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Moisture dependent physical properties of dehusked unsplitted pigeon pea

Feuchtigkeitsabhängige physikalische Eigenschaften von geschälten, nicht geteilten Straucherbsen

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Summary

Pigeon pea (*Cajanus cajan,* L.) is an important legume crop in semiarid tropics generally consumed as dried peas for making dhal, flour or green vegetable peas. Dehusked unsplitted pigeon pea also called gota are obtained during the primary processing for making dhal. Hence, the knowledge about the physical properties of gota is important for designing processing machineries. In this regard, the study of the physical properties of gota (dehusked unsplitted pigeon pea) in the moisture content range of 10.2–28.2% d.b. was conducted. Five different levels of moisture content in the above range were selected. The average length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity surface area, volume, thousand seed weight, bulk density, true density, porosity, angle of repose and coefficient of friction on plywood, mild steel and galvanized iron were determined in this moisture range. The values of average length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity and surface area varied from 5.33 to 5.43mm, 4.39 to 4.45mm, 3.93 to 3.77mm, 4.51 to 4.55mm, 4.88 to 4.5mm, 0.858 to 0.828 and 63.29 to 63.73mm2 respectively. At the given moisture levels, volume, thousand seeds weight ranged from 38.41 to 40.77mm3, 61.94g to 68.93g in the same moisture range, the bulk density and true density decreased linearly from 859.5 to 781.7 kg/m3 and 1306.6 to 1128 kg/m3 respectively and porosity decreased non linearly from 34.22 to 30.2%. The static coefficient of friction of gota over different materials, namely plywood, mild steel and galvanized iron increased linearly from 0.4491 to 0.8405, 0.4789 to 0.7882 and 0.2851 to 0.6775 respectively. In the selected moisture range, the angle of repose increased from 28.35° to 36.72°.

Keywords: dehusked unsplitted pigeon pea, gota, physical property, moisture content

Zusammenfassung

Die Straucherbse (*Cajanus cajan,* L.) ist eine wichtige Hülsenfrucht in semiariden Tropen, die im Allgemeinen in getrockneter Form zur Herstellung von Dhal, Mehl oder Erbsengemüse verzehrt wird. Während der Primärverarbeitung für die Herstellung von Dhal werden geschälte, nicht geteilte Straucherbsen, auch Gota genannt, gewonnen. Daher sind die physikalischen Eigenschaften von Gota für die Konstruktion von Bearbeitungsmaschinen von großem Interesse. Die Untersuchungen der physikalischen Eigenschaften der geschälten, nicht geteilten Straucherbsen wurden im Feuchtigkeitsgehaltbereich von 10,2–28,2%, bezogen auf die Trockenmasse, durchgeführt. Es wurden fünf verschiedene Feuchtigkeitsgehalte im genannten Bereich ausgewählt. Die durchschnittliche Länge, Breite, Dicke, der arithmetische mittlere Durchmesser, der geometrische mittlere Durchmesser, die sphärische Oberfläche, das Volumen, das Tausendkorngewicht, die Schüttdichte, die wahre Dichte, die Porosität, der Schüttwinkel und der Reibungskoeffizient auf Sperrholz, Weichstahl und verzinktem Eisen wurden in diesem Feuchtigkeitsbereich bestimmt. Die Werte der durchschnittlichen Länge, Breite, Dicke, des arithmetischen Durchschnittsdurchmessers, des geometrischen Durchschnittsdurchmessers, der Sphärizität und der Oberfläche variierten von 5,33 bis 5,43 mm, 4,39 bis 4,45 mm, 3,93 bis 3,77 mm, 4,51 bis 4,55 mm, 4,88 bis 4,55 mm, 0,858 bis 0,828 bzw. 63,29 bis 63,73 mm^2. Bei den angegebenen Feuchtigkeitsgraden, Volumen und der Tausendkernmasse lagen die Gewichte im Bereich von 38,41 bis 40,77 mm3, 61,94 g bis 68,93 g im gleichen Feuchtigkeitsbereich. Die Schüttdichte und die wahre Dichte nahmen linear von 859,5 auf 781,7 kg/m^3 und 1306,6 auf 1128 kg/m^3 ab. Die Porosität nahm nicht linear von 34,22 auf 30,2% ab. Der statische Reibungskoeffizient der Straucherbsen gegenüber der verschiedenen Materialien (Sperrholz, Weichstahl und verzinktem Eisen) stieg linear von 0,4491 auf 0,8405, 0,4789 auf 0,7882 bzw. 0,2851 auf 0,6775. Im ausgewählten Feuchtigkeitsbereich erhöhte sich der Ruhewinkel von 28,35° auf 36,72°.

