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Research Article

ENGINEERING PROPERTIES OF BLACK GRAM GRAIN AT VARIOUS MOISTURE CONTENT

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Abstract: Grain properties are important during the post-harvest operations like cleaning, grading, drying, storage and milling and also mainly used for design and operation of the material handling equipment. In this study, the effect of three levels of moisture content on engineering properties of black gram grains (*Vigna mungo*) were studied and presented. Properties like dimensions of grains, sphericity, surface area, bulk and true density, porosity, angle of repose and frictional coefficient. The three levels of moisture content 10.31%, 12.39% and 14.19% were taken for the study as it is safe storage levels for storing either grains or seeds. As the moisture content (w.b.%) increases, the grain dimensions like length, width, thickness were also increased linearly which ranging from 5.08 ±0.26 mm to 5.50 ±0.21 mm, 4.50 ±0.28 mm to 4.97 ±0.28 mm and 3.31 ±0.21 mm to 3.66 ±0.23 mm respectively. As the results of increase in three axial dimensions, the sphericity, surface area, arithmetic and geometric mean diameter of the grains were also increased with increasing moisture content. In contrast to the bulk density and true density, which were decreased with increase in moisture content of the grains ranging from 823 to 761 kg/m^3 and 1340 to 1284 kg/m^3 respectively. Increase in porosity and angle of repose were measured with increase in moisture content. Co-efficient of friction of black gram grains on different surfaces at various moisture content were also investigated and it was found to be increased with increase in moisture content, also it was varied with material to material because of the wetness and texture of the grains.

Keywords: *Black Gram, Engineering Properties, Moisture Content, Pulses, Post-Harvest Operation*

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Introduction

India contribute world's number one in pulses production and as well as consumer of pulses. In 2017-2018, the area of pulses cultivation in India was estimated to be about 25 million hectares with production of 22 million tons contributing around 25 to 28% of the total global production [5]. Major pulse producing states are Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Karnataka and Tamil Nadu. In Tamil Nadu, Pulses are cultivated in 927 thousand hectares with the production of 573 thousand tones [9]. In India, many varieties of pulses are grown like black gram, green gram, chickpea, moth bean, pigeon pea, lentil, lablab bean, horse gram, pea, and cowpea. Among these, black gram (*Vigna mungo*) is a rich source of protein and it is the second important component of Indian diet after cereals. After harvesting, the grains are conveyed and stored from place to place. So, it is necessary to know the properties of the black gram grains for efficient handling and storage of bulk materials. Basic information of the granular material properties is greater importance and significant for the engineers, processors and scientists for developing the efficient equipment [13, 2]. Engineering properties of grain data is important and relevant for storage, processing, size reduction, handling and conveying [3]. Physical properties of grain behave widely with change in moisture content and it is important because postharvest operations like soaking, washing, blanching, drying and cooking of grains involve moisture absorptions [18]. Various types of cleaning and grading equipment work on the basis of size and shape of the grains. For designing an air screener grain cleaner, the dimension of the grains is necessary for the determining the opening of the screen. The surface area, sphericity and related diameter are important to predict the terminal velocity of the grain for handling and drying purpose. Density and porosity of the bulk materials used for designing a storage silo and separation of impure materials from the grains. In addition to that the porosity which is also a necessary factor to design a dryer [12]. Frictional properties like angle of repose and coefficient of friction plays a vital role in designing of storage silos, hoppers, chutes and also for limits the maximum inclination angle of a belt conveyers, screw conveyers and pneumatic conveyors. Angle of repose is a useful parameter for the calculation of belt conveyor width and the angle of idle pulley. Coefficient of friction is most important for designing a storage silo, chutes, conveyors, hoppers, forage harvesters and threshers. Generally, materials move or slides in direct contact with casing, trough and other components of the equipment [7]. These parameters can also affect the efficiency of the machine which is mainly due to the frictional losses. Hence, the knowledge of physical and engineering properties of the agricultural materials is necessary for storage, handling and transportation.

