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Moisture-dependent engineering properties of SML-668 variety of green gram

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Abstract
Seed moisture content is significant in the handling, storage and processing of seeds. This study was carried out to determine the physical properties of green gram seeds as function of seed moisture content in the moisture range of 6-24% dry basis (d.b). The average length, width, thickness, geometric mean diameter, thousand grain mass, angle of repose and water activity increase as the moisture content increased from 6 to 24% (d.b) and the sphericity was found to decrease from 0.928 to 0.625. Also bulk density was found to decrease from 1096 to 913.34 kg m^{-3}, whereas true density decreased from 1369.5 to 1237 kg m^{-3}, while the porosity was found to increase from 18.09 to 30.73%. The static co-efficient of friction of green gram increased against various surfaces such as, wood, glass, GI sheet and mild steel sheet, as the moisture content increased from 6 to 24% (db.).

Keywords: green gram, engineering properties, moisture content, density, coefficient of friction

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 various bioactive compounds.

Green gram (*Vigna radiata*) is an important pulses crop in India and believed to be originated from India. It is commonly known as *Mung* in India. It is a short duration legume crop grown mostly as a fallow crop in rotation with rice. Similar to the leguminous pulses, green gram, enriches soil nitrogen content. It is grown mostly in Asian region traditionally while its cultivation has spread to Africa and Americas relatively in the recent times. More than 70% of world's green gram production comes from India. It produces about 1.5 to 2.0 million tons of Mung annually from about 3 to 4 million hectares of area, with an average productivity of 500 kg per hectare. Green gram output accounts for about 10-12% of total pulse production in the country. Other than India the mung bean is mainly cultivated in China, Korea, and Southeast Asia. It is used as an ingredient in both savory and sweet dishes. The grain forms an important source of protein, with 22.51% protein content (Kochhar and Hira, 1997) [12].

Engineering properties of bio-materials are determined to help primarily with the design aspects of storage, handling and processing equipment and machinery. Kumar *et al*. (2016) [13] reported that length, width, thickness, and geometric mean diameter Sphericity, volume and thousand seed weight porosity, angle of repose and static coefficient of friction of Chironji nut increased linearly when moisture content increased from 9.98% to 17.06% (d.b.). However, true density and bulk density decreased linearly in the same moisture range for Chironji nut. Similar trend has been reported by Tavakoli *et al*. (2009) [21] for soybean seed.

Sonawane *et al*. (2014) [20] recorded physical properties of horse gram grains (*Macrotyloma uniflorum*) as a function of moisture content in the range of 8.66 to 20.76% dry basis (d.b). Sangani and Davara (2013) [18] determined physical properties of pigeon pea grains (BDN-2) at five different moisture content levels of 10, 20, 30, 40 and 50% dry basis (d.b). The average value of triaxial dimensions, porosity and angle of repose of pigeon pea increased while bulk density and true density decreased with increase in moisture content. Wandkar *et al*. (2012) [25] observed that for soybean the geometric mean diameter increased from 5.44 to 5.57 mm and the sphericity varied between 0.83 and 0.84 as moisture content increased from 7.37 to 15.80% (d.b), respectively. In the same moisture range, the bulk and true densities decreased from

749.1 to 644.4 kg m^{-3} and 1250 to 1111.11 kg m^{-3}, respectively, whereas the corresponding porosity increased from 40.07 to 41.9%. As the moisture content increased from 7.37 to 15.80% (d.b) angle of repose was found to increase from 26.35° to 30.96°. The static coefficient of friction of soybean increased linearly against the surfaces of two structural materials, namely glass and wood as the moisture content increased from 7.37 to 15.80% (d.b).

Eissa *et al*. (2010) [7] recorded various engineering properties of chickpea seeds at four levels from 11.6 to 25.4% (d.b) and observed that the average bulk density, true density, porosity and angle of repose increased linearly with an increase in moisture content and the engineering properties were linearly dependent upon moisture content. Tavakoli *et al*. (2009) [21] evaluated average length, width, thickness, arithmetic mean diameter, geometric mean diameter, thousand grain mass, sphericity, surface area and repose angle bulk density, true density, porosity, static friction coefficient of barley grains at four levels of moisture content ranging from 7.34 to 21.58% (d.b). Işik and Ünal (2007) [9] measured the arithmetic and geometric mean diameters, thousand grain mass, true density, bulk density sphericity, porosity, projected area, terminal velocity and static coefficient of friction of white speckled red kidney bean grains in the moisture range of 9.77-19.62% (d.b).