Schlüsselwörter: Straucherbse, Gota, physikalische Eigenschaft, Feuchtigkeitsgehalt

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Introduction

Pigeon pea (*Cajanus cajan* L.) is a perennial and popular legume from the family *Fabaceae*. The dry seeds are boiled and eaten as a pulse or with other foods. The India's production of pigeon peas is estimated at 2.56 million tons (Annual report 2016–17, Department of Agriculture, Cooperation and Farmers' Welfare). India produces about 90% of world's total pigeon pea and remaining 10% produced by Africa and Caribbean countries (Nwokolo & Smartt, 1996). It is consumed on a large scale mainly for being a major source of protein. This pigeon pea is harvested at 28% d.b. moisture content to reduce the shuttering losses and processing recovery. The seeds are usually round or oval (orbicular), vary in size and color, being white, grayish, red, brown or purplish. The dehusked unsplitted pigeon pea is generally termed as 'Gota'. The quality of any food grains is mainly affected by its harvesting moisture content and this moisture content is very much relevant to is processing quality with nutritional security.

In the European era it's known as dehusked unsplitted pigeon pea grain. Dhal is prepared after the processing of dehusked splitted pigeon pea. Dhal is the term which is used after cleaning, grading and most important unit operation i.e. milling then after dhal is prepared. The German part of pigeon pea is Taubenerbse. The physical properties of pigeon pea, like other grains, are essential and important for designing the processing equipment for further handling and post-harvest processing. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of seeds (Sahay & Singh, 1994). Physical properties affect conveying characteristics of solid materials by air or water and cooling and heating loads of food materials.

The knowledge on the physical properties of a crop is essential for proper design of processing equipment. The size distribution and characteristic dimensions of grain is important for the design of equipment for cleaning, sorting and separation (Kachru et al., 1994). The bulk density is used to determine the capacity of storage and transport, while true density is useful to design proper separation equipment. Moreover, porosity of the grain mass determines the resistance to airflow during aeration and drying operation (Brooker et al., 1992; Kachru et al., 1994). Frictional properties such as angle of repose and coefficient of friction are important properties for the design of grain containers and other storage structures (Vilche et al., 2003). These properties are affected by factors such as size, form and moisture content of the grain. The review of literature showed that there is a lack of information on physical properties of gota for wide ranges of moisture content.

Hence, the knowledge of these physical properties are necessary for designing processing machines like cleaner, grader and dehusker. The properties of different types of grains and seeds have been determined by other researchers also (Deshpande & Ojha, 1993; Dutta, Nema, & Bhardwaj, 1988; Joshi, Das, & Mukherji, 1993; Oloso & Clarke, 1993; Singh & Goswami, 1996; Suthar & Das, 1996). They studied the physical properties of different variety of pigeon peas but no one determined the physical properties of dehusked unsplitted pigeon peas which further undergoes splitting to yield dhal.

Materials and method

Sample preparation

Whole pigeon pea seeds were procured from local market. The average initial moisture content was found to be 10.20% db. The grains were cleaned using cleaner cum grader to separate foreign matter, dust, dirt, twigs, broken and immature seeds. Moisture content of the sample was determined by hot air oven method as described by Nimkar and Chattopadhyay 2001. The grain moisture content range was selected between 10% to 28% dry basis because the harvesting is being practiced at about 28% and transportation, storage, handling and processing operations of the crop are being performed at about 10%.

