Effect of Moisture Content on Engineering Properties of Green Gram for Designing of Agricultural Equipment

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ABSTRACT

Background: Green gram is a popular pulse crop in India (with 2.02 MT production over a cultivated area of 4.26 Mha) and Odisha (20.8 lakh ha area with a yield of 10.60 lakh tonnes). The information on the engineering properties and its behavioural changes with moisture content is vital for handling and designing of different agricultural processing equipment.

Methods: This work mainly focused on studying green gram variety's (Sujata) engineering properties at five different moisture levels (within a moisture range of 10.58 to 45.45% (d.b.). Standard methods and procedures were followed in the study and the output results were compared with previous research work to justify the variation or anomaly in some cases. The curve estimation method (regression analysis) was followed to find the best-fit curve and equation for the parameters studied.

Result: The geometric mean diameter (GMD) of grain increased from 3.75 to 4.12 mm within the moisture content (MC) range and the variation was statistically significant ($p<0.05$). Sphericity and surface area varied significantly from 0.83 to 0.82 and 44.13 to 53.45 mm^2, respectively, within the range of moisture contents studied with a high correlation among the data. Mass of thousand grains augmented (44.13 to 53.45 g) with a rise in MC and the data followed logarithmic and inverse curves. Bulk and true densities of green gram declined significantly from 860 to 670 kg m^{-3} and 1330 to 1240 kg m^{-3} with an increase in the moisture content. The porosity of green gram increased significantly from 35.75% to 46.38% and the terminal velocity raised from 9.20 m s^{-1} to 11.10 m s^{-1} with an increase in MC. The dynamic angle of repose increased significantly from 30.95 to 46.57^0 with MC. A significant variation in the coefficient of internal friction (0.78 to 0.90) was observed for the grains. The coefficient of static friction of grain increased significantly for different surfaces (MS, SS, Plywood and GI) with a rise in MC. The MS surface produced the highest coefficient of static friction and SS had the least. The results confirmed significant effect of MC on all engineering properties of green gram.

Key words: Angle of repose, Bulk density, Coefficient of friction, Green gram, Moisture content, Porosity.

INTRODUCTION

Pulses contribute significantly to our daily diet and have been a rich source of protein and carbohydrates for its consumers. Pulses grown in India include grams, pigeon pea, lentil, field peas, *etc.* The country's diverse climate and soil types have played a vital role in cultivating pulse crops in the subcontinent. The primary pulse growing states are Madhya Pradesh (20.3%), Maharashtra (13.8%), Rajasthan (16.4%) and Uttar Pradesh (9.5%) (Singh *et al.*, 2015). The green gram production recorded was around 2.02 MT over a cultivated area of 4.26 Mha (Kharif + rabi) and at a yield level of 472 kg ha^{-1}. The major green gram producing states are Rajasthan, Madhya Pradesh, Maharashtra, Karnataka, Bihar, Andhra Pradesh, Odisha and Tamil Nadu (Anon., 2018). In Odisha, it is widely cultivated just after the Paddy crop and is very popular in our day-to-day diet. In Odisha, pulses are grown in 20.8 lakh ha with 10.60 lakh tonnes yield and green gram contributes 42% of total pulse area with a production of 4.14 lakh tonnes (OUAT Strategies, 2016). Being a legume, pulses require less fertiliser, the water requirement of the crop is low and it fits nicely in crop rotation with cereals. The primary chemical components of green gram include carbohydrates, proteins, fat, fibre, ash, fatty acids and amino acids, with protein contributing up to 14.6-33.0 g/100 g of seed (Dahiya *et al.*, 2015).

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The knowledge of engineering properties of green gram is vital, considering its wide use and cultivation in the state. Information on size, shape, sphericity, bulk density, true density and porosity is essential for designing the equipment for handling, harvesting, sieving, sorting and grading, drying

and storing the grain (Pandiselvam et al., 2015, Rani and Grewal, 2014, Sahay and Singh, 1994). The angle of repose and co-efficient of friction is essential in designing seed drill hoppers, bins, silos, storage structures, dehulling and packaging equipment (Niveditha et al., 2013, Singh et al., 2010). The bulk density of the grain plays a crucial role in determining the capacity of seed hoppers. Several researchers, including Mangaraj et al., 2005, Nimkar and Chattopadhaya, 2001, Pandiselvam et al., 2017, Sharon et al., 2015 and Unal et al., 2008 have studied on physical and engineering properties of a Green gram and few have considered their relation with moisture content. However, few researches have been reported on the varieties of green gram grown and found in Odisha. This paper investigates the engineering properties of a variety (Sujata) of green gram grown in Odisha. The properties like size (length, breadth, thickness), sphericity, grain weight, volume, bulk density, true density, porosity, static friction, coefficient of internal friction, angle of repose and terminal velocity are thoroughly studied over a wide range of moisture contents with 5, 10, 15 and 20% increase in existing moisture content levels. Then, the existing relationship between these grain properties and MC's rise was analysed using suitable statistical methods.