The object of this study was to investigate some moisture-dependent physical properties, namely, linear dimensions, size, sphericity, thousand grain mass, bulk density, true density, porosity, angle of Repose, water activity and static coefficient of friction of green gram at different moisture contents.

2. Materials and Methods

15 kg of Green gram of SML-668 variety was procured from PAU, Ludhiana. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature and broken seeds. Initial moisture content was found to be around 6% (d.b) by oven drying at 104 ± 1°C for 4-5 h until a constant reading is achieved followed by cooling in a desiccators. In order to obtain the desired moisture content, the samples were conditioned by adding a calculated quantity of water, mixing thoroughly and then sealing in low-density polyethylene bags of around 100 μm thickness. The samples were kept in a refrigerator at 5 °C. Before proceeding towards any test the sealed sample packs were first kept outside for 1-2 hrs in order to achieve room temperature. The physical properties of the grain were determined at moisture levels of 6, 8, 10, 15, 16, 18, 20, 22, 24% d.b.

2.1 Size

In order determine the average size of the seed, 125 seeds were randomly selected and their three linear dimensions namely, length L, width *B* and thickness *T* were measured using a vernier caliper having 0.02 mm least count. The geometric mean diameter (D_g) and sphericity (S) of grains were calculated using the relationships given by Mohsenin (1986):

$D_g = (LBT)^{1/3}$ Eq. 1 $S = D_g / L$ Eq. 5

2.2 Thousand grain mass

The thousand seed mass (M_{1000}) of gram was measured by counting 1000 seeds in a seed counter (N) and weighing (W) them in an electronic balance to an accuracy of 0.001g. Taking at least 5 replications of each sample the 1000 grain mass was calculated by using the following formula:

$$M_{1000} = \frac{W}{N} \times 1000 \qquad \text{Eq. 3}$$

2.3 Bulk density

The bulk density, (ρ_b) 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 grain and then weighing the amount of grain. The weight of the grains 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 on the surface for the grains to consolidate. The volume occupied was then noted. The process is replicated for three times and the average bulk density for each replication was calculated from the following equation:

$$\rho_b = \frac{\text{Weight of sample (W)}}{\text{Volume of container (V)}} \qquad \text{Eq. 4}$$

2.4 True Density

The true density (ρ_t) is defined as the ratio of mass of seeds to the true volume of seeds. The seed volume and its true density was determined using Toluene displacement technique. 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. The volume of toluene displaced was found by immersing a weighed quantity of seeds in the measured toluene. 5 ml of toluene was placed in a 10 ml graduated measuring cylinder and 5 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.

$$\rho_t = \frac{\text{Weight of sample (kg)}}{\text{Volume of toluene displaced } (m^3)} \qquad \text{Eq.5}$$

2.5 Porosity

The porosity (ε) of bulk grain was calculated from the values of true density and bulk density using the following formula given by Mohsenin, (1986):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad \text{Eq.6}$$

2.6 Angle of Repose

For measuring the angle of repose (ϕ), an apparatus consisted of an iron box of with 300×300×300 mm hopper size and a circular plate with 10 cm radius (r) fitted inside. A discharge gate at the bottom of the box is used. After filling the box with a grain sample, the grains were allowed to drop over the plate freely without disturbing the apparatus. The height of grain pile (h) retained on the circular disc was measured and used to determine the angle of repose by using the following formula

$$\phi = \tan^{-1}\frac{h}{r} \qquad \text{Eq. 7}$$

2.7 Static coefficient of friction

The static co-efficient (μ) of green gram seeds against five different surfaces, namely wood, glass, GI sheet 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 wooden sheet was placed on a leveled table and marked a line at which we put sample container. Now the bottomless container was placed at the marked line and filled with the samples up to top. Now the balance dish was hinged connected with the container by thread passing over a pulley. By putting some weight in balance dish at which the container starts sliding over the base sheet is noted as the dead load (W_d). Measure the weight of sample filled in the container by electronic balance (W). At least 5 replications of each sample for each of the base sheets were taken for experiment. The co-efficient of friction was calculated using the following formula.