The weight of the samples was recorded on an analytical balance (Model: TB403, Denver Instrument) of accuracy 0.001g in triplicate, and their average value was recorded. The sample was divided into lots that were conditioned for moisture content in the range of 10.20–28.20% db by adding predetermined amounts of distilled water calculated from the following relationship:

$$Q = W \times \frac{(M_f - M_i)}{(100 - M_f)}$$

Where, Q = Quantity of water to be added (g)
W = Quantity of sample (g)
Mi = initial moisture content of the sample (% db.)
Mf = desired moisture content of the sample (% db.)

The sample were kept at 5°C in a refrigerator for one week for uniform distribution of moisture throughout the sample. Before each test, the required quantity of sample was taken out of refrigerator and allowed to attain ambient temperature before carrying out the experiment.

Measurement of Properties

Size and shape

In order to determine the size and shape, fifty gota seeds were chosen at random from the overall sample. This random sampling method was similar to the one used by Dutta et al. 1988. For each grain, three-dimensional features (length (L), width (W) and thickness (T)) were measured with a digital vernier caliper (Absolute Digimatic, Make: Mitutoyo, Model: CD-'CSX') with an accuracy of 0.01 mm. The arithmetic mean diameter (Da), the geometric mean diameter (Dg) and sphericity of gota were calculated by the following equations (Mohsenin, 1986);

$$D_a = \frac{(L + W + T)}{3}$$

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

$$\phi = \frac{D_g}{L} \times 100$$

Surface area

The equivalent surface area of gota was obtained using the geometric mean diameter by analogy of a sphere (Deshpande et al., 1993; Nimkar et al., 2005) as:

$$A_s = \Pi D^2{}_g$$

Where, A_s = Surface area

Thousand grain weight

Thousand grain weight was determined by randomly selecting 100 grains from the overall sample, measuring their weight on a digital electronic balance with an accuracy of 0.001 g, and multiplying by 10 to get the mass of 1000 grains (Altuntas et al., 2005).

Density measurements

Bulk density (ρ_b) was considered as the ratio between the mass of a sample of grain and the total volume occupied by it. It was determined using a container of known volume (Deshpande et al., 1993; Vilche et al., 2003).

True density (ρ_t), defined as the ratio between the mass of the sample grains and the actual volume occupied by it, was determined for five moisture contents in the range of 10.20% –28.20% db using toluene displacement method with three replications (Singh and Goswami, 1996). This is the most useful method worldwide for determination of true density in agricultural commodity like all cereals, pulses and oilseeds.

Porosity (ε) of the grain bed was defined as the fraction of space in a bed of grains that is not occupied by the grains. The percentage porosity was calculated using the following equation (Mohsenin, 1986):

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$$

Angle of repose

Angle of repose is the angle with the horizontal at which the material will stand when piled. The static angle of repose was determined using a topless and bottomless cylinder of known dimensions. The cylinder was placed at the center of a raised circular plate and was filled with dehusked unsplitted pigeon peas. The cylinder was raised slowly until the grains formed a cone on the circular plate of known diameter. To determine the dynamic angle of repose, the dehusked unsplitted pigeon peas were allowed to fall freely from a hopper over a disc of known diameter to assume a natural slope. The static or dynamic angle of repose was then calculated from the measurement of the height and the radius of the cone (Kaleemullah and Gunasekar, 2002) using the following relationship:

$$\varphi = \tan^{-1} \frac{2H}{D}$$

Where, Ø = Angle of repose, degrees
H = Height of cone formed, mm, and
D = Diameter of cone, mm

Static Coefficient of Friction

Static coefficient of friction (μ) of gota was determined for the displacement of grains on three different materials, namely plywood, galvanized iron and mild steel, all with three replications. A wooden box was filled with gota and placed on different surfaces as mentioned above. The total weight required to move the box with grains was recorded. This value was used to calculate the static coefficient of friction over different surfaces.

