www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(3): 1269-1276

www.thepharmajournal.com
Received: 05-01-2022
Accepted: 11-02-2022

Leonce Harerimana
Ph.D., Scholar at IARI-Pusa Campus, Division of Agricultural Engineering, New Delhi, Lecturer at University of Rwanda, School of Agricultural engineering, Nyagatare Campus, P.O. Box 57 Nyagatare, Rwanda

Indra Mani
Principal Scientist and Head, Division of Agricultural engineering, IARI-Pusa Campus, New Delhi, India

Roaf Ahmad Parray
Scientist in the Division of Agricultural Engineering, IARI-Pusa Campus, New Delhi, India

Arun Kumar TV
Scientist in the Division of Agricultural Engineering, IARI-Pusa Campus, New Delhi, India

Corresponding Author:
Leonce Harerimana
Ph.D., Scholar at IARI-Pusa Campus, Division of Agricultural Engineering, New Delhi, Lecturer at University of Rwanda, School of Agricultural engineering, Nyagatare Campus, P.O. Box 57 Nyagatare, Rwanda

Effect of moisture content on engineering properties of Pusa-1431 variety of green gram

Leonce Harerimana, Indra Mani, Roaf Ahmad Parray and Arun Kumar TV

DOI: https://dx.doi.org/10.22271/tpi.2022.v11.i3q.11460

Abstract
The determination of grains engineering properties serves an important base to design appropriate agricultural machines. Sixteen properties were determined using the standard methods in laboratory at moisture content of 11.1% to 28.2% on dry basis. The geometric mean diameter ranged from 3.62 to 4.8 with the sphericity ranges from 0.69 to 0.84. The density and rupture force significantly reduced with the increase in moisture content at p>0.01 and they are in the range of 701.86 to 855.6 kg/m^3 and 43.92 to 92.16 N, respectively. The geometric size and frictional properties significantly increased with moisture content. The principal component analysis (PCA) has shown that 77.8% of the data revolves around the principal component one and 10.3% of data resonate on second component with manifest inter-variable patterns. The Pearson correlation coefficient showed the negative correlation between of length and the bulk density (r=-0.775, p=0.003) and positive correlations between length and friction properties.

Keywords: Engineering properties, coefficient of friction, angle of repose, Principal component analysis, Eigenvalue, Eigenvector

Introduction

Green gram (*Vigna radiata*) is an important pulse in India, the world's largest producer and consumer, with a share of 25% of the word production. India has one third of world pulse area and 30% of world pulse consumption [1]. Like other pulses, green gram constitutes the basic source of protein in diet for human and animal worldwide. Crop engineering properties are the base for the design of harvesting and post-harvest handling machines [2, 3]. The physical and engineering properties of grains such as diameter, length, width, thickness, surface area, volume, sphericity, density, porosity, friction, color and appearance, terminal velocity, rupture point and hardness serve as base to the prediction of the behaviour of the product to be handled and the design of particular equipment. Negligence of these properties of in the design of equipment leads to inefficiency and heavy losses in harvesting, threshing and handling and negatively affects farmers' income [4, 5].

Studies have been undertaken by many researchers on different crops at different levels of moisture content (MC) [1, 5–11]. These properties also help in the proper selection of the materials that are used in the manufacturing of the machines for unit operation of grains. These properties vary with crops, crop varieties, levels of maturities. Mainly these properties linearly vary with moisture content [8].

It has been reported that the physical properties of green gram vary with the moisture content from 6 to 24% MC_{db}. The length, thickness, geometric mean diameter, mass of 1000 grains, angle of repose, porosity and the coefficient of friction on various surfaces were found to increase with the MC. The bulk density and sphericity of grains were decreasing with its moisture content increase [1]. A similar trend was obtained in other grains such as soybean and maize [6, 7, 12]. The aerodynamic properties of the seed have great influence on their movement in relation with the air. It was found to decrease with the MC with the terminal velocity of 7.08 to 5.39 m/s for 30% and 7% MC wet basis respectively [13].

Research have been undertaken in the determination of physical properties of green gram but not many works are available on the mechanical properties of green gram grains and the ones found differ in methods, materials and targeted use. In view of this, the investigation was aimed to determine the effect of MC on the physical and mechanical properties of Pusa-1431 variety of green gram in line with the threshing and other grain handling activities.

The principal component analysis (PCA) was undertaken to condense the investigated properties into few factors and easily illustrate the pattern relationship among them.

