EFFECT OF MOISTURE CONTENT ON PHYSICAL AND GRAVINMETRIC PROPERTIES OF BLACK GRAM (*VIGNA MUNGO L.*)

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ABSTRACT

The study was carried out to evaluate the effect of moisture content on some physical and gravimetric properties of black gram. Four levels of moisture content ranging from 10.23 to 19.73% d.b. were used. The average length, width, thickness, geometric mean diameter, thousand seed mass and angle of repose were increased as the moisture content increased from 10.23 to 19.73 % d.b. As the moisture content increased from 10.23 to 19.73 % d.b., the bulk density was found to decrease from 692.30 to 661.50 kg m^{-3}, where as true density increase from 1012.34 to 1315.03 kg m^{-3}, while the porosity was found to increase from 31.58 to 49.67%. The static co-efficient of friction of black gram increased against various surfaces such as, plywood, cardboard, fibre board, glass and mild steel sheet, as the moisture content increased from 10.23 to 19.73 % d.b.

Key Words: Black Gram, Moisture content, Physical dimension, Angle of repose

1. INTRODUCTION

India is world's largest producer of pulses with its total pulse production contributing a quarter of world's total production. While one-third of world's total acreage under pulses is in India, Indian population consumes 30% of world's total pulses. Pulses are very important in the diets of human being throughout the world particularly to the vegetarian eaters supplementing their daily requirements of protein, carbohydrate and minerals and are the sources of bioactive compounds. Black gram (*Vigna mungo* L.), is an important pulse crop belonging to the family Leguminosiae and belongs to sub family of Papilionaceae. It contains about 26 per cent protein, which is almost three times that of cereals. It ranks fourth among the major pulses cultivated in India. The seed coat color is ascribed to the presence and quantity of polyphenols such as flavonol glycosides, condensed tannins and anthocyanins. These compounds have antioxidant, antimutagenic and anticarcinogenic activity and also free radical scavenging properties.

The knowledge on physical properties such as size, shape, mass, geometric mean diameter, sphericity, thousand grain weights, bulk density, true density, porosity, conveying, drying, aeration of grains is necessary for design of effective handling and processing equipments [22] [25]. Designing the seed processing equipment without considering engineering specifications may yield poor results [9].

Application of Physical Properties Of Black Gram

The size and shape are important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery [18]. The study of size is essential for uniformity and packing in standard material. Shape and physical dimensions, such as length, width and thickness, unit mass, volume and sphericity, are important in screening solids to separate foreign materials and in sorting various sizes of seeds. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate to heat and mass transfer during aeration and drying processes; useful in containerization, transportation and separation systems [13]. Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans. Grain densities have been of interest in breakage susceptibility and hardness studies. Quality differences in fruits, grains and seeds can be determined by the difference in density. Bulk and true density of agricultural materials play an important role in drying and storage, design of silos and storage bins, separation from undesirable materials, and grading [25].

Porosity and surface area affect the resistance to airflow through the bulk material and help in designing the dryers. Airflow resistance affects the performance of systems designed for forced convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids. Porosity allow gases, such as air and liquids to flow through a mass of particles in aeration, drying, heating and cooling operations. One thousand seed mass is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. It is also important in storage and machinery design. The theories used to predict the pressures and loads on storage structures [16] require information on bulk density. Also the design of grain hoppers for processing machinery requires data on bulk density. Hence, current study was conducted to investigate some physical properties of black gram.

2. MATERIALS AND METHODS

The dry seeds of black gram variety ADT 5 were used for all the experiments. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature and broken seeds. The initial moisture content of the seeds was determined by oven drying at 103± 1° C for 72 h [4]. The initial moisture content of the seeds was 10.0 % dry basis (d.b.). The samples of the desired moisture contents were prepared by adding pre-determined amounts of distilled water as calculated from the following relationship [7]:

$$Q = \frac{Wi(Mf - Mi)}{(100 - Mf)} \quad \text{……………..1}$$

Where Q is the mass of water added, kg, Wi is the initial mass of the sample in kg, M_i is the initial moisture content of the sample in d.b.% and M_f is the final moisture content of the sample in d.b.%.