Materials and Methods

The experiment was carried out in Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Freshly harvested black gram grains (VBN6 - Variety) was procured from the Department of Pulses, TNAU, Coimbatore and it was cleaned for the study. The moisture content of the grains was determined using hot air oven at the temperature of 130ºC for 6 hrs [1]. Initial moisture content of the grains found to be 11.5% and later then it was stabilized to bring the desired level of moisture contents such as 10.31%, 12%.39 and 14.19%. Using the following equation (1), the required quantity of water was added to achieve the desired moisture content [10].

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

Where,

Q- Weight of water to be added, g

Wi- Initial weight of grain, g

Table-1 *Three axial dimension of black gram grains at various moisture contents*

Samples	Moisture Content (w.b.%)								
	10%			12%			14%		
	Length	Width	Thickness	Length	Width	Thickness	Length	Width	Thickness
1	4.95	4.85	3.31	5.22	4.86	3.17	5.85	5.1	3.59
2	5.11	5.01	3.04	5.11	5.02	3.42	5.9	5.06	3.44
3	4.79	4.69	3.42	5.49	4.7	3.36	5.5	4.99	3.96
4	5.65	4.73	3.61	5.65	4.74	3.37	5.66	4.78	3.86
5	5.25	4.98	3.28	5.25	4.99	3.54	5.62	5.03	3.56
6	5.4	5.3	3.22	5.4	5.31	3.77	5.41	5.35	3.79
7	4.87	4.65	3.16	5.16	4.66	3.66	5.17	4.74	3.68
8	4.71	4.61	3.8	5.06	4.96	3.77	5.66	4.97	3.81
9	4.93	4.31	3.19	5.33	5.23	3.71	5.34	4.92	3.75
10	4.92	4.44	3.02	5.25	5.15	3.33	5.26	5.08	3.35
11	5.05	4.12	3.9	5.05	4.95	3.49	5.71	4.76	3.55
12	5.09	4.71	2.98	5.09	4.99	3.35	5.11	4.8	3.83
13	5.7	4.61	3.3	5.7	4.6	3.41	5.72	5.05	3.78
14	5.6	4.31	3.22	5.6	4.5	3.35	5.62	5.2	3.92
15	4.84	4.11	3.26	5.32	4.15	3.41	5.34	4.72	3.77
16	4.81	4.01	3.16	5.04	4.94	3.64	5.33	4.68	3.32
17	5.02	4.14	3.27	5.02	4.92	3.55	5.71	5.89	3.24
18	4.68	4.28	3.4	5.29	4.11	3.53	5.31	4.51	4.01
19	5.09	4.15	3.32	5.09	4.16	3.62	5.11	4.79	3.78
20	5.19	4.15	3.3	5.45	4.1	3.57	5.47	4.78	3.29
21	4.77	4.39	3.19	5.41	4.24	3.42	5.51	4.57	3.73
22	5.19	4.29	3.41	5.29	4.58	3.66	5.39	4.93	3.61
23	4.99	4.33	3.14	5.33	5.04	3.45	5.31	4.56	3.89
24	5.18	4.21	3.55	5.61	5.15	3.28	5.55	5.01	3.56
25	4.98	4.45	3.33	4.98	4.99	3.51	5.61	5.78	3.67
26	4.91	4.51	3.19	5.28	5.14	3.62	5.38	5.43	3.51
27	5.19	4.21	3.27	5.25	4.26	3.61	5.47	5.32	3.71
28	5.32	4.53	3.15	4.91	5.22	3.34	5.65	5.15	3.54
29	4.91	4.49	3.24	5.11	4.11	3.61	5.71	4.65	3.63
30	5.22	4.61	3.52	5.36	4.81	3.55	5.52	4.56	3.68
Mean	5.08	4.5	3.31	5.27	4.75	3.5	5.5	4.97	3.66
SD	0.26	0.28	0.21	0.21	0.39	0.15	0.21	0.28	0.23

Mi- Initial moisture content of the grain, % (w.b.)

Mf- Desired moisture content of the grain, % (w.b.)

Desired moisture content was brought down by spraying the determined quantity of water to the black gram grains. After uniform mixing of grains which were sealed in the polythene bags and kept at the refrigerator condition (5°C) and allowing it for stabilization. An equilibrium period of one week was provided to achieve the desired moisture level and uniformity. For determining the engineering properties of the grain, five replicates of the sample were taken from the three levels of moisture content (w.b.%) 10.31%, 12%.39 and 14.19%.