$$\text{Coefficient of friction } (\mu) = \frac{\text{Dead load } (W)_d}{\text{Weight of sample (W)}} \quad \text{Eq. 8}$$

2.8 Water Activity

Water activity or A_w is the partial vapor pressure of water in a substance divided by the standard state partial vapor pressure of water.

$$A_w = \frac{p}{p_o} \quad \text{Eq. 9}$$

Where p and p_o are the partial pressures of water above the sample and of pure solution respectively, under identical conditions. Water activity was measured with Rotronic Hygrolab C1 device using 2-5 g in each sample.

3. Results and Discussion

3.1 Grain dimensions

Average values of the three principal dimensions of green 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. The green gram expands in length, width and thickness in the moisture range of 6 to 24% (d.b). The average length, width and thickness varied from 3.69 to 7.47 mm, 3.30 to 3.65 mm and 3.23 to 3.74 mm, respectively as the moisture content increased from 6 to 24% (d.b). The geometric mean diameter increased with the increase in moisture content (Fig. 1). The average geometric mean diameter ranged from 3.39 to 4.66 mm, as the moisture content increased from 6 to 24 % (d.b) respectively.

Table 1: Dimensions of green gram at different moisture contents

Moisture content	Length (L) mm	Breadth (B) mm	Thickness (T) mm
6	3.69 ± 0.03	3.30 ± 0.02	3.23 ± 0.02
8	4.55 ± 0.03	3.35 ± 0.02	3.33± 0.02
10	4.53 ± 0.03	3.45 ± 0.02	3.43 ± 0.02
12	4.57 ± 0.03	3.50 ± 0.02	3.46 ± 0.02
15	4.86 ± 0.03	3.54 ± 0.02	3.47 ± 0.01
16	5.27 ± 0.03	3.74 ± 0.02	3.68 ± 0.02
18	5.43 ± 0.02	3.91 ± 0.02	3.71 ± 0.01
20	6.25 ± 0.03	3.95 ± 0.01	3.72 ± 0.01
22	6.18 ± 0.02	3.98 ± 0.01	3.73 ± 0.01
24	7.47 ± 0.02	3.65 ± 0.02	3.74 ± 0.01

3.2 Geometric Mean Diameter (D_g) and sphericity (S)

The geometric mean diameter and sphericity were calculated using the equation 1 and 2, and the results were plotted on a graph and trend line and equations were obtained. The geometric mean diameter increased linearly from 3.39 to 4.66 mm. The variation in grain size was significant in the studied moisture range ($p < 0.01$). The results were similar to sphericity was found to decrease from 0.93 to 0.62. Grain size was found to bear the following relationship with moisture content M:

$D_g = 0.068\ M + 3.029$ (R^2=0.957) Eq. 9 $S = 0.989 - 0.014\ M$ (R^2=0.861) Eq. 10