The samples were then sealed tightly in polyethylene bags and stored 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 seeds were withdrawn from the bags and allowed to warm up to room temperature for about 2 h [30] [5]. The physical properties of the seeds were assessed at moisture levels of 10.233, 13.49, 16.64 and 19.73 % d.b. with ten replications at each moisture content.

2.1. Size

To determine the average size of the seed, 20 seeds were randomly selected and their three linear dimensions namely, length L, width W and thickness T were measured using an screw gauge having least count 0.01 mm. the geometric mean diameter (Dg) and Sphericity (Φ) of grains were calculated using the relationships given by [70]

$$Dg = (LWT)^{1/3} \quad \text{……………2}$$

$$\phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad \text{……………3}$$

Where *L* is the length, *W* is the width and *T* is the thickness, all in mm.

2.2. Thousand seeds weight (TSW) or thousand grain mass (M_{1000})

The thousand seed mass in gram was measured by counting 1000 seeds and weighing them in an electronic balance to an accuracy of 0.001g.

2.3. Bulk density

The bulk density (kg m^{-3}) is the ratio of mass of a sample of the seeds to its total volume. It was determined by filling an empty 250 ml graduated cylinder with seeds from a height of about 18 cm, striking the top level and then weighing the contents [10]. The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder with seeds. To achieve the uniformity in bulk density the graduated cylinder was tapped for the seeds to consolidate. The volume occupied was then noted. The process is replicated five times and the average bulk density for each replication was calculated from the following equation:

$$\rho b = \frac{Ws}{Vs} \qquad \text{.................4}$$

Where ϱb is the Bulk density in kg m-3 , Ws is the Weight of the sample in kg, Vs is the Volume occupied by the sample in m^3.

2.4. True density

The true density (kg m^{-3}) is defined as the ratio of mass of seeds to the true volume of seeds [10]. The seed volume and its true density was determined using a liquid displacement technique [23]. Toluene was used instead of water so as to prevent the absorption during measurement and also to get the benefit of low surface tension of selected solvent [24] [19]. The volume of toluene (C7H8) displaced was found by immersing a weighed quantity of seeds in the measured toluene [26]. 50 ml of toluene was placed in a 100 ml graduated measuring cylinder and 10 g of seeds were immersed in the toluene. The amount of displaced toluene was recorded from the graduated scale of the cylinder. The ratio of weight of seeds to the volume of displaced toluene gave the true density.

2.5. Porosity

The porosity (%) of bulk seed was computed from the values of true density and bulk density using the following relationship [27] [17].

$$\varepsilon = \frac{\rho t - \rho b}{\rho t} \times 100 \qquad \text{..............5}$$

Where ε is the porosity in %, ρ_b is the bulk density in kg m^{-3} and ρ is the true density in kg m^{-3}.

2.6. Angle of Repose

The angle of repose was determined based on the method used by [28].

2.7. Static co-efficient of friction

The static co-efficient of black gram seeds against five different surfaces, namely plywood, card board, fiber board, glass and mild steel sheet was determined. These are common material used for handling and processing of grains and construction of storage and drying bins. The samples were placed on the test surface at the top edge. The inclined surface was tilted until the samples began to move leaving an inclined surface. The angle of inclination with the horizontal base was measured by a scale provided and taken as an angle of internal friction and tangent of the angle was taken as co-efficient of friction between surface and sample (Mohsenin, 1970).

$$\mu = \tan\theta \qquad \text{..............6}$$

Where μ_s is the Co-efficient of static friction and θ is the Angle of inclination of material surface in degrees.

3. RESULTS AND DISCUSSION

The effect of moisture content on all the physical and mechanical properties of black gram was significant at 5 % probability level. Results obtained are discussed in detail below.