Material and Methods

The crop samples of green gram, variety of Pusa-1431, were collected from the research field of ICAR-Indian Agricultural Research Institute, New Delhi. The grains were threshed manually and the initial MC was measured by means of oven drying method in the laboratory. To obtain the desired MC, grain were conditioned either by drying them to the desired lower MC or moistened to the desired higher MC. Data of the physical properties of grains were taken at 11.1, 16.3, 21.9 and 28.2% moisture content on dry basis (MC_{db}). The moistening consisted of the uniform addition of water needed for given sample. The moistened samples were kept in refrigerator at 6 degrees centigrade for 7 days. To achieve lower MC, the drying was done. Each measurement was replicated three times.

Geometric size properties

For every sample, the sizes of 30 grains were taken for each of the three replications. Three major dimensions from the main axes, length (L), breadth (B) and thickness (T) were measured in mm using a digital Vernier caliper *Mitutoyo CD-6″*.

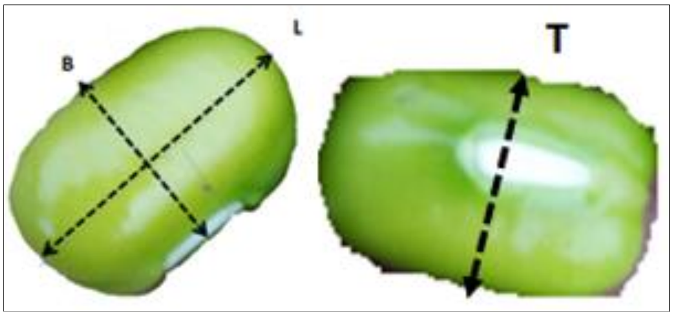


Fig 1: Illustration of the main axes of length, breadth and thickness

The Geometric mean diameter (D_g), sphericity (φ), surface area (A), equivalent diameter (De), Mean width (W_m)and Volume (V)were calculated using equations 1 to 6(12,14).

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

$$De = \frac{(L \times B \times T)}{3} \quad (2)$$

$$\varphi = \frac{D_e}{L} \quad (3)$$

The surface area (A) and volume (V) of the grain were determined; assuming the grain to be spheres of the geometric mean diameter in equation

$$A = \pi {D_g}^2 \quad (4)$$

$$W_m = (BT)^{1/2} \quad (5)$$

$$V = \frac{\pi B^2 T^2}{6(2L - W_m)} \quad (6)$$

Density

The bulk density (ρ_b) and true density (ρ_t) both in kg/m^3 were measured using the precision balance and the measuring cylinder. The weight over volume was calculated as the bulk density.

$$\rho_b = \frac{\text{Bulk mass (in kg)}}{\text{Bulk volume (in m}^3)} \quad (7)$$

The true density (ρ_t) was determined through fluid displacement method where the volume of solid is obtained by a pycnometer. Toluene, C_7H_8, was used as the displacement fluid because it is not quickly absorbed by the grain. The graduated cylinder was precisely weighed and filled with toluene at a known volume. The grains of known mass were added in the graduated cylinder with the toluene to read the total volume. The true volume of the solid (V_s) was determined by subtraction. Finally true density was calculated by using following equation (15)

$$\rho_t = \frac{\text{mass of grain}}{V_s} \quad (9)$$

Porosity

Porosity (f) is the index of relative pore space in the solid. It can be determined from the bulk and true density, porosity was calculated by the expression given by Hillel [16].

$$f = 1 - \frac{\rho_b}{\rho_t} \quad (10)$$

Angle of repose

The angle of repose (θ) was measured using a metallic apparatus of the funnel shape having the upper diameter of 30 cm; the bottom diameter is 3cm and the height was 30 cm. The discharge gate is a vertical pipe of 5 cm length and of 3 cm diameter. After filling the grains in funnel, it was lifted slowly and vertically and grains were allowed to pile naturally on the flat surface. The height (h) and diameter (d) of pile were measured. The angle of repose in degree is calculated as in the equation 11 [8, 9, 12, 14].

