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Some Physical and Mechanical Properties of Black-eyed Pea (*Vigna unguiculata* L.) Grains

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Abstract: The physical properties of black-eyed pea were evaluated as a function of moisture content. In the moisture range from 10.82 to 31.76% d.b., the dimensions of the major (length), medium (width) and minor (thickness) axes varied from 9.15 to 10.45 mm, 6.67 to 7.31 mm and 6.01 to 6.55 mm, respectively. In the above moisture range, the arithmetic and geometric mean diameters increased from 7.28 to 8.10 mm and from 7.16 to 7.93 mm, respectively, while the sphericity decreased from 0.783 to 0.761. Thousand grain mass, surface area and projected area increased from 245.4 to 279.3 g, from 161.22 to 198.38 mm^2 and from 57.75 to 68.18 mm^2, respectively. In the moisture range from 10.82 to 31.76% db, the bulk density of the rewetted grain decreased from 637.80 to 602.48 kg m^{-3}, true density increased from 1064.66 to 1205.99 kg m^{-3}, porosity increased from 40.05 to 49.60%. The terminal velocity and angle of repose increased linearly from 4.98 to 5.44 m s^{-1} and 20.91 to 27.69°, respectively. The static coefficient of friction increased on six structural surfaces namely, rubber (0.380-0.434), galvanised iron (0.355-0.399), aluminium (0.346-0.383), stainless steel (0.333-0.375), glass (0.323-0.374) and medium density fibreboard (0.278-0.342) as the moisture content increased from 10.82 to 31.76% d.b.. The shelling resistance of black-eyed pea decreased as the moisture content increased and the highest force were obtained while loading along the Z-axis (thickness).

Key words: Black-eyed pea, physical properties, mechanical properties, moisture contents, terminal velocity, static coefficient

INTRODUCTION

The black-eyed pea, also called black-eyed bean, blackeye, field peas, lobiya or chawli, is a subspecies of the cowpea, grown for its medium-sized edible bean, pale-colored with a prominent black spot. Its currently accepted botanical name is *Vigna unguiculata* subsp. *unguiculata*, although previously it was classified in the genus *Phaseolus*. *Vigna unguiculata* subsp. *dekindtiana* is the wild relative and *Vigna unguiculata* subsp. *sesquipedalis* is the related asparagus bean (Wikipedia, 2006). Crop is known by different names Turkish such as börülce, karnıkara, karagöz. However, they are all the species *Vigna unguiculata* (L.) Walp., which in older references may be identified as *Vigna sinensis* (L.) (Jefferson Institute, 1999).

Black-eyed pea is one of the most widely adapted, versatile and nutritious grain legumes (Ehlers and Hall, 1997). Black-eyed pea is not only grown for dry seed for human consumption and fodder for animal feed, but is also utilized the leaves and fruits for vegetables (Pekşen and Artık, 2004). The crop is grown on about 11 million ha in warm to hot regions of the world. Annual global production is about 4 million tons (FAO, 2003). Black-eyed pea originated in Africa and is widely grown in Africa, Latin America, Southeast Asia and in the southern United States. It is chiefly used as a grain crop, for animal fodder, or as a vegetable (Davis *et al*., 1991). Black-eyed pea sowing area of Turkey was 3000 ha and production was 2400 tons in 2003. Vegetable for fresh pods was nearly 15000 tons for the same year (SIS, 2004). Its importance in human nutrition in our country not known exactly. Black-eyed pea is widely grown in Aegean and Mediterranean regions of Turkey (Pekşen and Artık, 2004).

Black-eyed pea, an important legume in the tropics, has many uses. In fresh form, the young leaves, immature pods and peas are used as vegetables, while several snacks and main meal dishes are prepared from the grain. All parts of the plant that are used for food are nutritious,

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providing protein, vitamins (notably vitamin B) and minerals (Singh *et al.*, 1997). The grain forms an important source of protein, with 24% crude protein content. The grain also contains 53% carbohydrates and 2% fat (FAO, 2006).

Despite an extensive search, no published literature was available on the detailed physical properties of black-eyed pea and their dependency on operation parameters that would be useful for the design of processing machineries. In order to design equipment and facilities for the handling, conveying, separation, drying, aeration, storing and processing of black-eyed pea, it is necessary to their physical properties as a function of moisture content. Therefore, an investigation was carried out to determine moisture-dependent physical properties of black-eyed pea in the different moisture contents. The purpose of this study was to investigate some moisture-dependent physical properties, namely, axial dimensions, arithmetic and geometric mean diameters, sphericity, thousand grain mass, surface and projected areas, bulk and true densities, porosity, terminal velocity, static coefficient of friction and shelling resistance of black-eyed pea legume.