3.1. Grain dimensions

Average values of the three principal dimensions of black gram namely, length, width and thickness determined in this study at different moisture contents are presented in Table 1. Each principal dimension appeared to be linearly dependent on the moisture content as shown in Fig. 1. Very high correlation was observed between the three principal dimensions and moisture content indicating that upon moisture absorption, the black gram expands in length, width and thickness in the moisture range of 10.23 to 19.73 % d.b. The average length, width and thickness of the 100 seeds varied from 3.97 to 4.45 mm, 3.03 to 3.30 mm and 3.33 to 3.66 mm, respectively as the moisture content increased from 10.23 to 19.73 % d.b. Differences between the values are statistically important at $P < 0.05$. The geometric mean diameter increased with the increase in moisture content the results were presented in Table 1. The average geometric mean diameter ranged from 3.38 to 3.72 mm, as the moisture content increased from 10.23 to 19.73 % d.b. respectively ($P < 0.05$).

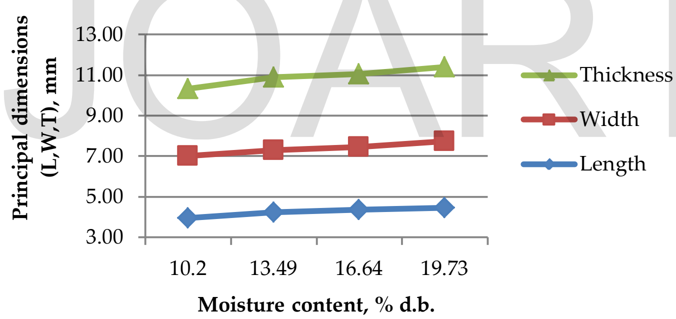

Fig 1. Variation of principal dimensions of black gram with moisture content.

Table1. Physical properties of black gram at different moisture contents.

Moisture content d.b.%	Length (mm)	Width(mm)	Thickness (mm)	Geometric mean diameter (mm)	Sphericity (%)	1000 seed wt (g)	Bulk density (kg m-3)	True density (kg m-3)	Porosity (%)	Angle of repose (°)
10.23	3.97^{c*}	3.03^{b}	3.33^{b}	3.38^{b}	85^{a}	43.65^{c}	692.30^{a}	1012.34^{d}	31.58^{d}	27.75^{b}
13.49	4.23^{b}	3.08^{b}	3.59^{ab}	3.56^{ab}	84^{b}	43.87^{b}	675.34^{b}	1074.64^{c}	37.15^{c}	29.83^{a}
16.64	4.37^{a}	3.09^{b}	3.60^{a}	3.60^{ab}	83^{c}	43.98^{b}	667.29^{c}	1234.78^{b}	45.93^{b}	30.55^{a}
19.73	4.45^{a}	3.30^{a}	3.66^{a}	3.72^{a}	84^{b}	44.13^{a}	661.50^{c}	1315.03^{b}	49.67^{a}	31.29^{a}
F-value	32.32	2.96	0.63	4.13	44	2.73	36.04	341.87	193.91	8.35
SED±	0.05	0.10	0.26	0.10	2	0.17	3.15	10.70	0.84	0.75
CD at 5%	0.12	0.22	0.60	0.22	5	0.40	7.27	24.68	1.93	1.72

* Values in the same columns followed by different letters (a-d) are significantly different (*P<0.05*).

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3.2 Sphericity

The values of sphericity were calculated individually using equation (3), and the results obtained are presented in Table 1. The sphericity of the blackgram seeds decreased from 85 to 83 % between 10.23 to 16.64 % moisture content, but later increased to 84 % at 19.73% moisture content dry basis. The relationship between sphericity (Φ) and moisture content (M) can be represented by the following equation:

$$\phi = -0.005M + 0.853 \qquad (R^2 = 0.478)$$

Similar trends has been reported by Davies and Zibokere (2011) for cowpea seeds.