$$\theta = \tan^{-1}\frac{h}{r} \quad (11)$$

Coefficient of friction

The coefficients of friction (CF) were determined on the surfaces of various materials used in the handling of grains namely the galvanized iron (CFGI), mild steel (CFMS) and aluminum (CFAl). In addition, the internal coefficient of friction (ICF) was determined between grains themselves using the same principle. The sample was kept in the bottomless cylindrical container of 10 cm height and 8cm diameter. For the ICF, the bottom container was kept at the level the table over which the matching top container slides. For CF over the plate materials, the base sheet is kept at the bottom and the bottomless container lies over it with the marked line. The table is leveled and the sliding container is connected with a thread passing over a pulley with a suspending balance dish. Load is added progressively on the dish whose weight will fail the container and starts sliding over the base plate. The weight of the sample filled in the container (W) and the weight of the deal load (W_d) were measured with electronic weighing balance [2, 14]. Three replications were taken in the measurement and the coefficient was calculated as shown in equation 12.

$$CF = \frac{W_d}{W} \quad (12)$$

Terminal velocity

The determination of terminal velocity was based on the air-column experimental device. The device consists of the transparent hollow made in plastic for air column with adjustable air input from the electric air blower below [11, 17]. A sample weight 40 g for each measurement was fed in the air column and the air flow rate was adjusted to suspend the seed in the air current for 30 second. This air velocity was measured at the outlet of the hollow cylinder using the anemometer, ATP ET-965 and noted as the terminal velocity.

Point of rupture

The rupture and deformation forces were observed on the randomly selected grains from all the samples. The vertical compression test was conducted on the grain lateral axes using the texture analyzer, HD plus Texture Analyze equipped with 50 kg load cell and a computer having a data acquisition system.

Principle component analysis (CPA)

The principle components (CP) are linear condensation of multiple variables in few factors with minimal loss of information [18]. From the main variables, the main components were calculated each of them being the combination of linear original variables coefficients became their eigenvector of correlation matrix. The optimal numbers CPs were obtained by the rule of Kaiser-Guttmann. This rule provides that number of components equals the number of factors that have eigenvalue higher than one [4].

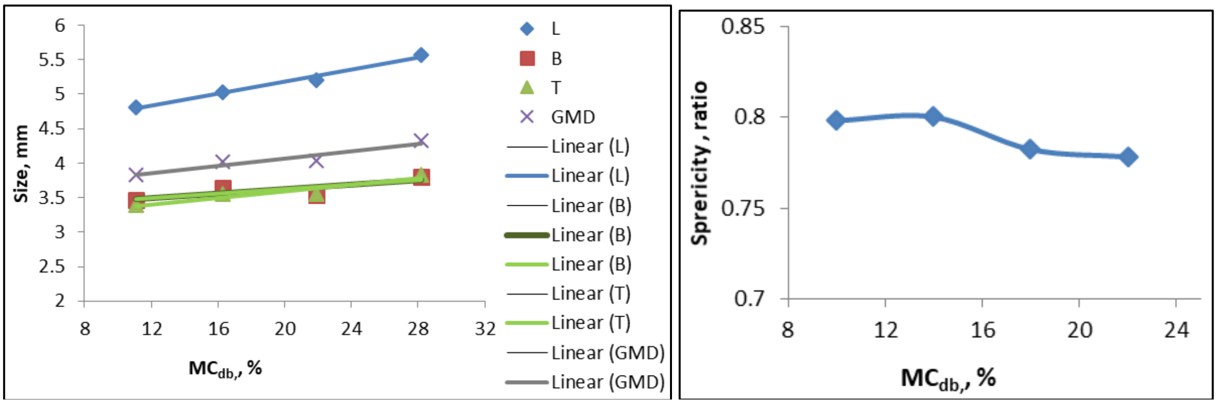
The data were collected and arranged in excel table. Minitab software version 19 was used to perform the ANOVA, correlation and principal component analysis.

Results and Discussion

The results of the test showed that all the measured properties were affected change with the MC. There have been significant differences in the measured parameters among the levels of MC. The findings summary is given in the Table 1 as mean values and range while the model equations are portrayed in table 2. The findings on the properties are discussed in details in the subsequent paragraphs.

Geometric sizes

The size and shape aspects are shown by the properties of length, breadth, thickness, diameter, area, volume and sphericity are portrayed by the figures 2 (a and b).The effect of the MC to the size showed that there is increase in the same direction as the MC from 11.1% to 28.2% MC_{db}. The statistical analysis proved that, there is significant differences among the treatments for all the geometric sizes properties ($p < 0.01$). It is evident that the size as the drying removes water from grain and grain retracts to itself. The linear relationships of size parameter are shown in regression equations 13 to 15.The results with the same trends were found by [1, 19] on the grains of green gram grain. The shape distribution is shown by the sphericity of the grain. The three grain types showed the sphericity ranging from 0.7 to 088. For this, the grains can be considered as spherical in design of sieve holes based on all of three grains. The statistical analysis showed the difference in sphericity ($p < 0.05$) at various MC. Equation 16 models the relationship of the sphericity with MC. The change in sphericity happens in respective dimensions of seed [11].