MATERIALS AND METHODS

The black-eyed pea 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 oven drying at 105±1°C for 24 h (Yalçın and Özarslan, 2004). The initial moisture content of the grains was 10.82% d.b.

The desired moisture contents were obtained by adding calculated amounts of distilled water on the grains. 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 to warm up to the room temperature for about 2 h (Singh and Goswami, 1996).

All the physical properties of the grains were determined at five moisture levels of 10.82, 16.77, 20.24, 25.16 and 31.76% d.b. with ten replications at each moisture content.

To determine the average size of the grain, 100 grains were randomly picked and their three axial dimensions namely, major L, medium W and minor T were measured using a calliper with a sensitivity 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).

$$D_a = (L + W + T)/3 \quad (1)$$

$$D_g = (LWT)^{1/3} \quad (2)$$

The sphericity ϕ of grains was calculated by using the following relationship (Nimkar and Chattopadhyay, 2001).

$$\phi = D_g/L \quad (3)$$

The surface area A_s in mm^2 of black-eyed pea 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; Dursun and Dursun, 2005; Tunde-Akintunde and Akintunde, 2004).

$$A_s = \pi D^2_g \quad (4)$$

The projected area A_p was determined from the pictures of black-eyed peas which were taken by a digital camera (Nikon Coolpix 4100), in comparison with the reference area to the sample area by using the Sigma Scan Pro 5 program (Ozdemir and Akinci, 2004).

The thousand grain mass was measured by using a digital balance with a sensitivity of 0.001 g.

The average bulk density of the grain was determined using the standard test weight procedure (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 grain in the toluene (Singh and Goswami, 1996; Yalçın and Özarslan, 2004).

The percentage porosity of black-eyed pea at five different moisture contents was calculated from the following relationship (Gupta and Das, 1997; Yalçın and Özarslan, 2004):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)100 \quad (5)$$

where: ε 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 having a least count of 0.1 m s^{-1} (Mohsenin, 1970; Ozdemir and Akinci, 2004).

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 30 cm diameter and 50 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 70 cm and was filled with black-eyed peas. The cylinder was raised slowly until it formed a cone on a circular plate. The angle of repose of grains was calculated from the diameter and height of a heap on a circular plate. The angle of repose θ was calculated using the following equation (Kaleemullah and Gunasekar, 2002):

$$\theta = \tan^{-1} (2H/D) \qquad (6)$$

The static coefficient of friction of black-eyed pea against six different structural materials, namely rubber, galvanised iron, aluminium, stainless steel, glass and medium density fibreboard (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; Yalçın and Özarslan, 2004). The coefficient of friction was calculated from the following relationship:

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

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

Shelling resistance R_s was determined by forces applied to three axial dimensions (length, width and thickness). The shelling resistance of grain was determined under the point load by using a penetrometer (Bosch BS45 tester).

RESULTS AND DISCUSSION

Grain dimensions: The mean values and standard errors of the axial dimensions of the black-eyed pea 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 10.82 to 31.76% d.b. The dimensional increases in major axis, medium axis and minor axis were 14.2, 9.6 and 8.9%, respectively.

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 7.28 to 8.10 mm and 7.16 to 7.93 mm as the moisture content increased from 10.82 to 31.76% d.b., respectively.

Sphericity: The values of sphericity were calculated individually with Eq. 3 by using the data on geometric mean diameter and the major axis of the grain and the results obtained are presented in Fig. 1. The results indicated that the sphericity of the grain was found decreased from 0.783 to 0.761 in the specified moisture levels. The relationship between sphericity and moisture content M_c in % d.b. can be represented by the following equation:

$$\phi = 0.7903 - 0.001\ M_c \qquad (8)$$

with a value for R^2 of 0.9026.

Similar trends have been reported by Nimkar and Chattopadhyay (2001) for green gram, Baryeh and Mangope (2002) for pigeon pea.