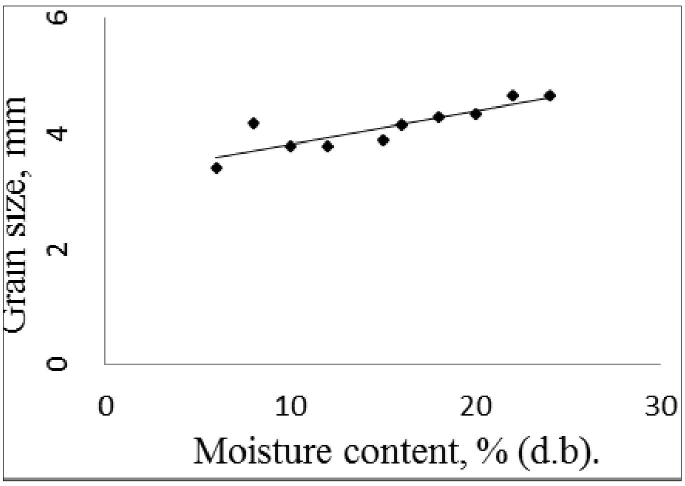

Fig 1: Effect of moisture content on grain size

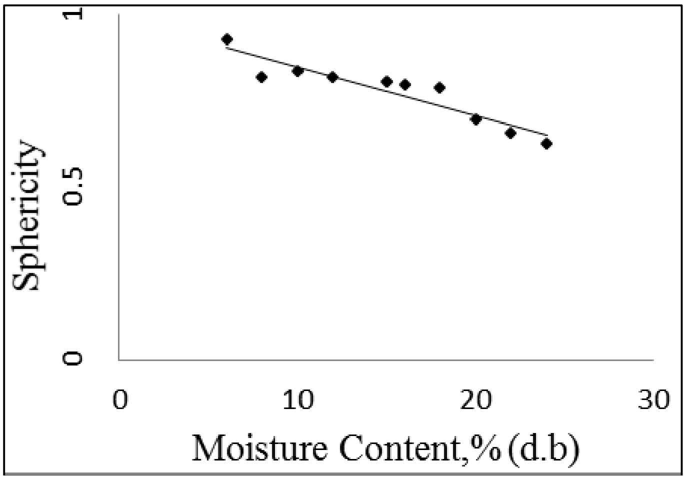

Fig 2: Effect of moisture content on sphericity

Similar trend has been reported by Nimkar and Chattopadhyay (2001) [15] for green gram; Davies and Zibokere (2011) [5] for cowpea seeds.

3.3 Thousand grain mass

The thousand seed mass (M_{1000}) of green gram increased linearly from 47.45 to 58.44 g as the moisture content increased from 6 to 24% (d.b) (Fig. 3). This relationship between 1000 grain mass (M_{1000}) and the moisture content (M) can be represented by the following equation

$$M_{1000} = 43.10 + 0.623\,M \quad (R^2=0.981) \qquad \text{Eq. 11}$$

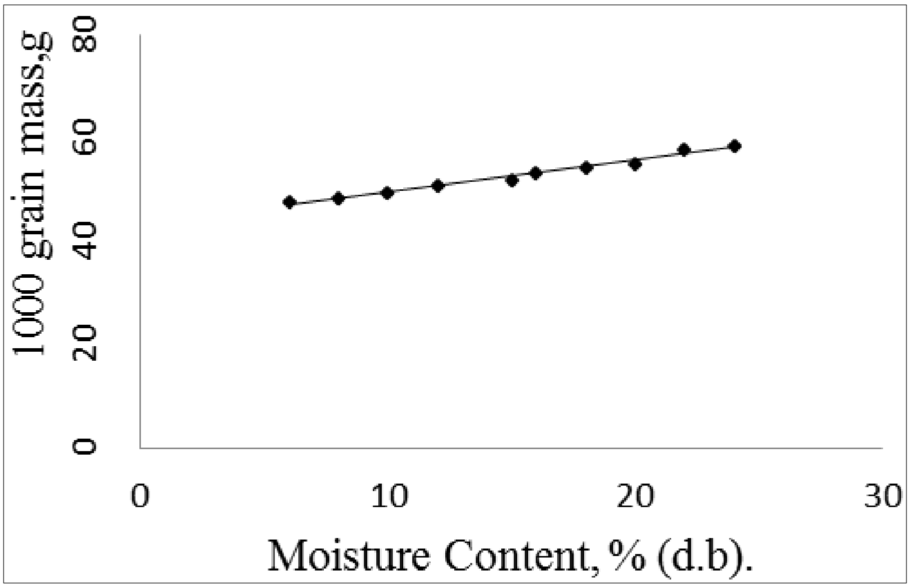

Fig 3: Effect of moisture content on thousand grain mass

Similar increasing trend has been reported by Nimkar and Chattopadhyay (2001) [15] for green gram, Kasap and Altuntaş (2006) for sugarbeet seeds, Altuntaş and Yildiz (2007) [3] for faba bean grains, Pradhan *et al*. (2008) [8] for karanja kernel and Tavakoli *et al*. (2009) [21] for soybean grains.