(a) (b)

Fig 2: Effect of MC on geometric size size and shape of grains (a) MC and Length, Breath and thickness (b) MC and Sphericith urace area

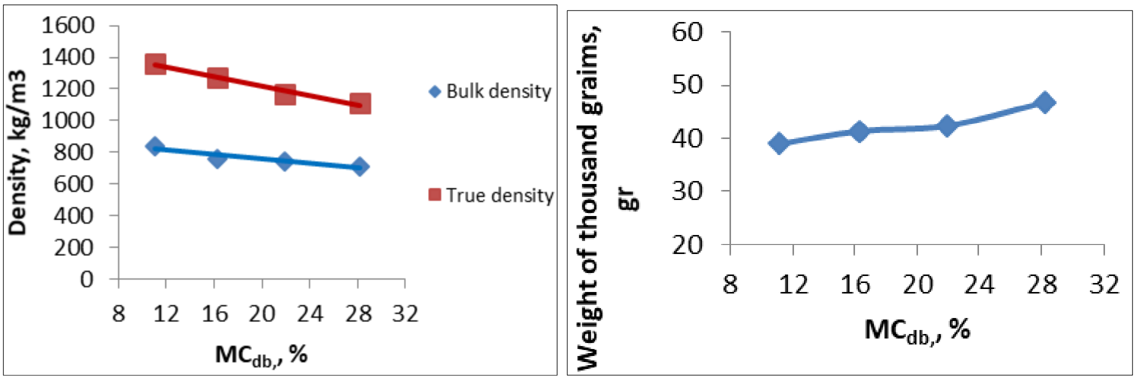
Density and mass of thousand grains

The mass of 1000 grains was illustrated in figure 3 (b) and change with a linear increase from 37.97 to 47.87 g at 11.1 to 28.2% MC_{db}. The relationship was represented by the equation 19. The bulk density showed the linear decrease with MC from 827.58 to 719.5 kg/m^3. The trend is the same for the true density with the decrease from 1334.51 to 1089.86 kg/m^3. Figure 3 (a) depicts the relationships of density with MC which are modeled by equations 17 and 18.

A similar trends in grain mass and density were reported by [1,8,11,192]. The analysis of variance showed that there is difference among the 1000 grains mass and density at different levels MC with statistically significant difference ($p < 0.05$).

Coefficient of friction and angle of repose

As portrayed by the fig. 4 (a), the coefficients of friction increased with the MC from 11.1 to 28.2% ($MC_{d.b}$); following the linear relationships given in equations 20 to 23. Fig 4.a reports the ICF that ranged from 0.55 to 0.70, the CFGIS ranging from 0.33 to 0.55, the CFMSfrom0.47 to 0.64, and the CFAl that range from 0.34 to 0.59. The statistical analysis of variance resulted that, the tested grains have the statistically significant difference in the coefficients of friction for all the levels of MC (p< 0.05).



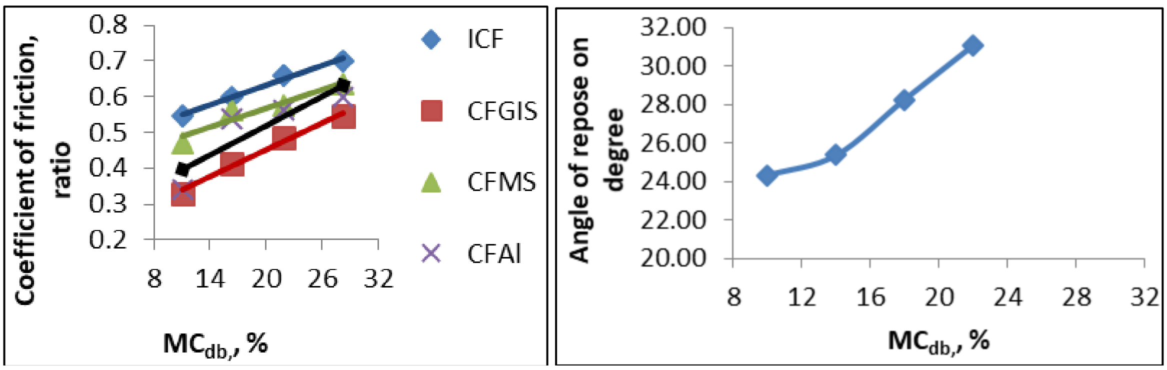
(a) (b)