Dimensional Properties

Dimensional properties of the black gram grains were determined by taking 30 random grains from the bulk of the moisture stabilized grains and their linear dimensions like length (L), width (W) and thickness (T) were measured using the screw gauge. Using the following equations [Eq-2-5], the arithmetic mean diameter Da and geometric mean diameter Dg of the grains was determined by the measured three axial dimensions.

$$D_a = \frac{(L+W+T)}{3} \quad \text{--- (2)}$$

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

The sphericity (δ) and surface area (A_s) of the grains was calculated using the following expression.

$$\delta = \frac{(LWT)^{1/3}}{L} \times 100 \quad \text{---(4)}$$

$$A_s = \pi {D_g}^2 \quad \text{---(5)}$$

Physical Properties

Bulk density (ρb) of the grain was determined by taking the know volume of cylindrical container (V) to occupy the unknown mass of grain (M) which was measured by electronic balance and then the density was calculated by using the following equation [Equ-6]..

$$Bulk\ density\ (kg/m^3) = \frac{Mass\ (kg)}{Volume\ (m^3)} \quad \text{---(6)}$$

True density (ρt) of the grains was measured for three different levels of moisture content with three replications by using the toluene displacement method. Then the porosity (γ) was determined by using both the values of bulk density and true density by applying in the equation given below [Equ-7].

$$\gamma = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad - \quad \text{---(7)}$$

Frictional Properties

Angle of repose (μ) is the angle formed by a heap of the granular materials to the base of the piled grains on the horizontal plane. It was determined by opening the grain container to fall on the circular horizontal plane to form a heap on its natural slope. Then the height of the cone (heap) from the plane and radius of the circular horizontal plane was measured and calculated using the following equation [Equ-8].

$$\mu = tan^{-1}(\frac{H}{R}) \quad \text{---(8)}$$

Where

μ = angle of repose, degree

H = height of the cone, cm

R = radius of the circular horizonal base, cm

Coefficient of friction (μ) is the measure of force of friction between the grains and the surface of the plane in contact at rest. The known weight of grains (N) was Taken and filled in the bottomless container to contact the surface of the plane. Then the grain container was pulled by a string which was attached to the hanging mass (F) through the frictionless pulley to move freely. Normal force (N) and frictional force (F) was noted when the addition of mass required to slide or pull the grain on the surfaces [Equ-9]. The friction coefficient of grain was determined with the combination of various moisture content and plane surfaces like ply wood, mild steel sheet, galvanized iron sheet and rubber sheet.

$$\mu = \tan^{-1}(\frac{F}{N}) \quad \text{---(9)}$$

Statistical Analysis

All the results obtained were subjected to analysis of variance (ANOVA) using AGRESS software and regression analysis using MS Excel were done.

Results and Discussion

Dimensions of Grains

The axial dimensions of the black gram grains at various moisture content was measured and presented [Table-1]. From the table, the mean values of length, width and thickness are increases with increase in moisture contents. The mean values of the grain dimensions measured at the moisture content of 10.31% (w.b.) are length 5.08 ±0.26 mm, width 4.50 ±0.28 mm and thickness 3.31 ±0.21 mm. The mean values of the grain dimension measured at the moisture content of 12.39% (w.b.) are length 5.27 ±0.21 mm, width 4.75 ±0.39 mm and thickness 3.50 ±0.15. At moisture content 14.19 % (w.b.), the mean values of length, width and thickness are 5.50 ±0.21 mm, 4.97 ±0.28 mm and 3.66 ±0.23 mm respectively. Arithmetic mean diameter [Fig-1] and geometric mean diameter [Fig-2] of the black gram grains were increased with increase in grain moisture content which is due to the increased axial dimensions of the grains.

Increase in grains dimensions could be attributed to the grain expansion which is due to the absorption of water content by the grain's intercellular gaps. Similar results were also reported by [19]. The moisture dependence of the grain dimensional properties could be predicted by the following equation [Equ-10-14].