MATERIALS AND METHODS

Sample preparation

The green gram variety was procured from International centre for Agricultural Research in Dry Area (ICARDA), Odisha and cleaned manually to separate foreign matter. It was passed through a sieve to separate broken and immature grains. The graded and clean grain was sundried and its initial moisture content was determined using a hot air oven method. The grain samples were then added with a calculated amount of distilled water at four increments (5, 10, 15 and 20%) and put in airtight polyethene pouches. The samples were kept in the refrigerator at 5°C for a week to ensure uniform moisture distribution throughout the sample (Nimkar and Chattopadhyay, 2001, Singh et al., 2010). Before conducting the tests, the sample of required quantities were taken out of the refrigerator and put at room temperature. The actual moisture content (MC) of the sample were measured by placing them in a hot air oven at 103±2°C for 72 h followed by cooling and weighing to determine its MC (Nimkar and Chattopadhyay, 2001). The final MC of different treatments of grain observed after placing them in room temperature were 10.58, 20.25, 26.88, 36.23 and 45.45% (d.b.). Measurement of several engineering properties (Physical, aerodynamic and mechanical properties) was done at different moisture content levels with three replications at Department of Agricultural Processing and Food Engineering laboratory, College of Agricultural Engineering and Technology, OUAT in the year 2020.

Size

For measuring the grain's dimensions, 50 grains were selected randomly from the sample and their three principal dimensions (length, width and thickness) were measured using a digital Vernier calliper with a least count of 0.01 mm. The geometric mean diameter (GMD) D_m was computed using the following equation (Singh et al., 2010 and Pawase et al., 2019):

$$D_m = (LBT)^{1/3} \qquad ....(1)$$

Sphericity

The degree of sphericity ϕ_g is derived from the geometric dimensions and calculated using the following equation (Singh et al., 2010):

$$\phi_g = (LBT)^{1/3}/L \qquad ....(2)$$

Surface area

The surface area of green gram (S_g) was determined as per the equation used by Dursun and Dursun, 2005 and Singh et al., 2010 with GMD as the grain's representative sphere.

$$S_g = \pi D_m^2 \qquad ....(3)$$

Thousand-grain weight

Determination of thousand-grain weight (W_{gt}) was done as per the standard IS 4333 part IV (ISI, 1968b) at different moisture contents.

Bulk density

The bulk density (ρ_{bg}) is the ratio of the mass of grain to its total volume. It was obtained by filling a measuring cylinder or container of known mass with a green gram. Then the contents are weighed using an electronic digital balance with an accuracy of 0.001 g. Following equation (4) was used to calculate bulk density (Singh et al., 2010).

$$\rho_{bg} = M/V \qquad ....(4)$$

True density

The true density ρ_{tg} is the ratio between the grain mass and actual volume of grain, i.e., volume devoid of external pore spaces. It was determined using the toluene displacement method (Pandiselvam et al., 2017, Singh et al., 2010).

Porosity

The porosity of the grain (bulk) (ε) is the ratio of the volume of the void to the total bulk volume. It was determined using the equation by Mohesenin, 1986.

$$\varepsilon = \left(1 - \frac{\rho_{bg}}{\rho_{tg}} \right) \qquad ....(5)$$

Angle of repose

The angle of repose (θ) was measured using an apparatus, which consisted of a box with a transparent face and a mirror attached on the opposite side. A scale is fixed to the transparent face to take the readings. The box has a circular plate inside it with a diameter of 80 mm and it has a conical opening at the bottom to allow smooth flow of grain. Initially, the box was filled with green gram and then the bottom lid was removed, causing the grains to slowly flow out of the box, resulting in the formation of a heap of green grams over the circular plate. The pile's height was measured

through the mirror and a measuring scale placed inside the box using the formula (Singh *et al.*, 2010, Mohesenin, 1986).

$$\theta = \tan^{-1}\left(\frac{2\,h}{D}\right)$$

.........(6)