3.4 Bulk Density (ρ_b) & True Density (ρ_t)

The bulk density of grain at different moisture contents varied from 1096 to 913.34 kg m^{-3}, and indicated a decrease in bulk density with an increase in moisture content from 6 to 24% (d.b). Similarly with an increase in moisture content the true density was noted to decrease from 1369.47 to 1237 kg m^{-3}.

From the results obtained it is found that the Bulk Density (ρ_b) & True Density (ρ_t) of grains was found to have the following relationship with moisture content (M):

$$\rho_b = 1131 - 9.775\,M \quad (R^2=0.932) \qquad \text{Eq. 12}$$

$$\rho_t = 1422 - 9.140\,M \quad (R^2=0.970) \qquad \text{Eq. 13}$$

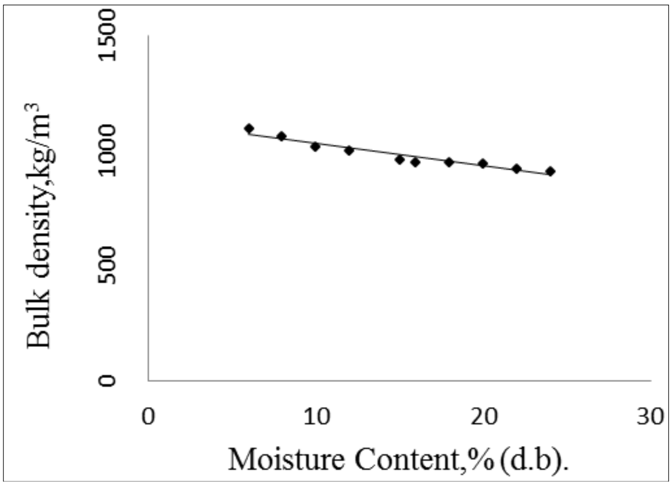

Fig 4: Effect of moisture content on bulk density

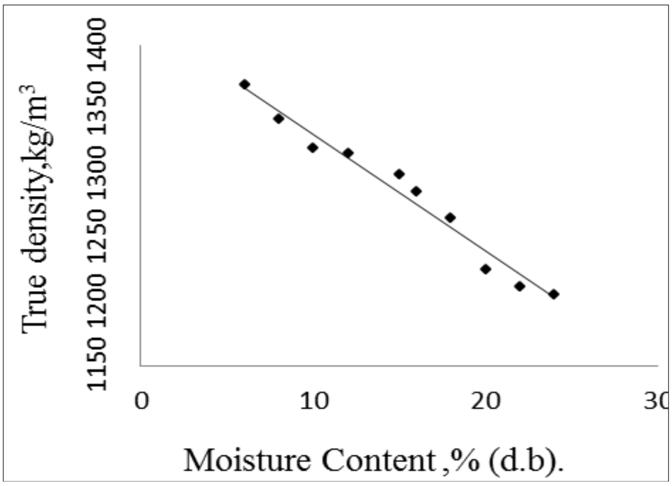

Fig 5: Effect of moisture content on true density

Similar decreasing trend in bulk density has been reported by Nimkar and Chattopadhyay (2001) [15] for green gram, Yalçin *et al*. (2007) for pea seed, Altuntaş and Demirtola (2007) for some legumes seeds, Garnayak *et al*. (2008) [8] for jatropha seed and Pradhan *et al*. (2008) [8] for karanja kernel. The relative reduction in the densities at high moisture content could be attributed to less weight gain due to the added moisture in relation to the concomitant volumetric expansion of the grain. Similar trend has been observed for pigeon pea (Baryeh and Mangope, 2002) and green gram (Nimkar and Chattopadhyay, 2001) [15]. The decrease in true density value for the lathyrus grain with increase in moisture content might be attributed to the relatively higher true volume as compared to corresponding mass of the grain attained due to absorption of water.

