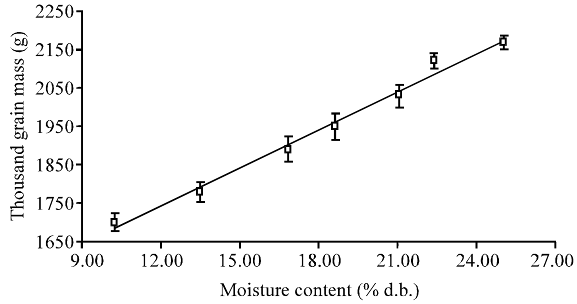

Fig. 2: Effect of moisture content one thousand grains mass of Turkish Göynük Bombay beans

One thousand grain mass: The one thousand Turkish Göynük Bombay beans grain mass M_{1000} increased linearly from 1700 to 2170 g as the moisture content increased from 10.25 to 25.63% d.b. (Fig. 2).

An increase of 27.64% in the one thousand grain mass was recorded within the above moisture range. The linear equation for one thousand grain mass can be formulated to be:

$$M_{1000} = 1342.4 + 33.218 M_c \quad (R^2 = 0.9890) \qquad (8)$$

A linear increase in the one thousand Turkish Göynük Bombay bean grains mass as the grain moisture content increases has been noted by Saçılık *et al.* (2003) for hemp, Yalcin and Ozarslan (2004) for vetch, Ogut (1998) for white lupine, Deshpande *et al.* (1993) for soybean, Aviara *et al.* (2005) for *Balanites aegyptiaca* nuts, Vilche *et al.* (2003) for quinoa seeds, Dursun and Dursun (2005) for caper seed and Nimkar and Chatopadhyay (2001) for green gram.

Surface area of grain: The variation of the surface area with the Turkish Göynük Bombay bean grains moisture content is plotted in Fig. 3. The figure indicates that the surface area increases linearly with increase in grain moisture content. The surface area of Turkish Göynük Bombay bean grains increased from 673.192 to 692.889 mm^2 when the moisture content increased from 10.25-25.63% d.b.

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

$$A_s = 658.36 + 1.2923 M_c \qquad (9)$$

with a value for the coefficient of determination R^2 of 0.8914.

Table 1: Means and standard errors of the grain at different moisture content

Moisture content, % d.b.	Axial dimensions (mm) Length (L)	Width (W)	Thickness (T)	Average diameters (mm) Arithmetic mean (D_a)	Geometric mean (D_g)
10.25	22.60±0.160	13.57±0.091	10.25± 0.1234	15.477	14.617
13.51	22.63±0.1584	13.37±0.0883	10.43±0.1231	15.488	14.641
16.82	23.25±0.1406	14.07±0.0827	9.77±0.0910	15.696	14.707
18.62	24.29±0.1584	15.24±0.0859	8.64±0.0820	16.055	14.708
21.07	24.56±0.1824	15.16±0.0977	8.60±0.1015	16.105	14.704
22.40	24.58±0.1623	15.33±0.0912	8.63±0.0969	16.181	14.791
25.63	24.82±0.1915	15.51±0.1018	8.52±0.1012	16.283	14.825

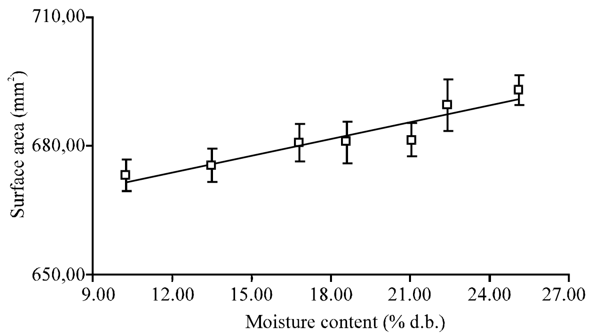

Fig. 3: Effect of moisture content on surface area of Turkish Göynük Bombay beans

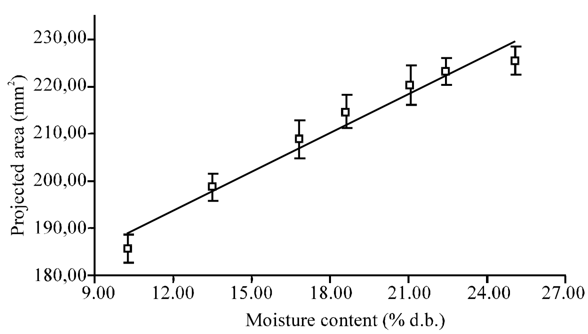

Fig. 4: Effect of moisture content on projected area of Turkish Göynük Bombay beans

Similar trends have been reported by Dursun and Dursun (2005) for caper seed, Deshpande *et al*. (1993) for soybean and Saçılık *et al*. (2003) for hemp seed.