Static coefficient of friction

The static coefficient of friction of green gram was measured against four different surfaces (mild steel, stainless steel, ply wood and galvanised iron sheet). The apparatus used for the determination of the coefficient of static friction (μ) consist of a plywood box (165 × 80 × 75 mm) kept on a flat table. The table has a frictionless pulley arrangement through which weights can be attached to the plywood box using a loading pan. Weights are added to the loading pan until the empty box began to slide over the study surface. The same box filled with grain was also allowed to slide and the corresponding weight was recorded. The experiment was conducted three times at each moisture content and the average value was recorded (Mohesenin, 1986).

$$\text{Co-efficient of friction } (\mu_s) = \frac{\text{Lateral force } F}{\text{Normal force } N} = \frac{W_2 - W_1}{W_g}$$

.......(7)

Co-efficient of internal friction

For determining the co-efficiency of internal friction, the setup consisted of a flat table with a frictionless pulley arrangement and two rectangular plywood boxes with free surfaces. The dimensions of the two boxes are 285 × 120 × 75 mm and 165 × 80 × 75 mm each. While reading, the larger box is placed on the table and is filled with grain and levelled. The smaller box (empty) is kept over the grain and load is applied using the loading pan until it slides using the rope and pulley arrangement. The same experiment is further conducted with grain filled in both the boxes and the top one is made to slide over the bottom one. The grain mass (normal force) put inside the top container is taken into consideration. The difference of weights causing the top box to slide with and without the grain is the grain's frictional force. The coefficient of internal friction was calculated using the following equation (Mohesenin, 1986).

$$\text{Co-efficient of internal friction } (\mu_e) = \frac{\text{Lateral force } F}{\text{Normal force } N} = \frac{W_3 - W_4}{W_{g1}}$$

.........(8)

Terminal velocity

The green gram's terminal velocity was determined using an air column in which the green gram was suspended in the air stream. The setup (Fig 4) has an A.C. motor and a blower arrangement and a controller was provided to control the flow of air by regulating the incoming current. During testing, grain was dropped inside the air column and the air flow rate was gradually increased until the grains are suspended on the air. At that instant, the air velocity was measured using a van vane anemometer having the least count of 0.1 m s^{-1} (Mohesenin, 1986).

Statistical analysis

The impact of moisture content on various physical properties of green gram (GMD, surface area, sphericity, bulk density, true density, angle of repose, *etc.*) was studied through Regression analysis. The curve estimation method was followed to find the best-fit curve and equation in those cases of low R^2 in Linear Regression. Logarithmic, inverse, quadratic, cubic, power and S Regression models were studied and the best two curves were considered. Also, the effect of both material surface and moisture content on the friction coefficient of green gram was studied using Regression. The best-fit Regression models (with a high coefficient of determination, R^2 and low standard error of estimation, S_e) were considered.

RESULTS AND DISCUSSION

Geometric mean diameter

The mean geometric dimensions (L, B, T) of the 50 grains measured at different MC (10.58 to 45.45% d.b.), along with the standard errors, are shown in Table 1. The values indicate a rise of 12.30, 8.45 and 9.50% in the dimensions (L, B and T) with an increase in MC, respectively. The coefficients and Regression model values (Eqs. 9 to 37) are shown in Table 2. The GMD (D_{gm}) of green gram was computed and the variation in GMD over the change in moisture content was studied using Regression analysis. The trend (Fig 1) shows the mean diameter of green gram increased (3.75 to 4.12 mm) with an increase in moisture content (10.58 to 45.45%, d.b.) and the Regression equations 9 and 10 represent the best fit curves for the data.

$$D_{gm} = 4.245 - \frac{5.193}{M}, \qquad \text{(Inverse, } R^2 = 0.996) \quad ....(9)$$

$$\text{Ln }(D_{gm}) = 1.448 - \frac{1.321}{M}, \quad \text{(S-curve, } R^2 = 0.995) \quad ......(10)$$

There is a 9.87% increase in the value of GMD with an increase in moisture content. This was due to increase in the overall dimension of the grain with additional gain of moisture. The high R^2 value and low standard errors (0.01 and 0.003) imply the goodness of fit among the data and the variation is statistically significant (p< 0.05) for the range of moisture studied. Several researchers like Alibas and Koksal, 2015 (soybean) and Nimkar and Chattopadhyay. 2001, Pandiselvam *et al.*, 2017 and Unal *et al.*, 2008 (green gram) observed similar trends in their work.

Sphericity

The sphericity of green gram was calculated and shown in Fig 1. Equation 11 and 12 shows the relationship between MC and sphericity of grain. The data initially increased from 0.833 to 0.844 and then reduced to 0.819. Data fitted well with cubic and quadratic curves (S_e = 0.003 and 0.002). The variation was non-significant (p = 0.208) for cubic function. Very less variation was observed in the sphericity of the grain within the MC studied.