The total weight required to make the box with grain slide uniformly over the friction surface was used to measure the dynamic coefficient of friction (Kaleemullah, 1992).

$$\upsilon = \frac{F}{N}$$

Where, F = Force required just to move the box with grain, N, and W = Weight of box + grain, N.

Statistical Analysis

The experimental results were subjected to analysis of variance (ANOVA) using AGRES (version 7.01) software and least significant difference test was used to describe the means with 95% confidence.

Results and discussion

Grain Dimensions

The length (L), arithmetic mean diameter (D_a) and geometric mean diameter (D_g) increased significantly ($p \leq 0.01$) from 5.23 to 5.51 mm, 4.52 to 4.64 mm and 4.49 to 4.59 mm, respectively with increase in moisture content from 10.20 to 18.30 % db. However, the dimensions decreased to 5.44 mm, 4.56 mm and 4.50 mm, respectively on increasing the moisture content to 28.20% db. In the moisture range between 10.20 to 24.30 % db, the width (W) increased from 4.40 to 4.53 mm then decreased to 4.46 mm with the increase of moisture content to 28.20 % db of dehusked unsplitted pigeon peas whereas thickness (T) values linearly decreased from 3.94 to 3.77 mm in the entire range of this moisture content.

The increase in size could be attributed to the expansion of the grain as a result of moisture absorption in the intercellular spaces inside the grains (Solomon and Zewdu, 2009). The dependence of these properties with moisture content could be represented by the following equations:

$$L = -0.0024m^2 + 0.1014m + 4.4494 \quad R^2 = 0.9762$$
$$W = -0.0011m^2 + 0.0475m + 4.0101 \quad R^2 = 0.8302$$
$$T = -0.0002m^2 - 0.0019m + 3.9673 \quad R^2 = 0.9739$$
$$D_a = -0.0012m^2 + 0.049m + 4.1424 \quad R^2 = 0.9866$$
$$D_g = -0.0011m^2 + 0.0443m + 4.1487 \quad R^2 = 0.9731$$

Where, m is the moisture content of grain in % db

Similar trends were reported for increase in dimensions with increase in moisture content upto 18.30 % db. for jatropha, guna, chickpea, neem nut and barley (Dutta et al., 1988; Visvanathan et al., 1996; Aviara et al., 1999; Garnayak et al., 2008; Solugubik et al., 2013).

Beyond the moisture content between 18.30 to 28.20% db, the decrease in grain dimension might be due to voids in the seed which when being filled with water make the voids contract due to surface tension resulting in reduction in dimensions.

Sphericity

Sphericity (φ) was calculated from the geometric mean diameter and the main axis (L) of gota. The results are presented in Fig. 2. Sphericity displayed significant differences with change in moisture content of the grain. The values of the sphericity decreased from 0.859 to 0.828 in the moisture range from 10.20 to 28.20 % db. According to Dutta et al. 1988 and Bal and Mishra 1988, the gota can be considered as spherical since the sphericity value was more than 0.70. The decrease in sphericity might have been caused by a proportional increase in the length as compare to width and thickness of the gota. The relationship between moisture content (% db) and sphericity (φ) of the grain could be represented by the following polynomial equation:

$$\varphi = 0.0002m^2 - 0.0078m + 0.9179 \quad R^2 = 0.8912$$

Where m is the moisture content of grain in % db

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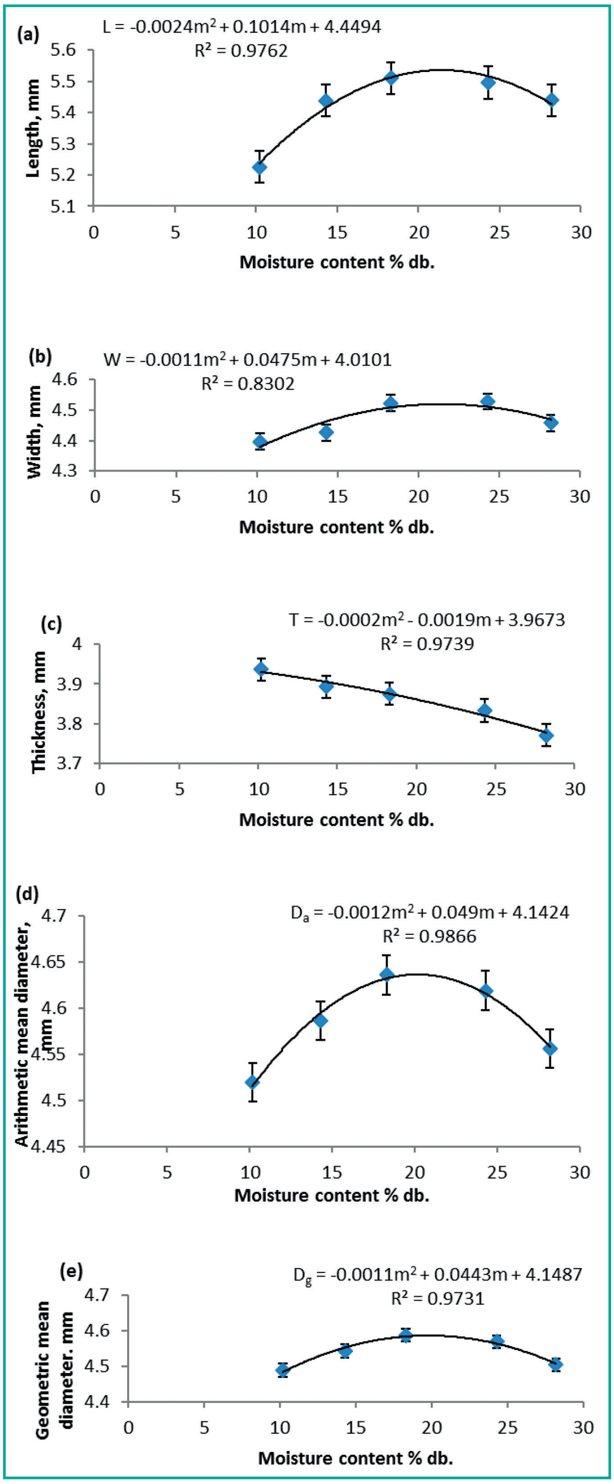

FIGURE 1: *Effect of moisture content on (a) length (b) width (c) thickness (d) arithmetic mean diameter and (e) geometric mean diameter of dehusked unsplitted pigeon pea.*

Similar trend in the entire moisture range 10.20% to 18.30% db were also observed where an initial increase in sphericity of the grains, followed by its decrease, were reported for okra, pea and barley (Sahoo and Srivastava, 2002; Yalcin et al., 2007; Sologubik et al., 2013).

Surface Area

The surface area increased from 63.30 to 66.13 m² with increase in moisture content from 10.2% to 18.3% db moisture content and then decreased to 63.73 m² with in-

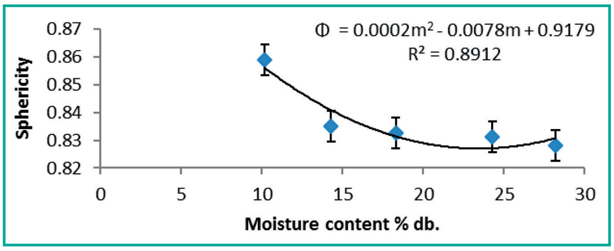

FIGURE 2: *Effect of moisture content on sphericity of gota.*

crease in moisture content up to 28.20 % db. The relation between surface area and moisture content is given by the equation:

$$AS = -0.0319m^2 + 1.2611\ m + 53.609 \quad R^2 = 0.9723$$

Where m is the moisture content of grain in % db

Sologubik et al., 2013, Garnayak et al., 2008, Pradhan et al., 2008, Zareiforoush et al., 2009, Altuntas et al., 2005 and Selvi et al., 2006 also reported similar trend in whole moisture range for grains of Scarlett barley, jatropha, karanja kernel, rice, fenugreek and lin grain respectively.