Length, L = 0.2098Mc + 4.8616 ---(10)

Width, W = 0.233Mc + 4.2753 ---(11)

Thickness, T = 0.1777Mc + 3.1339 ---(12)

Arithmetic Mean Diameter, Da = 0.2068Mc + 4.0903 ---(13)

Geometric Mean Diameter, Dg = 0.2068Mc + 4.0188 ---(14)

Where Mc is the moisture content of the grains and the corresponding R2 values of the equation for length, width, thickness, arithmetic and geometric mean diameter are 0.97, 0.98, 0.95, 0.97 and 0.95 respectively.

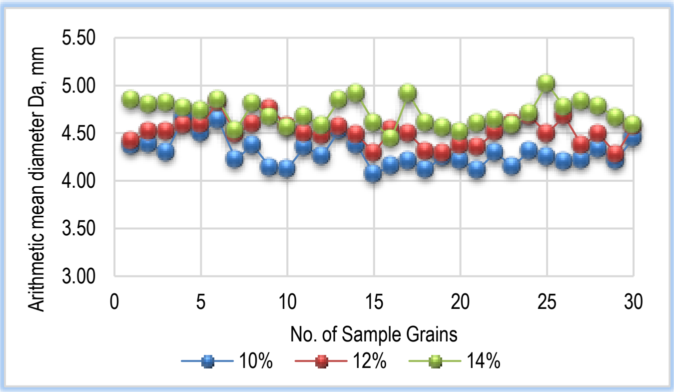

Fig-1 Effect of moisture content on arithmetic mean diameter

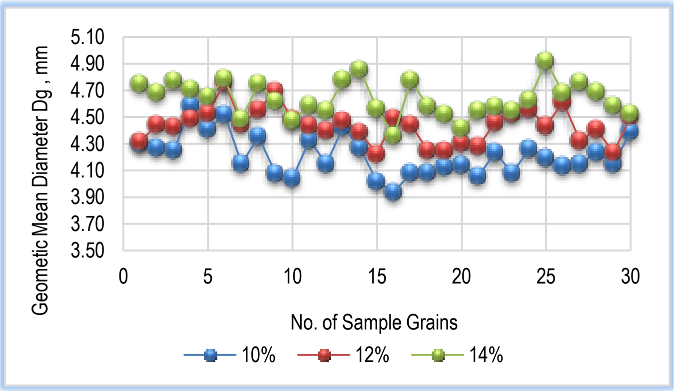

Fig-2 Effect of moisture content on geometric mean diameter

Sphericity, δ

Individual values of the grain sphericity were determined by the [Equ-4] using the geometric mean diameter of the grains. The results are presented in the [Fig-3]. The sphericity of the grains was increased when the moisture content is increased from 10% to 14% (w.b). Average value of the grain sphericity at the moisture content 10.31%, 12.39% and 14.19% are 83.29%, 84.32% and 84.41% with the deviation of 3.69, 3.07 and 2.88 respectively. Increase in the grain sphericity may be caused due to the proportional increase in the grain dimensions such as length, width and thickness. Similar results also reported for okra seeds [17]. The relationship between the sphericity (δ) and moisture content (Mc) can be represented by the following power model equation [Equ-15] with maximum regression value of 0.91.

Sphericity, δ = 1.069ln(Mc) + 83.373 ---(15)