Surface area of grain: The variation of the surface area with the grain moisture content is plotted in Fig. 2. The figure indicates that the surface area increases linearly with increase in grain moisture content. The surface

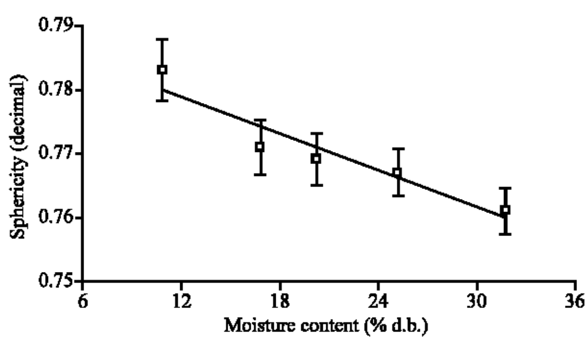

Fig. 1: Effect of moisture content on sphericity of black-eyed pea

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

	Axial dimensions (mm)			Average diameters (mm)	
Moisture content (% d.b.)	Major axis (L)	Medium axis (W)	Minor axis (T)	Arithmetic mean (D_a)	Geometric mean (D_g)
10.82	9.15±0.089	6.67±0.044	6.01±0.054	7.28	7.16
16.77	9.68±0.091	6.86±0.047	6.22±0.050	7.59	7.44
20.24	9.90±0.085	7.07±0.047	6.26±0.043	7.74	7.59
25.16	10.16±0.082	7.14±0.046	6.49±0.052	7.93	7.77
31.76	10.45±0.090	7.31±0.045	6.55±0.044	8.10	7.93

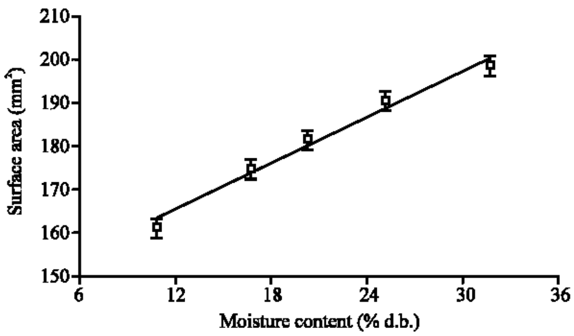

Fig. 2: Effect of moisture content on surface area of black-eyed pea

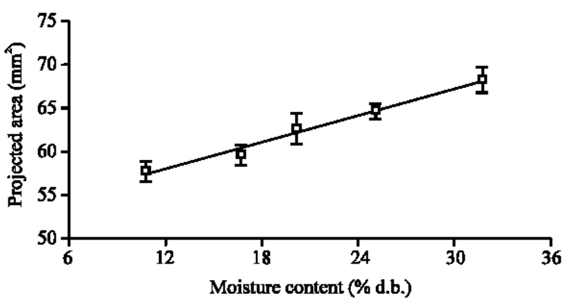

Fig. 3: Effect of moisture content on projected area of black-eyed pea

area of black-eyed pea grain increased from 161.22 to 198.38 mm^2 when the moisture content increased from 10.82 to 31.76% d.b.

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

$$A_s = 143.96 + 1.7788\ M_c \tag{9}$$

with a value for the coefficient of determination R^2 of 0.9828.

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

Projected area of grain: The projected area of black-eyed pea increased from 57.75 to 68.18 mm^2, while the moisture content of grain increased from 10.82 to 31.76% db (Fig. 3). The variation in projected area A_p in mm^2 with

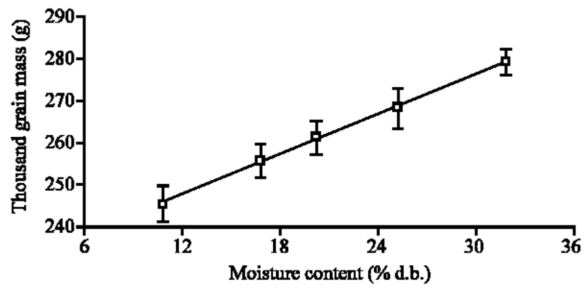

Fig. 4: Effect of moisture content on thousand grains mass

moisture content of grain can be represented by the following equation:

$$A_p = 51.877 + 0.5016\ M_c \tag{10}$$

with a value for the coefficient of determination R^2 of 0.9865.

Similar trends have been reported by Öğüt (1998) for white lupin, Dursun and Dursun (2005) for caper seed, Aydin *et al.* (2002) for Turkish mahaleb and Tang and Sokhansanj (1993) for lentil.