Projected area of grain: The projected area of Turkish Göynük Bombay bean grains increased from 185.80 to 225.44 mm^2, when the moisture content of grain increased from 10.25 to 25.63% d.b. (Fig. 4).

The variation in projected area with moisture content of Turkish Göynük Bombay bean grains can be represented by the following equation:

$$A_p = 161 + 2.74M_c \quad (R^2 = 0.9657) \tag{10}$$

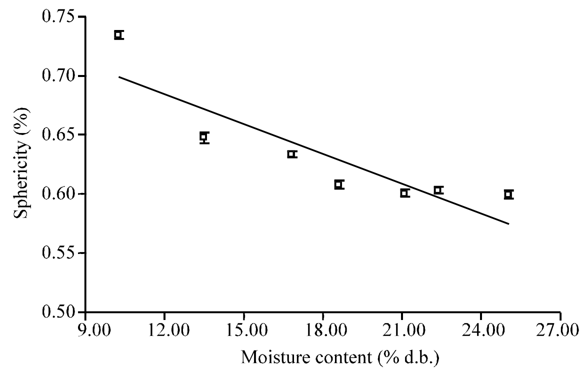

Fig. 5: Effect of moisture content on sphericity of Turkish Göynük Bombay beans

Similar trends have been reported by Tang and Sokhansanj (1993) for lentil, Ogut (1998) for white lupine, Ozarslan (2002) for cotton and Konak *et al.* (2002) for chick pea grain and for Turkish mahaleb, Dursun and Dursun (2005) for caper seed.

Sphericity: The sphericity of Turkish Göynük Bombay bean grains decreased from 0.734 to 0.599 with the increase in moisture content (Fig. 5). The relationship between sphericity and moisture content M_c in % d.b. can be represented by the following equation:

$$\phi = 0.7856 - 0.0084M_c \quad (R^2 = 0.7878) \tag{11}$$

Bulk density: The values of the bulk density for different moisture levels varied from 664.95 to 536.19 kg m^{-3}(Fig. 6). The bulk density of grain was found to bear the following relationship with moisture content:

$$\rho_b = 770.2 - 9.2094M_c \tag{12}$$

with a value for R^2 of 0.969.

A similar decreasing trend in bulk density has been reported by Gupta and Das (1997) for sunflower grain, Ogut (1998) for white lupin, Nimkar and Chattapadhyay

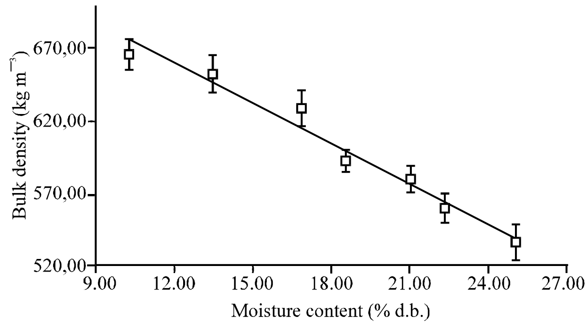

Fig. 6: Effect of moisture content on bulk density of Turkish Göynük Bombay beans

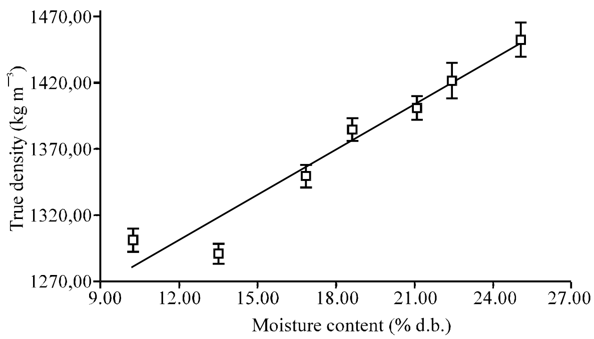

Fig. 7: Effect of moisture content on true density of Turkish Göynük Bombay beans

(2001) for green gram, Sahoo and Srivastava (2002) for okra, Konak *et al.* (2002) for chick pea, Saçılık *et al.* (2003) for hemp seed and Coskun *et al.* (2006) for sweet corn seed.