3.5 Porosity (ε)

Porosity was calculated using Eq. (6). The porosity of green gram seeds increases linearly from 18.09 to 30.73 %. As the moisture content increased from 6 to 24% (d.b), the relationship between porosity and the moisture content M of the grain was obtained as:

$\varepsilon = 14.82 + 0.752\ M\ (R^2=0.925)$ Eq. 14

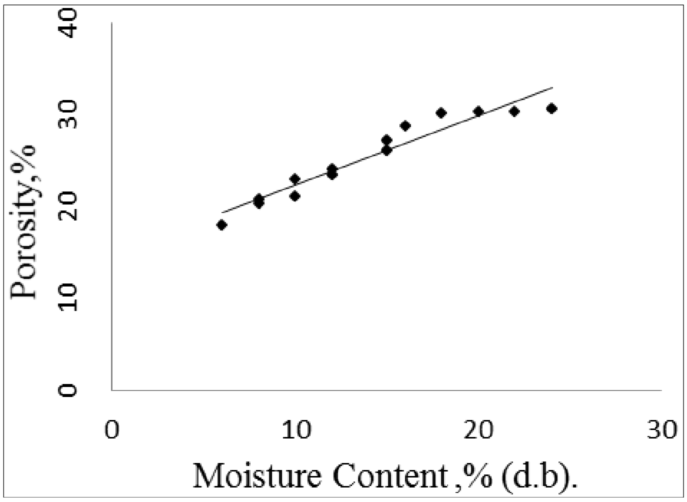

Fig 6: Effect of moisture content on porosity

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.

3.6 Angle of repose

The experimental results for the angle of repose with respect to moisture content are shown in Fig 7. The values were found to increase from 18.71° to 30.68° in the moisture range of 6 to 24% (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) [8]. The values of the angle of repose (ø) for green gram bear the following relationship with its moisture content

(M):$\text{Ø} = 15.93 + 0.614\ M\ (R^2 = 0.982)$ Eq. 5

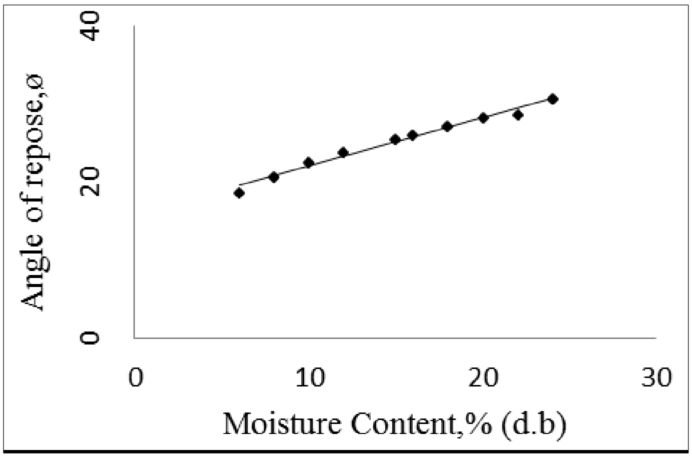

Fig 7*:* Effect of moisture content on angle of repose

These results were similar to those reported by Nimkar and Chattopadhyay (2001) [15] for green gram, Kasap and Altuntaş (2006), Altuntaş and Yildiz (2007) [3], Garnayak *et al*. (2008) [8], and Pradhan *et al*. (2008) [8], for sugarbeet seeds, faba bean grains, jatropha seed and karanja kernel, respectively.

3.7 Static co–efficient of friction

The static coefficients of friction of green gram on four different surfaces (wood, glass, Galvanised iron and mild steel sheet) against moisture content in the range of 6 to 24% (d.b) are presented. 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) [8]. The increase in static coefficient of friction was due to increased adhesion between the seeds and the rough surfaces of the test materials while the decrease was due to the smoothness and more polished surfaces compared with other test materials. At all moisture contents, the static coefficient of friction was greatest against mild steel sheet (0.46 to 0.71) followed by G I sheet (0.35 to 0.64), glass (0.30 to 0.63) and wooden sheet (0.325 to 0.593), Table 2 shows the summary of the values of static coefficient of friction of green gram on four different structural surfaces.