Thousand grain mass: The thousand black-eyed peas mass M_{1000} increased linearly from 245.4 to 279.3 g as the moisture content increased from 10.82 to 31.76% d.b. (Fig. 4). An increase of 13.9% in the thousand grain mass was recorded within the above moisture range. A linear increase in thousand grain mass with increase in grain moisture content has been reported by 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, Nimkar and Chatopadhyay (2001) for green gram and Yalçın and Özarslan (2004) for vetch seed.

The relationship between thousand grain mass and moisture content can be represented by the following regression equation:

$$M_{1000} = 228.5 + 1.598\ M_c \tag{11}$$

with a value of R^2 of 0.9989.

Bulk density: The experimental results of the bulk density of black-eyed pea at different moisture levels are

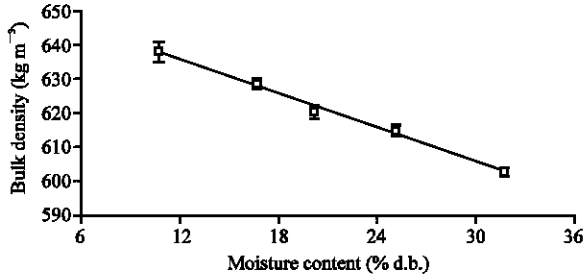

Fig. 5: Effect of moisture content on bulk density

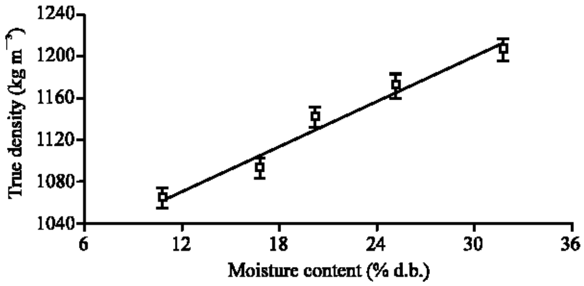

Fig. 6: Effect of moisture content on true density

presented in Fig. 5. The bulk density decreased from 637.80 to 602.48 kg m^{-3} as the moisture content increased from 10.82 to 31.76% d.b. The bulk density of grain was found to bear the following relationship with moisture content:

$$\rho_b = 655.58 - 1.6652\ M_c \quad (12)$$

with a value for the coefficient of determination R^2 of 0.9926.

A similar decreasing trend in bulk density has been reported by Nimkar and Chattapadhyay (2001) for green gram, Sacilik *et al.* (2003) for hemp seed, Sahoo and Srivastava (2002) for okra seed, Coşkun *et al.* (2006) for sweet corn seed, Öğüt (1998) for white lupin and Gupta and Das (1997) for sunflower seed.

True density: The true density varied from 1064.66 to 1205.99 kg m^{-3} when the moisture level increased from 10.82 to 31.76% d.b. (Fig. 6). The true density and the moisture content of grain can be correlated as follows:

$$\rho_t = 987.39 + 7.0719\ M_c \quad (13)$$

with a value for R^2 of 0.9078.

The results were similar to those reported by Yalçın and Özarslan (2004) for vetch seed, Singh and Goswami (1996) for cumin seed, Coşkun *et al.* (2006) for sweet corn seed and Aviara *et al.* (2005) for *Balanites aegypticiaca* nuts.

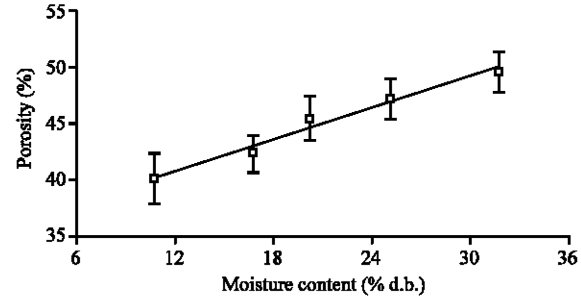

Fig. 7: Effect of moisture content on porosity of black-eyed pea

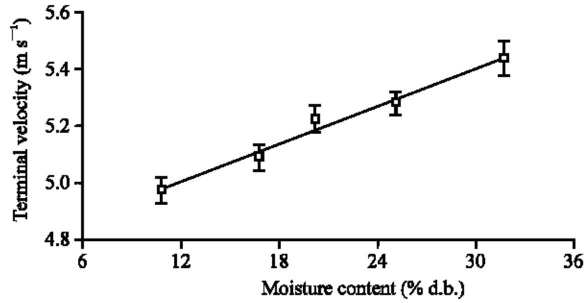

Fig. 8: Effect of moisture content on terminal velocity

Porosity: The porosity of black-eyed pea increased from 40.05 to 49.60% with the increase in moisture content from 10.82 to 31.76% d.b. (Fig. 7). The relationship between porosity and moisture content can be represented by the following equation:

$$\varepsilon = 35.101 + 0.4698\ M_c \quad (14)$$

with a value for R^2 of 0.9751.

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

Terminal velocity: The experimental results for the terminal velocity of black-eyed pea at various moisture levels are shown in Fig. 8. The terminal velocity was found to increase linearly from 4.98 to 5.44 m s^{-1} as the moisture content increased from 10.82 to 31.76% d.b. The relationship between terminal velocity V_t in m s^{-1} and moisture content can be represented by the following equation:

$$V_t = 4.7393 + 0.022\ M_c \quad (15)$$

with a value for R^2 of 0.9835.

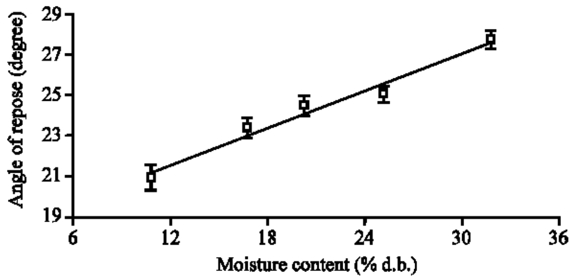

Fig. 9: Effect of moisture content on angle of repose of black-eyed pea

Similar results were reported by Gupta and Das (1997), Coşkun *et al.* (2005), Singh and Goswami (1996), Çalışır *et al.* (2005), Suthar and Das (1996) and Nimkar and Chattopadhyay (2001) in the case of sunflower, sweet corn, cumin, okra, karingda and green gram seeds, respectively.

Angle of repose: The experimental results for the angle of repose with respect to moisture content are shown in Fig. 9. The values were found to increase from 20.91° to 27.69° in the moisture range of 10.82-31.76% d.b. The variation in angle of repose with the moisture content can be correlated as follows:

$$\theta = 17.922 + 0.3046\ M_c \quad (16)$$

with a value for R^2 of 0.971.

A linear increase in angle of repose as the grain moisture content increases has also been noted by Baryeh and Mangope (2002) for pigeon pea, Suthar and Das (1996) for karingda seeds, Nimkar *et al.* (2005) for moth gram, Chandrasekar and Viswanathan (1999) for coffee, Aydin *et al.* (2002) for Turkish mahaleb and Sacilik *et al.* (2003) for hemp seed.

Static coefficient of friction: The data regarding the static coefficient of friction of black-eyed pea against various structural materials, namely, rubber, galvanised iron, aluminium, stainless stell, glass and medium density fibreboard (mdf) sheet are presented in Fig. 10. It was found that for black-eyed pea the static coefficient of friction increased with increase in the corresponding moisture contents of 10.82-31.76% d.b. This is due to the increased adhesion between the grain and the material surfaces at higher moisture values. The static coefficient of friction increased from 0.380 to 0.434 for rubber, 0.355 to 0.399 for galvanised iron, 0.346 to 0.383 for aluminium, 0.333 to 0.375 for stainless steel, 0.323 to 0.374 for glass and 0.278 to 0.342 for mdf as the grain moisture content increased from 10.82 to 31.76% db. Increases of 14.21,

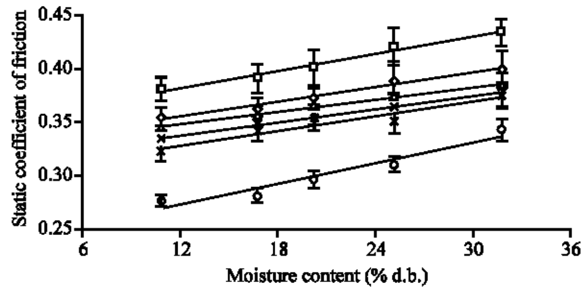

Fig. 10: Effect of moisture content on static coefficient of friction of black-eyed pea against various surface: (■) rubber; (◆) galvanized iron; (▲) aluminium; (x) stainless steel; (*) glass; (o) mdf