Φ_g= 0.810 + 0.003 M - 6.44 × 10^{-5} +1.47 × 10^{-7} M^3,
   (Cubic, R^2 = 0.892, p>0.05)   ....(11)

Φ_g= 0.812 + 0.003 M - 5.19 × 10^{-5} M^2,
   (Quadratic, R^2 = 0.945, p< 0.05   ....(12)

   The results of this study are in agreement with studies by Nimkar and Chattopadhyay. 2001 and Unal *et al.,* 2008 who observed similar results for green grams through their work. Zewdu and Solomon. 2007 detected low sphericity values at higher MC for Tef seed in his study.

Surface area

The surface area of green gram changed from 44.13 to 53.45 mm^2(Fig 2), with an increase in moisture content (10.58 to 45.45%). The relation between them is established using Regression analysis (Eqs. 13 and 14).

S_g = 56.56 - $\dfrac{131.058}{M}$,   (Inverse, R^2 = 0.997) ....(13)

S_g = 36.57 + 0.865 M - 0.011 M^2,   (Quadratic, R^2 = 0.969)
        ....(14)

Table 1: Means and standard errors of geometric dimensions of grain at different MC.

Moisture content, % (d.b.)	Major axis, (L), mm	Medium axis (T), mm	Minor axis (B), mm
10.58	4.51 ±0.05	3.48 ±0.03	3.36 ±0.03
18.26	4.71 ±0.07	3.71 ±0.04	3.58 ±0.03
26.89	4.84 ±0.08	3.77 ±0.05	3.65 ±0.06
36.24	4.95 ± 0.09	3.82 ± 0.04	3.68 ± 0.04
45.45	5.06 ±0.1	3.81 ±0.03	3.65 ±0.03

Table 2: Parameters of Regression models obtained through Curve fit method.

Eqs. No.	Model Summary				Parameter Estimates			
	R^2	Adjusted R^2	Std. Error, S_e	Sig.(p-value)	Constant	b1	b2	b3
9	0.997	0.996	0.010	0.00	4.245	-5.193		
10	0.996	0.995	0.003	0.00	1.448	-1.321		
11	0.973	0.892	0.003	0.208	0.810	0.003	-6.44*10^{-5}	1.48*10^{-7}
12	0.973	0.945	0.002	0.027	0.812	0.003	-5.19*10^{-5}	
13	0.998	0.997	0.197	0.00	56.56	-131.06		
14	0.984	0.969	0.016	0.016	36.57	0.865	-0.011	
15	0.990	0.986	0.411	0.00	30.299	6.075		
16	0.987	0.982	0.470	0.001	55.36	-119.9		
17	0.977	0.969	0.013	0.002	0.622	2.467		
18	0.978	0.97	0.016	0.001	-0.459	3.214		
19	0.999	0.998	0.002	0.00	1.214	1.219		
20	0.999	0.998	0.001	0.00	0.196	0947		
21	0.967	0.956	0.847	0.003	48.85	-135.48		
22	0.965	0.954	0.021	0.003	3.903	-3.348		
23	0.997	0.996	0.049	0.00	8.627	0.054		
24	0.997	0.994	0.057	0.003	8.690	0.048	9.98*10^{-5}	
25	0.980	0.978	0.868	0.00	51.56	-214.94		
26	0.973	0.971	0.027	0.00	3.979	-5.642		
27	0.994	0.992	0.004	0.00	0.744	0.003		
28	0.995	0.989	0.005	0.005	0.749	0.003	7.33*10^{-6}	
29	0.864	0.859	0.00	0.00	0.252	0.008	-0.013	
30	0.968	0.966	0.019	0.00	0.270	0.008		
31	0.968	0.963	0.020	0.00	0.271	0.008	1.393*10^{-6}	
32	0.945	0.941	0.022	0.00	0.212	0.007		
33	0.961	0.958	0.045	0.00	0.245	0.017		
34	0.946	0.942	0.025	0.00	-0.180	0.191		
35	0.956	0.952	0.06	0.00	-0.407	-9.912		
36	0.954	0.951	0.027	0.00	0.176	0.009		
37	0.959	0.956	0.062	0.00	0.073	0.543		

The independent variable is MC.

Both the curves fitted well for the surface area values with low S_e and a high coefficient of determination (R^2) and the effect was statistically significant ($p < 0.05$). It indicates that with an increase in moisture content, the grain dimensions increased significantly, resulting in a higher surface area. Similar results have been reported by Sacilik *et al.*, 2003 (Hempseed), Sharon *et al.*, 2015 (Black gram), Singh *et al.*, 2010 (Barnyard millet) through their works.