Table 2: Effect of grain moisture content on static coefficient of friction of green gram on different material surfaces

Moisture Content (%)										
9	6	8	10	12	15	16	18	20	22	24
wooden sheet	0.328	0.38	0.417	0.438	0.439	0.45	0.458	0.532	0.566	0.593
glass sheet	0.359	0.39	0.419	0.446	0.448	0.462	0.478	0.567	0.592	0.636
GI sheet	0.365	0.393	0.425	0.46	0.473	0.478	0.508	0.572	0.626	0.641
M S sheet	0.464	0.397	0.434	0.488	0.508	0.509	0.528	0.64	0.69	0.701

Coefficient of friction increased with the moisture content as recorded by Shepherd and Bhardwaj 1986; Dutta *et al*. 1988; Kulkelelko *et al*. (1988); Visvanathan *et al*. (1996); Nimkar and Chattopadhyay (2001) [15]; Garnayak *et al*. (2008) [8]; and Pradhan *et al*. (2008) [8].

3.8 Water activity
The experimental results for the water activity with respect to moisture content are shown in Fig 8. The values were found to increase from 0.74 to 1 in the moisture range of 6 to 24% (d.b). This increasing trend in water activity is due to the fact that the free or available water in a food which is known as water activity supports microbial growth, and participates in and supports chemical and enzymatic reactions and spoilage processes.

The values of the water activity (A_w) for green gram bear the following relationship with its moisture content

$$(M): A_w = 0.695 + 0.014\,M \quad (R^2 = 0.829) \qquad \text{Eq. 16}$$

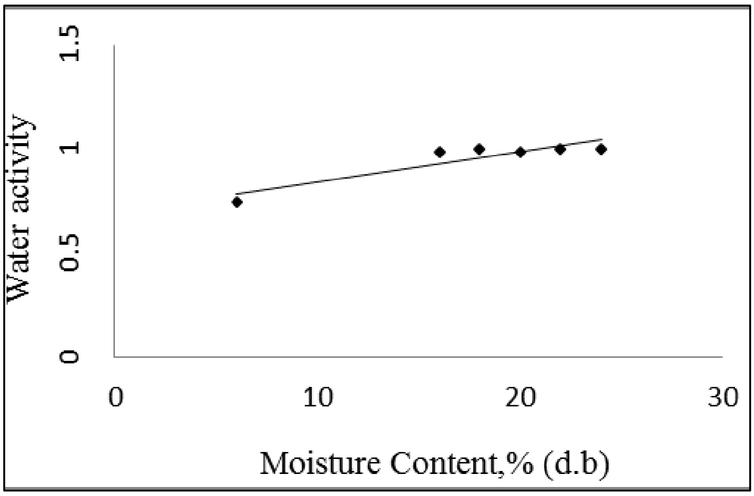

Fig 8: Effect of moisture content on water activity

4. Conclusions
The following conclusions are drawn from the investigation on the moisture dependent physical properties of green gram:

1. In the moisture content range of 6 to 24% (d.b), the average length, width, thickness, and thousand grain mass of green gram ranged from 3.69 to 7.47 mm, 3.30 to 3.65 mm, 3.23 to 3.74 mm and 47.45 to 58.44 g and respectively.
2. The geometric mean diameter was recorded to increase from 3.39 to 4.66 mm whereas angle of repose increased from 18.71° to 30.68° in the moisture range 6 to 24% (d.b).
3. The sphericity was found to decrease from 0.928 to 0.625 in the moisture range of 6 to 24% (d.b).
4. As the moisture content increased from 6 to 24% d.b., the bulk density decreased from 1096 to 913.34 kg m^{-3}, where as true density decreased from 1369.5 to 1237 kg m^{-3}, while the porosity was found to increase from18.09 to 30.73%.
5. The static coefficient of friction was greatest against mild steel sheet (0.46 to 0.71) followed by G I sheet (0.35 to 0.64), glass (0.30 to 0.63) and wooden sheet (0.325 to 0.593) when the moisture content increased from 6 to 24% (d.b).
6. The water activity was found to increase from 0.745 to 1 in the moisture range of 6 to 24% (d.b).

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