3.3 Thousand seed mass

The thousand seed mass of black gram increased linearly from 43.65 to 44.13 g (P<0.05) as the moisture content increased from 10.23 to 19.73 % d.b. (Table 1). This relationship between 1000 grain mass (m_{1000}) and the moisture content (M) can be represented by the following equation:

$$m_{1000} = 0.155M + 43.52 \qquad (R^2 = 0.981)$$

Similar increasing trend has been reported by Kasap and Altuntaş (2006) for sugarbeet seeds, Altuntaş and Yildiz (2007) for faba bean grains, Pradhan *et al*. (2008) for karanja kernel and Tavakoli *et al*. (2009) for soybean grains.

3.4 Bulk density

The seeds bulk density at different moisture levels varied from 692.30 to 661.50 kg m^{-3} (P < 0.05) (Fig.2) and indicated a decrease in bulk density with an increase in moisture content from 10.23 to 19.73 % d.b. This was due to the fact that an increase in mass owing to moisture gain in the sample was lower than accompanying volumetric expansion of the bulk (Pradhan *et al*., 2008). The bulk density (ρ_b) of the seeds was found to have the following relationship with the moisture content (M):

$$\rho b = -10.04 + 699.2 \qquad (R^2 = 0.938)$$

Similar decreasing trend in bulk density has been reported by Yalçin *et al*. (2007) for pea seed, Altuntaş and Demirtola. (2007) for some legumes seeds, Garnayak et al. (2008) for jatropha seed and Pradhan *et al*. (2008) for karanja kernel.

3.5 True density

The true density of black gram seeds at different moisture contents increased from 1012.34 to 1315.03 kg m^{-3}, (Fig.2). The values of true density at different moisture levels as shown in (Table. 1). The moisture (M) dependence of the true density (ρ_t) was described by a equation as follows:

$$\rho t = 106.8M + 892.1 \qquad (R^2 = 0.971)$$

Although the results were similar to those reported by Altuntas and Yildiz (2007) for faba bean grains, Garnayak *et al*. (2008) for jatropa seed and Pradhan *et al*. (2008) for Karanja kernel but different trend was reported by Sacilik *et al*. (2003) for hemp seeds, Yalcin *et al*. (2007) for pea seed, Tavakoli *et al*.(2009) for soybean grain.

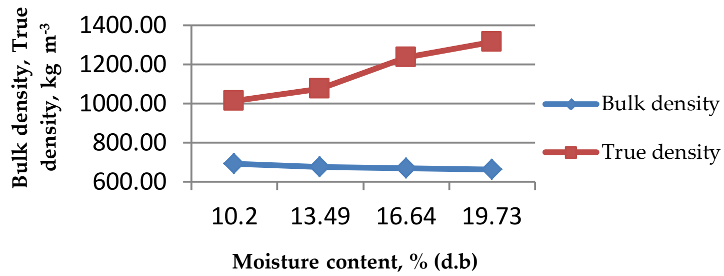

Figure 2. Variation of bulk density, true density of black gram seeds with moisture content.

3.6 Porosity

Porosity was calculated using Eq. (5). As seen from the Table.1, the porosity of black gram seeds increases linearly from 31.58 to 49.67 % (P<0.05) as the moisture content increased from 10.23 to 19.73 % d.b. The linear decrease in bulk and particle densities with increased moisture level producing higher values of porosity was also reported by Adegbulugbe and Olujimi (2008), for cowpea varieties (TVX 3236, Ife Brown and IT81D-994). Porosity is an essential characteristic used in the calculation of rate of aeration and cooling and drying and heating and design of heat exchangers and packaging equipment.

3.7 Angle of repose

The experimental results for the angle of repose with respect to moisture content are shown in Table 1. The values were found to increase from 27.75° to 31.29° ($P < 0.05$) in the moisture range of 10.23 to 19.73 % d.b. This increasing trend in angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the aggregate of grain together by the surface tension (Pradhan *et al.*, 2008). The values of the angle of repose (θ) for black gram bear the following relationship with its moisture content (M):

$$\theta = 1..133M + 27.02 \qquad (R^2 = 0.922)$$

These results were similar to those reported by Kasap and Altuntaş (2006), Altuntaş and Yildiz (2007), Garnayak *et al*. (2008), and Pradhan *et al*. (2008), for sugarbeet seeds, faba bean grains, jatropha seed and karanja kernel, respectively.