12.39, 10.69, 12.61, 15.79 and 23.02% were recorded in the case of rubber, galvanised iron, aluminium, stainless steel, glass and mdf, respectively as the moisture content increased from 10.82 to 31.76% d.b. At all moisture contents, the least static coefficient of friction was on mdf sheet. 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_{ru}, galvanised iron μ_{gi}, aluminium μ_{al}, stainless steel μ_{ss}, galss μ_g and medium density fibreboard μ_{mdf} can be represented by the following equations:

$$\mu_{ru} = 0.3488 + 0.0027\ M_c \quad (17)$$

$$\mu_{gi} = 0.3274 + 0.0023\ M_c \quad (18)$$

$$\mu_{al} = 0.327 + 0.0018\ M_c \quad (19)$$

$$\mu_{ss} = 0.314 + 0.002\ M_c \quad (20)$$

$$\mu_g = 0.3009 + 0.0023\ M_c \quad (21)$$

$$\mu_{mdf} = 0.2359 + 0.0031\ M_c \quad (22)$$

with values for R^2 of 0.9815, 0.9665, 0.9817, 0.9868, 0.9237 and 0.932, respectively.

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

Shelling resistance: The results of the shelling resistance tests are presented in Fig. 11. The results show that the

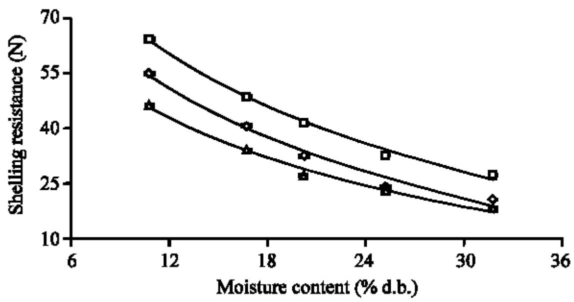

Fig. 11: Effect of moisture content on shelling resistance: (■) thickness; (◆) length; (▲) width

shelling resistance along any of the three major axes is highly dependent on the moisture content for the range of moisture content investigated (10.82-31.76% d.b.). It indicates that greater forces were necessary to cracking the grains with lower moisture. The highest forces were obtained while loading along the Z-axis (thickness), whereas loading along the X-axis (width) required the least force to resistance. The small forces at higher moisture content might have resulted from the fact that the grain became more sensitive to shelling resistance at high moisture. The relationships between the shelling resistance and moisture content of the black-eyed pea along the three major axes (Z-axis, thickness; Y-axis, length; X-axis, width) can be represented by the following equations:

$$R_{s\text{-}z} = 146.86 - 34.94 \, \mathrm{Ln}\,(M_c) \quad (23)$$

$$R_{s\text{-}y} = 132.64 - 32.89 \, \mathrm{Ln}\,(M_c) \quad (24)$$

$$R_{s\text{-}x} = 108.59 - 26.425 \, \mathrm{Ln}\,(M_c) \quad (25)$$

with a value for R^2 of 0.9947, 0.983 and 0.9882.

Yalçın and Özarslan (2004), Konak *et al.* (2002) and Özarslan (2002) reported as similar decrease in shelling resistance when the moisture content was increased for vetch, chick pea and cotton seeds, respectively.

Nomenclature

A_p	Projected area (mm^2)	ρ_b	Bulk density (kg m^{-3})
A_s	Surface area (mm^2)	ρ_t	True density (kg m^{-3})
D	Diameter of the cone (mm)	ε	Porosity (%)
D_a	Arithmetic mean diameter of grain (mm)	μ	Coefficient of friction
D_g	Geometric mean diameter of grain (mm)	α	Angle of tilt (deg)
H	Height of the cone (mm)	θ	Angle of repose (deg)
L	Length of grain (mm)	ϕ	Sphericity of grain
M_c	Moisture content (% d.b.)	Subscripts	
M_{1000}	Thousand grain mass (g)	al	Aluminium
R_s	Shelling resistance (N)	*gi*	Galvanised iron
R^2	Coefficient of determination	gl	Glass
T	Thickness of grain (mm)	mdf	Medium density fibreboard
V_t	Terminal velocity (m s^{-1})	ru	Rubber
W	Width of grain (mm)	ss	Stainless steel

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