Thousand grain weight

The variation of thousand grain weight of gota with moisture content, is presented in Fig. 4, which showed that thousand grain weight increased from 61.95 g to 68.94 g as the moisture content increased from 10.20 to 28.20% db ($p \leq 0.01$). It was found to be a linear function of moisture content and the relationship could be expressed using the following equation:

$$W_s = 0.0003m^2 + 0.3768m + 57.981 \quad R^2 = 0.9858$$

Where m is the moisture content of grain in % db

Similar linear increase had been noted by Dutta et al. 1988 for gram, Deshpande et al. 1993 for soybean, Singh and

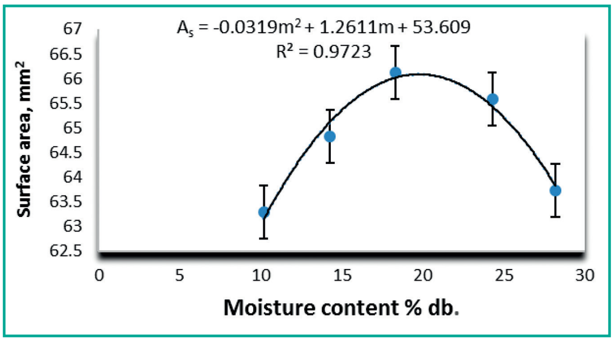

FIGURE 3: *Effect of moisture content on surface area of gota.*

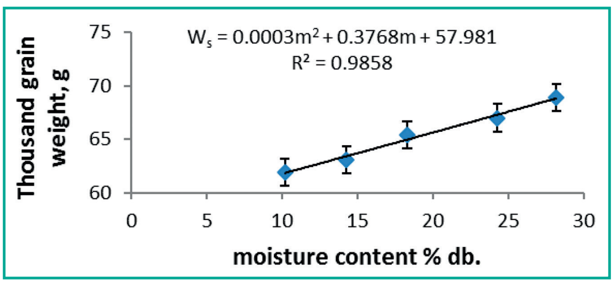

FIGURE 4: *Effect of moisture content on thousand grain weight of gota.*

Goswami 1996 for cumin grains, Altuntas and Yildiz 2007 for faba bean, Esref and Halil 2007 for red kidney bean and Sologubik et al. 2013 for barley.

Bulk density

Bulk density (ρ_b) of gota at different moisture content varied significantly (p≤0.01) from 859.5 to 781.7 kg/m³ when moisture content increased from 10.20 to 28.20% db Fig. 5 (a). This behavior could be attributed to the fact that the increased mass of the sample associated with increased moisture was lower than the volume expansion experienced by the grains (Sologubik et al., 2013). This would have resulted in having greater compaction (higher bulk density) in dry gota compared with wet gota. The relationship of bulk density (ρ_b) of gota and moisture content can be expressed by the following equation:

$$\rho_b = -0.0456m^2 - 2.4785m + 887.71 \qquad R^2 = 0.9856$$

Where m is the moisture content of grain in % db

Parde et al. 2003 also found similar trend for Koto and Manisoba cultivar at moisture content (wb.) range of 14.8% – 17.9% and 13.0% – 17.0%, respectively. Similar relationships have been reported for chickpea (Konak et al., 2002) and locust bean seed (Sobukola and Onwuka, 2010).

True density

The true density of gota decreased from 1306.60 to 1128 kg/m³ as the moisture content of the gota increased from 10.20% to 28.20% db. It could be seen from Fig. 5 (b) that true density had a linear relationship with moisture content and could be represented as:

$$\rho_t = 0.0298m^2 - 11.731m + 1429.9 \qquad R^2 = 0.9851$$

Where m is the moisture content of grain in % db

Similar trends of bulk density and true density have been reported for various materials like guna grains (Aviara et al., 1999), green gram (Nimkar and Chattopadhyay, 2001), cotton (Ozarslan, 2002), Lentil grain (Amin et al., 2004) and barley (Sologubik et al., 2013).