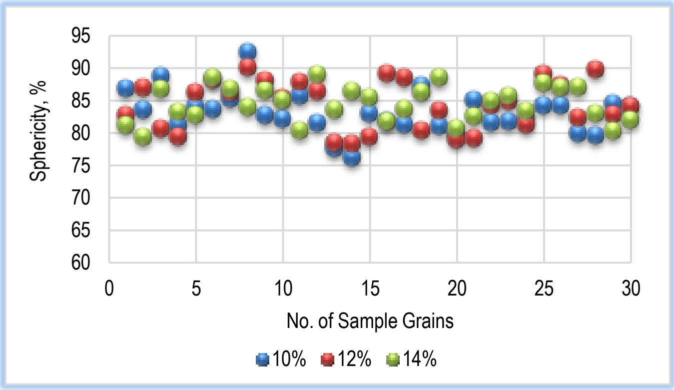

Fig-3 Effect of moisture content on sphericity of grains

Surface Area, As

Surface area of the black gram grains were increased linearly with increase in moisture content as shown in [Fig-4]. The mean values of the surface area at the moisture content of 10.31%, 12.39% and 14.19% are 56.05 ±4.30 mm, 61.89 ±3.85 mm and 67.55 ±4.01 mm respectively. Remarkable increase in surface area with respect to moisture content is due the absorption of moisture content by the grains which attributes by the slight increase in grain length. Similar trends were also reported for rice and jatropha seeds [12]. The relationship of surface area, as of black gram and moisture content can be expressed [Equ-16] by the following linear equation with the R2 value of 0.96.

Surface Area, As = 5.7478Mc + 50.337 ---(16)

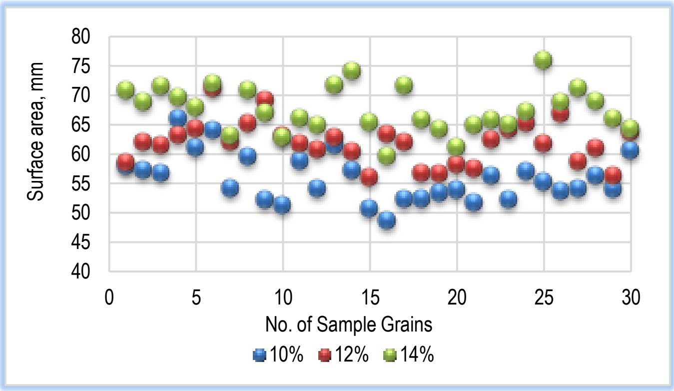

Fig-4 Effect of moisture content on surface area of grains

Bulk Density, ρb

Bulk density of the black gram grain varied significantly (P<0.05) with varying moisture content of 10%, 12% and 14% as shown in the [Table-2]. Average values of bulk density were decreased with increase in moisture content 10%, 12% and 14% are 823 kg/m3, 798 kg/m3 and 761 kg/m3 respectively. This decreasing behavior of bulk density of grain is due to the fact that volume expansion of grain will occur as the results of increase in moisture content of the grain as well as the sample associated with rise in humidity inside the grains. As the result, the high moisture grain occupies the more air than the less moisture grain which leads to more increased volume and decreased mass of grains. Similar behavior has been observed by the reporter [21] for barley and soy beans. The relationship among varying moisture content (Mc) and bulk density (ρb) of black gram grains can be expressed [Equ-17] as the following linear equation with maximum regression value of 0.98.

$$\text{Bulk density, } \rho b = -31Mc + 856 \quad \text{---(17)}$$

True Density, ρt

The true density of the black gram was decreased significantly at ($P<0.05$) varying moisture content are presented in [Table-2]. It was observed that true density is inversely proportional to the moisture content of the grains. This may be due to the increase in weight of the grains by the absorbed moisture content which results in accommodation of grain will be less than the dry grains in the container [4]. The following [Equ-18] having R2 value of 0.97 which is used to predicts the dependency of the true density (ρt) with moisture content (Mc).

$$\text{True density, } \rho t = -28Mc + 1370.3 \quad \text{---(18)}$$

Porosity, γ

Black gram porosity was determined by the equation () by using the mean values of the bulk density and true density. From the Table 1, the porosity was increased with respect to the increasing moisture content from 10% to 14% (w.b.). Significant increase ($P<0.05$) in porosity was observed with varying moisture content which is due to the elongation in the length of the grains. This behavior helps to increase the volume of the individual grain which cause the grains occupying in the fixed volume reduces as well as bulk density decreases or bulk volume increases. As the results, porosity increases with the high moisture content which leads by expansion ratio between the mass and volume of the gains. Similar behaviours were reported for the niger seeds [19] and the three varieties of sorghum [14]. The relationship [Equ-19] between the moisture content (Mc) and porosity (γ) of the black gram grains was given below having a R2 value 0.96.