Mass of 1000 grains

With an increase in moisture content from 10.58 to 45.45% (d.b.), the mass of 1000 grains varied from 44.13 g to 53.45 g (Fig 2). The equations (15 and 16) displaying the relationship between grain mass and MC are given below.

$$W_{gt} = 30.299 + 6.075 \times Ln\ (M), \quad \text{(Logarithmic, } R^2 = 0.986)$$ ....(15)

$$W_{gt} = 55.36 - \frac{119.92}{M} \quad \text{(Inverse, } R^2 = 0.982)$$ ....(16)

Within MC's range, the grain mass increased by 20.39% and the variation in mass was statistically significant ($p < 0.05$). The increase in 1000 grain weight was due to absorption of moisture by the molecules of the grain. The low S_e values predict the closeness among the data. Many researchers have reported a surge in the mass of 1000 grains with a rise in MC (Nimkar *et al.*, 2005, Pandiselvam *et al.*, 2017, Singh *et al.*, 2010 and Sharon *et al.*, 2015).

Bulk density

The bulk density of green gram reduced significantly ($p < 0.05$) from 860 kg m^{-3} to 670 kg m^{-3} (Fig 3) with an increase in moisture content from 10.58 to 45.45%. The bulk density and MC display the following relationship (Eqs. 17 and 18). The respective standard errors are 0.013 and 0.016, which reflect close fit among the values.

$$\rho_{bg} = 0.622 + \frac{2.467}{M}, \quad \text{(Inverse, } R^2 = 0.969)$$ ....(17)

$$Ln\ (\rho_{bg}) = -0.459 + \frac{3.214}{M}, \quad \text{(S-curve, } R^2 = 0.970)$$ ....(18)

There was a reduction in bulk density by 22.09% with MC and it may be due to an increase in its size and dimensions, causing more inter-granular space between the bulk. The corresponding increase in mass was less pronounced than the grains' volumetric expansion, resulting in lower bulk density. Balasubramanian and Viswanathan. 2010 (Minor millets), Nimkar and Chattopadhyay. 2001 (Green gram), Sharon *et al.*, 2015 (Black gram), Shelke *et al.*, 2019 (Black gram) and Unal *et al.*, 2008 (Mung bean) have observed a decrease in bulk density values with rising in MC in their respective works.
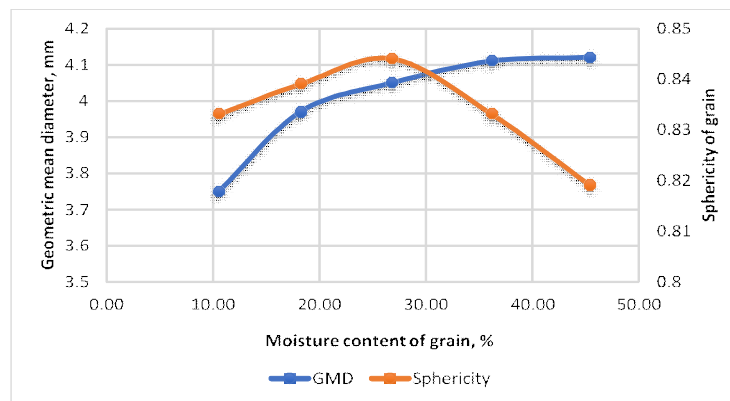

Fig 1: Effect of moisture content on geometric mean diameter (GMD) and Sphericity of grain.
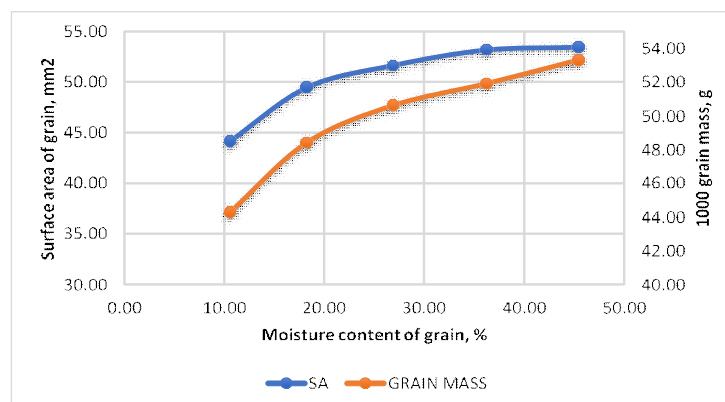

Fig 2: Effect of moisture content on surface area (SA) and 1000 grain mass.