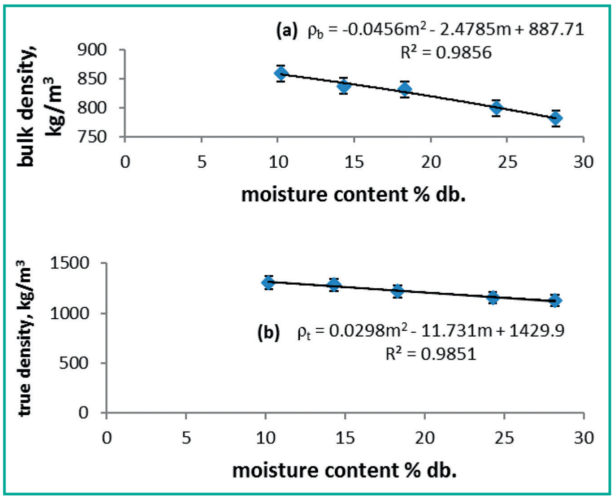

FIGURE 5: *Effect of moisture content on (a) bulk density and (b) true density of gota.*

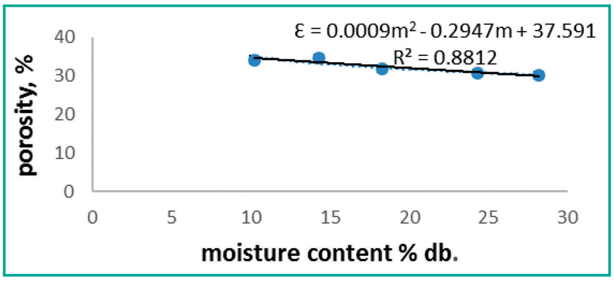

FIGURE 6: *Effect of moisture content on porosity of gota.*

Porosity

It was observed that when moisture content increased from 10.20 to 28.20% db, porosity decreased significantly (p≤0.01) from 34.22 to 30.20% as shown in Fig. 6. The relationship between the value of porosity (ε) and the moisture content can be expressed as:

$$\varepsilon = 0.0009m^2 - 0.2947m + 37.591 \qquad R^2 = 0.8812$$

Where m is the moisture content of grain in % db

Similar behaviors were reported for beniseeds, pumpkin, and pigeon pea seeds (Shepherd and Bhardwaj 1986).

Angle of repose

The experimental results of angle of repose with respect to moisture content are shown in Fig. 7, exhibiting a significant increase of angle from 28.35° to 36.73° (p≤0.01) with moisture content from 10.20 to 28.20% db. The trend could be due to the fact that moisture in the surface layer of the grain kept them bound together by surface tension (Pradhan et al., 2008). The angle of repose is of paramount importance in the design of hopper openings, side walls and storage structures in the bulk of grains per ramp (Solomon and Zewdu, 2009). The linear relationship between the angle of repose and the moisture content can be described by the following equation:

$$\Theta = 0.0203m^2 - 0.3008m + 29.194 \qquad R^2 = 0.9967$$

Where m is the moisture content of grain in % db

Similar behavior of the angle of repose with respect to moisture content were observed for buckwheat (Koto, Koban and Manisobacvs), barley, sorghum, jatropha and karanja (Parde et al., 2003; Sologubik et al., 2013; Mwithiga and Sifuna, 2006; Garnayak et al., 2008; Pradhan et al., 2008).