True density: The true density varied from 1301.60 to 1452.80 kg m^{-3} when the moisture level increased from 10.2% to 25.63% d.b. (Fig. 7).

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

$$\rho_t = 1164.6 + 11.373 M_c \tag{13}$$

with a value for R^2 of 0.9425.

The results were similar to those reported by Singh and Goswami (1996) for cumin grain, Ozarslan (2002) for cotton, Yalcin and Ozarslan (2004) for vetch seed, Aviara *et al.* (2005) for *Balanites aegypticiaca* nuts and Coskun *et al.* (2006) for sweet corn seed.

Porosity: The porosity of Turkish Göynük Bombay bean grains increased from 46.287 to 63.047% with the increase in moisture content from 10.25 to 25.63% d.b. (Fig. 8).

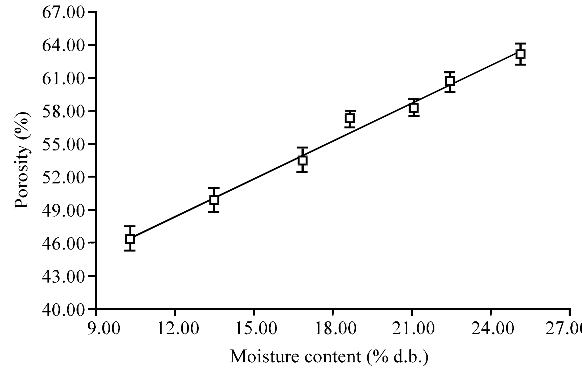

Fig. 8: Effect of moisture content on porosity of Turkish Göynük Bombay beans

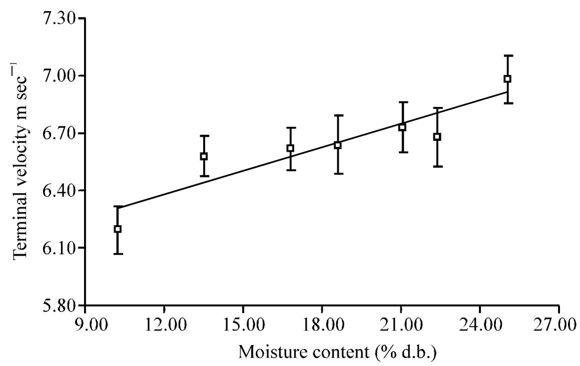

Fig. 9: Effect of moisture content on terminal velocity of Turkish Göynük Bombay beans

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

$$P_f = 34.497 + 1.1522 M_c \tag{14}$$

with a value for R^2 of 0.9890.

Gupta and Das (1997), Ogut (1998), Nimkar and Chattopadhyay (2001), Konak *et al.* (2002), Nimkar *et al.* (2005), Aviara *et al.* (2005) and Coskun *et al.* (2006) reported similar trends in the case of sunflower grain, white lupine, green gram, chick pea, moth gram, *Balanites aegyptiaca* nuts, okra seed and sweet corn seed, respectively.

Terminal velocity: The experimental results for the terminal velocity of Turkish Göynük Bombay bean grains at various moisture levels are shown in Fig. 9.

The terminal velocity was found to increase linearly from 6.20 to 6.98 m s^{-1} as the moisture content increased from 10.25 to 25.63% d.b. The relationship between terminal velocity and moisture content can be represented by the following equation:

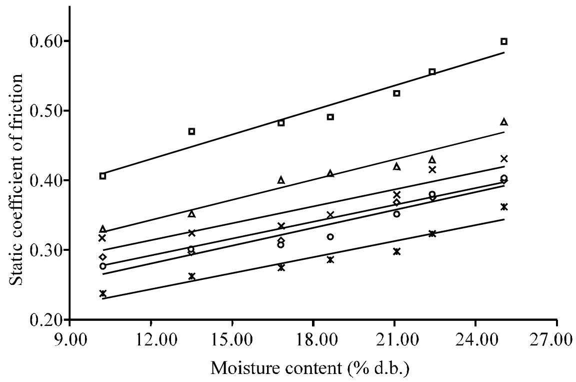

Fig. 10: Effect of moisture content on static coefficient of friction of Turkish Göynük Bombay beans against various surface: (□) rubber; (×) galvanized iron; (Δ) aluminium; (◊) stainless steel; (o) glass; (ж) mdf

$$V_t = 5.8847 + 0.041M_c \quad (R^2 = 0.8348) \tag{15}$$

Similar results were reported by Joshi *et al.* (1993), Suthar and Das (1996), Gupta and Das (1997) and in the case of pumpkin grains, sunflower, karingda and respectively.