3.9. Static coefficient of friction

The static coefficients of friction of black gram on five different surfaces (plywood, cardboard, fibre board, glass and mild steel sheet) against moisture content in the range of 10.23 to 19.73 % d.b. are presented in Fig. 3. It was observed that the static coefficient of friction increased with an increase in moisture content for all contact surfaces. The reason for the increase in friction coefficient at higher moisture content may be owing to the water present in the grain offering a cohesive force on the surface of contact (Garnayak *et al*., 2008). An increase of 0.30 to 0.39, 0.33 to 0.39, 0.37 to 0.40, 0.36 to 0.42 and 0.35 to 0.43 were recorded in the case of plywood, cardboard, fibre board, glass and mild steel surfaces respectively, as the moisture content increased from 10.23 to 19.73 % d.b. At all moisture content values, the maximum friction was offered by plywood, followed by galvanized iron sheet and glass surface. The least static coefficient of friction may be owing to smoother and more polished surface of the glass compared to the other materials used. Plywood also offered the maximum friction for pigeon pea, gram, rape seed, neem nut, Jatropha seed and karanja kernel and the coefficient of friction increased with the moisture content (Shepherd and Bhardwaj 1986; Dutta *et al*., 1988;

Kulkelelko *et al*., 1988; Visvanathan *et al*., 1996; Garnayak *et al*., 2008; Pradhan *et al*., 2008). The relationships between static coefficient of friction (μ) and the moisture content (M) on plywood (wd), glass (gl), galvanized iron sheet (gi) and mild steel sheet (ms) can be represented by the following equations:

$$\mu_{wd} = 0.023M + 0.295 \qquad (R^2 = 0.7)$$

$$\mu cd = 0.018M + 0.318 \qquad (R^2 = 0.656)$$

$$\mu_{fd} = 0.008M + 0.366 \qquad (R^2 = 0.954)$$

$$\mu_{gl} = 0.019M + 0.348 \qquad (R^2 = 0.771)$$

$$\mu_{ms} = 0.026M + 0.401 \qquad (R^2 = 0.121)$$

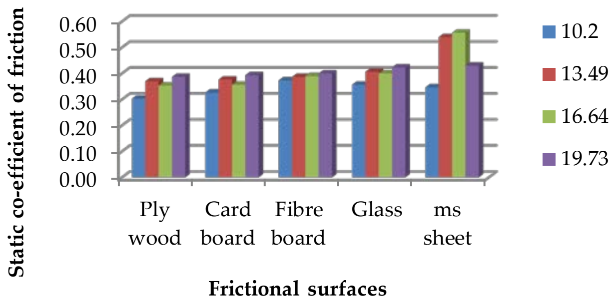

Fig 3. Effect of moisture content on static coefficient of friction of black gram.

4. CONCLUSIONS

The following conclusions are drawn from the investigation on the physical and mechanical properties of black gram in the moisture content range of 10.23 to 19.73 % d.b. The average length, width, thickness, geometric mean diameter, thousand grain mass and angle of repose of black gram ranged from 3.97 to 4.45 mm, 3.03 to 3.30, 3.33 to 3.66 mm, 3.38 to 3.72 mm, 43.65 to 44.13 g and 27.75° to 31.29 respectively. The sphericity was found to decrease from 85 to 83 % in the moisture range of 10.23 to 19.73 % d.b. As the moisture content increased from 10.23 to 19.73 % d.b., the bulk density decreased from 692.30 to 661.50 kg m-3, where as true density increased from 1012.34 to 1315.03 kg m-3, while the porosity was found to increase from 31.58 to 49.67%. The static coefficient of friction increased for all five surfaces, namely, plywood, cardboard, fibre board, glass and mild steel (0.30 to 0.39, 0.33 to 0.39, 0.37 to 0.40, 0.36 to 0.42 and 0.35 to 0.43) respectively, as the moisture content increased from 10.23 to 19.73 % d.b. Differences between all values were statistically important at $P<0.05$.

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