True density (Toluene displacement method)

True density of green gram varied from 1330 kg m^{-3} to 1240 kg m^{-3} (Fig 3) with rise in moisture content from 10.58 to 45.45%. The variation in true density was statistically significant (p< 0.05) with low S_e values and the relation is represented by Regression equations below.

$$\rho_{tg} = 1.214 + \frac{1.219}{M}, \quad \text{(Inverse, R}^2 = 0.998) \quad ....(19)$$

$$Ln\ (\rho_{tg}) = 0.196 + \frac{0.947}{M}, \quad \text{(S-curve, R}^2 = 0.998) \quad ....(20)$$

Relatively higher true grain volume against its rising weight is attributed to a decline in the grain's true density. The results were in accordance with several other researchers, including Nimkar and Chattopadhyay. 2001 (green gram), Nimakar *et al.*, 2005 (Moth gram) and Sharon *et al.* 2015 (black gram).

Porosity

The porosity of grains is computed from the data of bulk and true densities. It was observed, with an increase in moisture content from 10.58 to 45.45%, the porosity increased from 35.75 to 46.38% (Fig 4). Regression equations 21 and 22 signify the relation between porosity and MC of grains.

$$\varepsilon = 48.847 - \frac{135.481}{M}, \quad \text{(Inverse, R}^2 = 0.956) \quad ....(21)$$

$$Ln\ (\varepsilon) = 3.903 - \frac{3.348}{M}, \quad \text{(S-curve, R}^2 = 0.954) \quad ....(22)$$

The increase in porosity is well defined from the bulk and true density values, which declined with rising MC. The low p-values and low S_e values portray the statistical significance of MC's variation and a high correlation among the values is also observed. Nimkar and Chattopadhyay. 2001 (Green gram), Pandiselvam *et al.*, 2017 (Green gram), Sharon *et al.*, 2015 (Black gram) and Unal *et al.*, 2008 (Mung bean) also reported this incline in porosity in their studies.

Terminal velocity

The terminal velocity of green gram varied significantly (p< 0.05) from 9.20 to 11.10 m s^{-1} with an increase in moisture content from 10.58 to 45.45%. The linear and quadratic regression equations (23, 24) represent a high coefficient of determination with the goodness of fit with 0.049 and 0.057 S_e values, respectively.

$$V_g = 8.627 + 0.054\ M, \quad \text{(Linear, R}^2 = 0.996) \quad ....(23)$$

$$V_g = 8.690 + 0.048\ M + 9.98 \times 10^{-5}\ M^2, \quad \text{(Quadratic, R}^2 = 0.994) \quad ....(24)$$
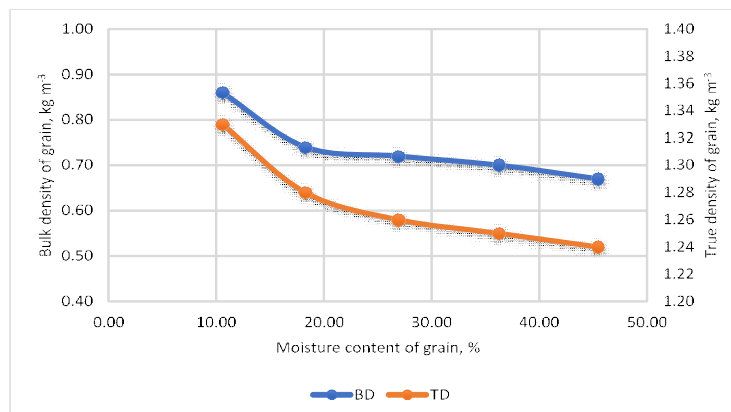

Fig 3: Effect of moisture content on bulk density (BD), true density (TD) of grain.
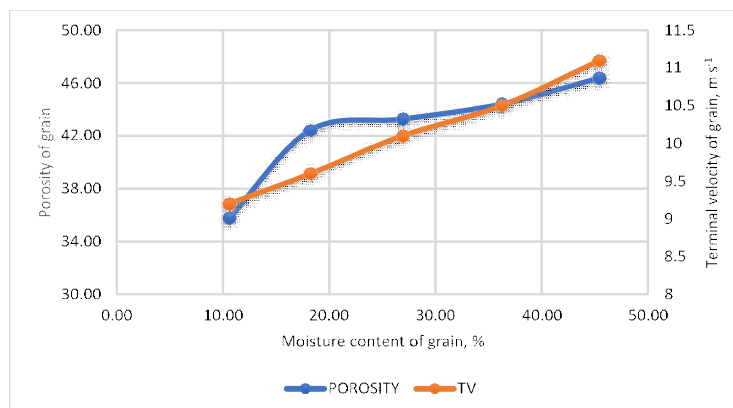

Fig 4: Effect of moisture content on porosity and terminal velocity (TV) of grain.