Static coefficient of friction: The static coefficient of friction of Turkish Göynük Bombay bean grains on six surfaces (rubber, stainless steel, aluminum, glass, mdf and galvanized iron) against moisture content in the range 10.25-25.63% d.b. are presented in Fig. 10.

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 grain and the material surfaces at higher moisture values. Increases of from 0.41 to 0.60, 0.29 to 0.40, 0.33 to 0.48, 0.28 to 0.40, 0.24 to 0.36 and 0.32 to 0.43 were recorded in the case of rubber, stainless steel, aluminum, glass, mdf and galvanized iron, respectively, as the moisture content increased from 10.25 to 25.63% d.b.

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

$$\mu_{ru} = 0.2889 + 0.0118M_c \quad (R^2 = 0.9479) \tag{16}$$

$$\mu_{ss} = 0.1950 + 0.0081M_c \quad (R^2 = 0.9490) \tag{17}$$

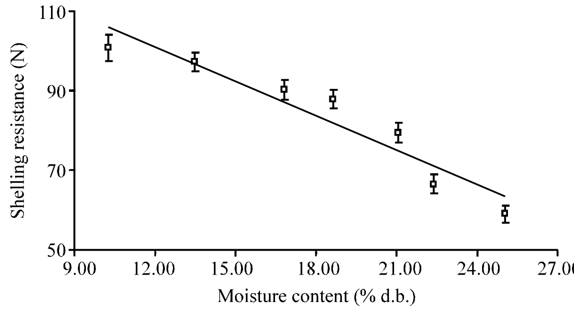

Fig. 11: Effect of moisture content on shelling resistance of Turkish Göynük Bombay beans

$$\mu_{al} = 0.2266 + 0.0097M_c \quad (R^2 = 0.9557) \tag{18}$$

$$\mu_{gl} = 0.0085 + 0.1776M_c \quad (R^2 = 0.9190) \tag{19}$$

$$\mu_{mdf} = 0.1531 + 0.0076M_c \quad (R^2 = 0.9264) \tag{20}$$

$$\mu_{gi} = 0.2171 + 0.0081M_c \quad (R^2 = 0.8696) \tag{21}$$

Similar results were found by Singh and Goswami (1996), Chandrasekar and Viswanathan (1999), Nimkar and Chattopadhyay (2001), Sahoo and Srivastava (2002), Yalcin and Ozarslan (2004), Dursun and Dursun (2005), Nimkar *et al.* (2005), Coskun *et al.* (2006) and for cumin, coffee, green gram seeds, okra, vetch, caper, moth gram and sweet corn, respectively.

Shelling resistance: The shelling resistance of Turkish Göynük Bombay beans was found to decrease with the increase in moisture content (Fig. 11).

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 shelling resistance of Turkish Göynük Bombay beans R_s in N with moisture content can be represented by the following equation:

$$R_s = 135.43 - 2.8729M_c \tag{22}$$

with value for R^2 of 0.9075.

Ozarslan (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.

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NOMENCLATURE

A_p Projected area (mm^2)
A_s Surface area (mm^2)
D_a Arithmetic mean diameter of grain (mm)
D_g Geometric mean diameter of grain (mm)
L length of grain (mm)
M_{1000} Thousand grain mass (g)
M_i Initial moisture content of sample (%d.b.)
M_f Final moisture content of sample (%d.b.)
M_c Moisture content (% d.b.)
P_f Porosity (%)
R_s Shelling resistance (N)
R^2 Coefficient of determination
Q Mass of water to added (kg)
T Thickness of grain (mm)
V_t Terminal velocity, (m s^{-1})
W Width of grain (mm)
W_i Initial mass of sample (kg)
α Angle of tilt (°)
μ Static coefficient of friction
ρ_b Bulk density (kg m^{-3})
ρ_t True density (kg m^{-3})
ϕ Sphericity of grain

Subscripts

al Aluminum
gi Galvanized iron
gl Glass
mdf Medium density fiberboard
ru Rubber
ss Stainless steel

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