Fig 3: Effect of MC on mass and density of grain. a) MC and bulk and true density and b. MC and mass of grains

The friction of the grain is important in the design of their conveyance and moving materials and the statistical difference matters in choice of materials [14].The increase in static coefficients of friction with the increases in grains MC may be due to increase the cohesion of wet seeds among themselves and between wet seed and structural plate surface as the surface becomes sticky at high MC [1, 9]. Similar trends have been reported by the [13]. On the legumesgrains, [20] for dekoko seed, [12] for corn seed and [11] for millet grain and kernels.The same trend of results was found on the angle of repose of the tested grains. Fig 4.b illustrates the results of the investigation on the angle of repose increasing from 23.7 to 33.09. The increase of the angle of repose with respect to MC is modeled in the equation 24. The increase in grain angle of repose may be ascribed to the increase in internal friction and the contact area among the grains.The same trends was observed by [2, 9, 11–13, 20, 21].

Table 1: The properties of grain at various MC levels

Grain Properties	Green gram							
	1% MC_{db}		16.3%MC_{db}		21.9% MC_{db}		28.2% MC_{db}	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Length, mm	4.81	4.42-5.61	5.03	4.42-5.63	5.20	4.48-5.87	5.58	4.61-6.58
Breadth, mm	3.46	3.27-4.08	3.63	3.21-4.48	3.54	3.06-3.91	3.80	3.38-4.15
Thickness, mm	3.39	3.14-3.80	3.55	3.21-3.94	3.55	3.21-3.96	3.83	3.30-4.36
Geometric mean diameter, mm	3.83	3.62-4.43	4.01	3.67-4.35	4.03	3.71-4.40	4.33	3.73-4.80
Sphericity	0.80	0.75-0.85	0.80	0.71-0.87	0.78	0.69-088	0.78	0.69-0.84
Bulk density, (Kg/m^3)	841	827.58-855.16	760	759.4-	759.4-761.94	733.1-750.24	709	701.86-719.5
True density, (Kg/m^3)	1,358	1334.51-1380.28	1,272	1240.75-1279.75	1,170	1140.75-1202.79	1,111	1089.86-1123.88
Porosity,%	38.1	37.16-39.14	40.2	39.57-40.63	36.6	34.96-39.05	36.2	35.60-37.02
Weight of thousand grain (g)	38.93	37.97-39.49	41.35	41.23-41.45	42.32	42.24-42.45	46.74	44.67-47.87
Internal coefficient of friction	0.55	0.50-0.57	0.60	0.59-62	0.66	0.63-0.69	0.70	0.70-0.71
Friction coefficient on GI	0.33	0.29-0.38	0.42	0.36-0.48	0.48	0.44-0.57	0.55	0.51-0.62
Friction coefficient on MS	0.47	0.44-0.49	0.56	0.55-0.58	0.58	0.56-0.62	0.64	0.61-0.67
Friction coefficient of on Al, Rario	0.34	0.33-0.36	0.54	0.53-0.56	0.56	0.55-0.58	0.60	0.57-0.63
Angle of repose (Degrees)	24.33	23.70-24.80	25.37	25.10-25.7	28.27	27.30-28.9	31.06	29.20-33.09
Terminal velocity (m/s)	6.44	6.31-6.57	7.08	9.95-7.21	7.73	7.12-7.84	8.22	8.1-8.74
First Rupture force, N	98.36	92.16-103.5	72.45	68.79-76.74	57.47	52.68-63.41	47.51	43.92-50.22



(a) (b)