The mean values of terminal velocity at different moisture levels are shown in Fig 4. The increase in terminal velocity value is due to a rise in grain mass due to moisture absorption. Nimkar and Chattopadhyay. 2001 (green gram), Nimakar *et al.*, 2005 (Moth gram), Singh *et al.*, 2010 (Barnyard millet and kernel) and Unal *et al.*, 2008 (mung bean) obtained similar results during their studies on grains.

Dynamic angle of repose

The experimental values (Fig 5) confirmed that with a rise in MC, the angle of repose increased significantly from 30.95 to 46.57° (50.46% increase). It may be due to higher internal friction at elevated MC resulting from more contact surface area of the grains.

$$\theta = 51.56 - \frac{214.941}{M}, \quad \text{(Inverse, } R^2 = 0.978) \quad ....(25)$$

$$Ln\,(\theta) = 3.979 - \frac{5.642}{M}, \quad \text{(S-curve, } R^2 = 0.971) \quad ....(26)$$

The regression equations (25 and 26) with higher R^2 values, low p and S_e values indicate good dependency and statistical significance among the data. Various other researchers reported similar outcomes from their study (Baryeh. 2002, Pandiselvam *et al.*, 2017, Singh *et al.*, 2010 and Unal *et al.*, 2008).

Coefficient of internal friction

There was an increase in the mean value of coefficient internal friction from 0.78 to 0.90 (Fig 5) with increase in MC of green gram. The variation in the values were represented using the equations (27 and 28) obtained through Regression analysis. Data shows good dependency (high R^2 and low S_e) and the values are statistically significant.

$$\mu_e = 0.744 + 0.003\,M, \quad \text{(Linear, } R^2 = 0.992) \quad ....(27)$$

$$\mu_e = 0.749 + 0.003\,M + 7.328 \times 10^{-6}\,M^2, \quad \text{(Quadratic, } R^2 = 0.989) \quad ....(28)$$

The increased coefficient of internal friction at higher MC may be due to increased cohesion among the grains. Balasubramanian and Viswanathan. 2010 and Singh *et al.*, 2010 observed similar trends for minor millets and barnyard millets, respectively.

Coefficient of static friction

The effect of different surfaces and MC (10.58 to 45.45% d.b.) on the static coefficient of friction of grain was studied using Regression and it showed a linear relationship (0.859% R^2 value) and the equation (29) is presented below. The combined effects of both surface and MC were statistically significant ($p < 0.05$). The mean values of the coefficient of static friction are presented in Table 3.

$$\mu_s = 0.252 + 0.008\,M - 0.013\,S, \quad \text{(Linear, } R^2 = 0.859) \quad ....(29)$$

Further, the impact of moisture on the friction coefficient on different surfaces was studied and the Regression equations (30 to 37) are presented below. The coefficient data of green gram shows, there is a change from 0.35 to 0.64 (82.86%) for mild steel (Fig 6), 0.29 to 0.54 (86.20%) for stainless steel (Fig. 6), 0.26 to 0.56 (115.38%) for plywood (Fig 6) and from 0.26 to 0.60 (130.77%) for galvanised iron
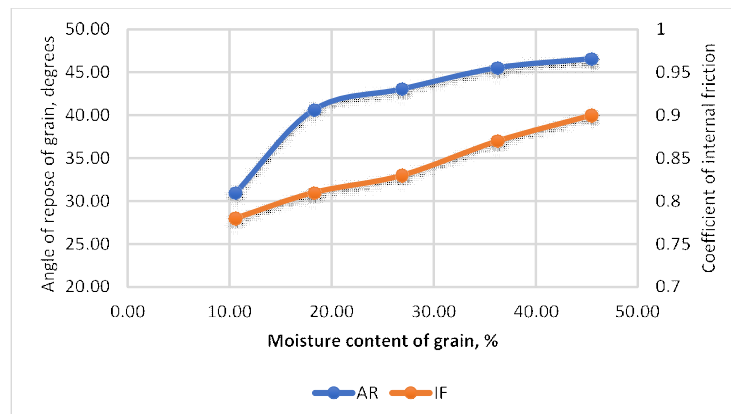

Fig 5: Effect of moisture content on angle of repose (AR) and coefficient of internal friction (IF) of grain.

Table 3: Coefficient of static friction for green gram.