$$\text{Porosity, } \gamma = 1.075Mc + 37.455 \quad \text{---(19)}$$

Angle of repose, μ

Increase in angle of repose was observed with increase in grain moisture content as shown in the [Table-2]. When the moisture content of grain increased from 10% to 14%, the significant increase in angle of repose was measured at the level of $P<0.05$. This trend may be caused due to the fact that moisture in the grain surface layer keeps them bound together by surface tension effect which creates the grain friction to increase in height of the heap [15]. Angle of repose is useful in designing a storage structure, silo opening hopper and conveyors. Therefore, angle of repose of grains is taken into account for designing such structures and equipment. Similar trend was reported for jatropha, sorghum and Karanja with respect to moisture content [14]. The relationship between the moisture content (Mc) and angle of repose of the black gram grains can be described by the given equation with R2 value of 0.95.

$$\mu = 1.05Mc + 26.933 \quad \text{---(20)}$$

Table- 2 *Effect of moisture content on physical properties of black grams*

Properties	Moisture content % (w.b.)		
	10%	12%	14%
Bulk density (kg/m³)	823	798	761
True density (kg/m³)	1340	1319	1284
Porosity (%)	38.58	39.50	40.73
Angle of repose, Degree	28°	29°	30.1°

Coefficient of friction

The static coefficient of friction of black gram grains were determined with the various surfaces (rubber sheet, ply wood, aluminium sheet and mild steel) and moisture content as shown in the [Fig-5]. It was observed that significant increase in friction coefficient of grain with respect to moisture content 10%, 12% and 14%. Coefficient of friction of black gram grains showed as increase of 0.39 to 0.43, 0.42 to 0.46, 0.41 to 0.44 and 0.5 to 0.54 rubber sheet, ply wood, aluminum sheet and mild steel respectively. Maximum friction was measured with the mild steel followed by ply wood, aluminium and rubber. The reason behind increase in coefficient of friction is due to the change in grain moisture increases the force of friction which tends to increase the flow resistant of the grain on surfaces. Similar study was reported for the barley grain [16]; [6].

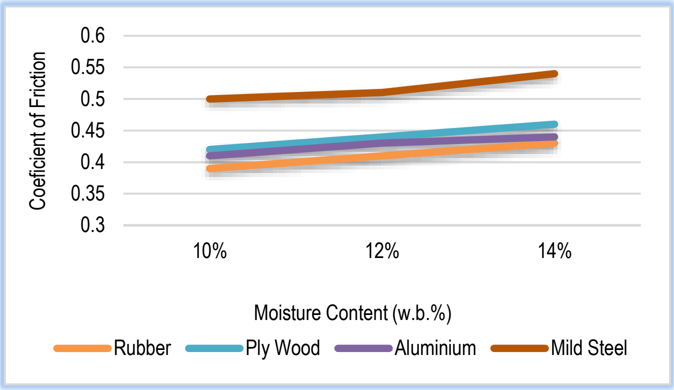

Fig-5 Effect of moisture content on coefficient of friction at different surfaces

Conclusion

In this study, the relationship on the effect of some engineering properties of black gram (*Vigna mungo*) and various moisture content was observed. The grain dimensions, mean diameter, sphericity, surface area of grains was increased with high moisture content. A well as the true density and bulk density were observed decrease with increasing moisture content (w.b.%). Porosity of the grains was increased when the moisture content of grain increased. Frictional properties like angle of repose and coefficient of friction were also increased when the moisture content increased from 10% to 14%. The maximum friction coefficient was observed with mild steel surface followed by plywood, aluminium sheet and then rubber.

Application of research

Engineering properties of grains could be used for designing a post harvest equipment. Also, it helps in computer modelling and simulating of the farm power machineries, storage silo and material handling equipment.

Research Category: Agricultural engineering, Grain properties.

Abbreviations:
w.b.-Wet basis
mm- Millimetre
SD-Standard deviation

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Study area / Sample Collection: Department of Pulses, Tamil Nadu Agricultural University, Coimbatore.

Cultivar / Variety name: Black gram (*Vigna mungo*)– VBN6

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Ethical Committee Approval Number: Nil

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