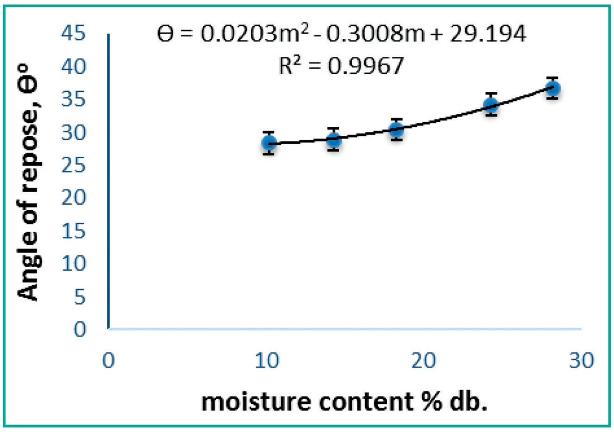

FIGURE 7: *Effect of moisture content on angle of repose of gota.*

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Static Coefficient of Friction

Variation of static coefficient of friction for gota on three surfaces (Plywood, mild steel, and galvanized iron) with moisture content is shown in fig. 8. The static coefficient of friction increased significantly with moisture content for all the surfaces. This was due to the increased adhesion between the grain and the material surfaces at higher moisture contents leading to higher values. Similar results have been reported for faba bean (Altuntas and Yildiz 2007). The static coefficient of friction ranged from 0.44 to 0.84, 0.47 to 0.78, and 0.28 to 0.67, respectively for plywood, mild steel, and galvanized iron surfaces in the experimental moisture content range. Variation of static coefficient of friction with moisture content of gota is expressed as:

$$\mu_{GI} = 0.0202m + 0.0396 \qquad R^2 = 0.8788$$
$$\mu_{MS} = 0.0174m + 0.3465 \qquad R^2 = 0.8854$$
$$\mu_{PW} = 0.024\ m + 0.1659 \qquad R^2 = 0.9649$$

Parde et al., 2003 found similar increase in the friction coefficient of buckwheat (Koto cultivar) with moisture content. Other researchers also found that as the moisture content increased, the static coefficient of friction also increased (Baryeh, 2002; Altuntas and Yildiz, 2007; Pradhan et al., 2008). As stated by Thompson and Ross, 1983 and Lawton, 1980, at low moisture contents particles of grain tend to be elastic. As moisture content increased, the grain particles became more elastic and were able to deform requiring increased force to break the bonds between sliding grain and surfaces.

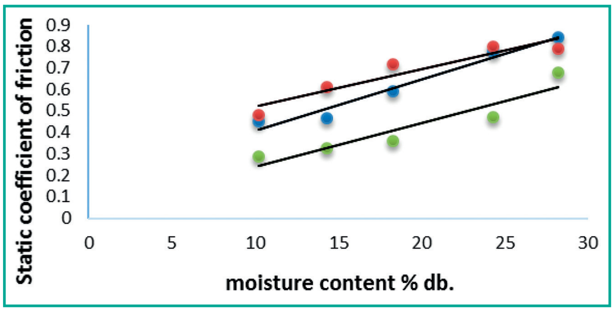

FIGURE 8: *Effect of moisture content on static coefficient of friction of gota.*

The coefficient of friction at all moisture contents was highest on mild steel followed by plywood and galvanized iron. This was due to the smoother surface of galvanized iron as compared to plywood and mild steel. The order reported for locust bean seed (Sobukola and Onwuka, 2010) is plywood followed by mild steel and galvanized iron sheet. However, Amin et al., 2004 have reported that no variation existed between plywood and galvanized iron for lentil seeds.

Conclusion

The values of physical dimension of gota such as length, width, arithmetic mean diameter, geometric mean diameter and surface area increased up to moisture content 18.30% db significantly ($p \leq 0.01$) and then decreased, whereas thickness, sphericity, bulk density and true density decreased ($p \leq 0.01$) with increasing moisture content from 10.20% to 28.20% db. Thousand grain weight, angle of repose and static coefficient of friction of the gota were also significantly influenced by moisture content and increased linearly with increase in moisture content in the experimental moisture range. These properties will be very much helpful in designing different machineries for processing of pigeon pea.

Conflict of interest

There is no conflict among us.

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