Moisture content, % (d.b.)	Coefficient of friction, μ			
	Mild steel	Stainless steel	Plywood	Galvanised iron
10.58	0.35 (0.02)	0.29 (0.01)	0.26 (0.02)	0.26 (0.02)
18.26	0.42 (0.02)	0.35 (0.01)	0.40 (0.03)	0.36 (0.02)
26.89	0.49 (0.01)	0.37 (0.02)	0.45 (0.01)	0.43 (0.02)
36.24	0.54 (0.02)	0.44 (0.02)	0.48 (0.01)	0.50 (0.04)
45.45	0.64 (0.02)	0.54 (0.02)	0.56 (0.02)	0.60 (0.03)

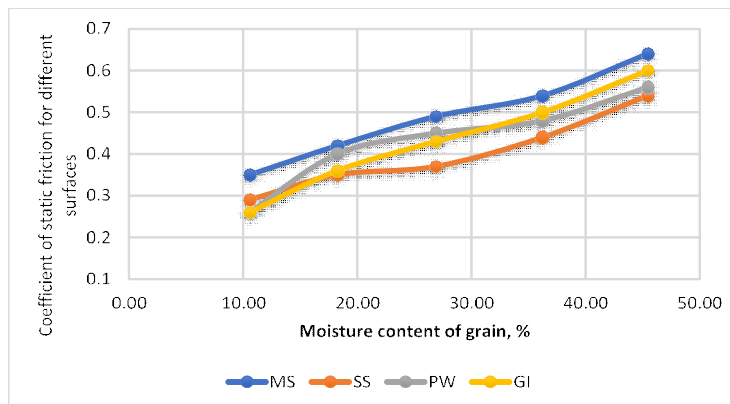Numbers in parentheses are S.D.s.

Fig 6: Effect of moisture content on coefficient of static friction of grain on different surfaces.

surface (Fig 6). The MS surface had the highest coefficient of static friction values at 45.45% MC, followed by GI, plywood and stainless steel. The highest percentage of increase (130.77%) in the coefficient of friction is observed for the GI surface and the least increase is detected for MS (82.86%) surface within the range of MC studied. It might be because the mild steel surface offered the highest resistance among all the surfaces to the grain movement, while stainless steel had the least resistance due to its roughness. The static coefficient of friction for green gram increased for all the surfaces with an increase in MC due to increased adhesive force between grains and the surface. Similar results were obtained by Nimkar and Chattopadhyay. 2001, Pandiselvam *et al.*, 2017 and Singh *et al.*, 2010 during their research work. The relationship between moisture and coefficient of friction of grain at different surfaces are presented below.

Mild Steel (MS)

$\mu_{ms} = 0.270 + 0.008\ M$,   (Linear, $R^2 = 0.966$)   ....(30)

$\mu_{ms} = 0.271 + 0.008\ M + 1.39 \times 10^{-6}M^2$, (Quadratic, $R^2 = 0.963$)   ....(31)

Stainless Steel (SS)

$\mu_{ss} = 0.212 + 0.007\ M$,   (Linear, $R^2 = 0.941$)   ....(32)

$Ln\ (\mu_{ss}) = Ln\ (0.245) + 0.017\ M$,   (Exponential, $R^2 = 0.958$)   ....(33)

Ply wood (PW)

$\mu_{pw} = -0.180 + 0.191 \times Ln\ (M)$, (Logarithmic, $R^2 = 0.942$)   ......(34)

$Ln\ (\mu_{pw}) = -0.407 - \dfrac{9.912}{M}$, (S-curve, $R^2 = 0.952$) ....(35)

Galvanised Iron (GI)

$\mu_{gi} = 0.176 + 0.009\ M$,   (Linear, $R^2 = 0.951$)   ....(36)

$Ln\ (\mu_{gi}) = Ln\ (0.073) + 0.543 \times Ln\ (M)$,   (Power, $R^2 = 0.956$)   ....(37)

The regression equations of green gram for all the four surfaces reflect a high coefficient of determination (R^2) with low S_e values. The Regression models display the goodness of fit among the data. The p-values ($p < 0.05$) also imply the statistical significance of the variation with moisture increase.

CONCLUSION

The result highlights the significant effect of MC on various properties of Green gram. The moisture dependent properties of grain play a crucial role for deciding optimum design parameters of any agricultural equipment for handling the grain (seed hopper, graders, sieve size) or storing them (silos, bins etc.). Due to some time constraints additional properties like grains' rupture strength and impact of loading rate and moisture on it could not be studied. Grain breakage becomes an important factor while using mechanical planters and seed drills thereby reducing germination rate. More research on factors affecting grain damage and role of MC needs to be conducted to minimise the loss of grains and maximise productivity.

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