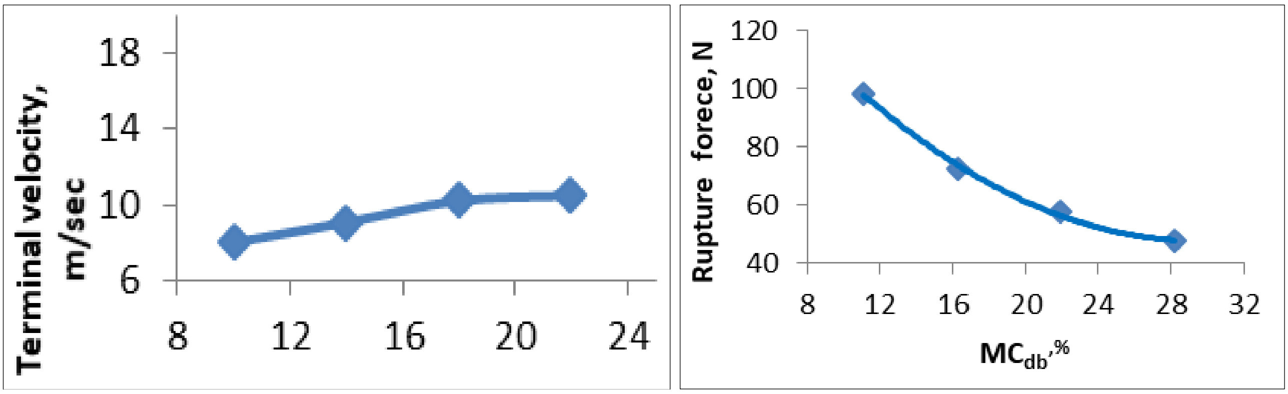
Fig 4: Effect of moisture content on grain coefficient of friction over various materials (a) and on angle of repose

Table 2: Functional relationship of grain engineering properties and MC

Sr. No	Properties	Regression eq.	R^2	Eq. No
1	Length	$y = 0.043x + 4.304$	$R^2 = 0.983$	13
2	Breadth	$y = 0.016x + 3.292$	$R^2 = 0.693$	14
3	Thickness	$y = 0.023x + 3.122$	$R^2 = 0.886$	15
7	Sphericity	$y = 0.821e^{-0.00x}$	$R^2 = 0.822$	16
8	Bulk density	$y = -7.176x + 901.9$	$R^2 = 0.890$	17
9	True density	$y = -14.72x + 1513$	$R^2 = 0.980$	18
10	Weight of thousand grains	$y = 0.61x + 32.578$	$R^2=0.9312$	19
11	Internal coefficient of friction	$y = 0.009x + 0.449$	$R^2 = 0.985$	20
12	Coefficient of friction on GIS	$y = 0.012x + 0.198$	$R^2 = 0.987$	21
13	Coefficient of fraction on MS	$y = 0.008x + 0.389$	$R^2 = 0.909$	22
14	Coefficient of friction on Al	$y = 0.013x + 0.245$	$R^2 = 0.767$	23
15	Angle of repose	$y = 0.027x^2 - 0.304x + 24.52$	$R^2 = 0.993$	24
16	Terminal velocity, m/s	$y = 0.104x + 5.338$	$R^2 = 0.99$	25
17	Rupture force, N	$y = 0.146x^2 - 8.674x + 176.2$	$R^2 = 0.997$	26

Terminal velocity and rupture force

It was observed that the terminal velocity increased from 6.31 to 8.74, as the MC increased from 11.1 to 28.2% MC_{db}, refer to figure 5a. This increase can be attributed to the increase of individual mass of grain per surface area [10, 11]. The linear representation of the results is shown by the equation 25. The analysis of variance showed a significant difference in terminal velocity for all the levels of MC ($p< 0.05$). The rupture force was found to be range from 43.92 N and 98.36 N and decrease as the MC increased from 11.1 to 28.2% MC_{db}. It is modeled by equation 26 in table 2.



(a) (b)

Fig 5: Effect of moisture content on terminal velocity and rupture force

Principle composite analysis (CPA)

Referring to the rule of Kaiser-Guttmann, the main components were taken from the principal components with the eigenvalue greater than one for the compression of readings. Table3 shows eigenvalues and the proportions of data along 11 principal components at the confidence level of 0.95. Accordingly there will be two main components as there are only two eigenvalues greater than 1.

Table 3: Eigen analysis of the Correlation Matrix

Factor	1	2	3	4	5	6	7	8	9	10	11
Eigen values	12.441	1.645	0.685	0.515	0.31	0.208	0.087	0.051	0.033	0.021	0.002
Proportion	0.778	0.103	0.043	0.032	0.019	0.013	0.005	0.003	0.002	0.001	0
Cumulative	0.778	0.88	0.923	0.955	0.975	0.988	0.993	0.996	0.999	99.998	1

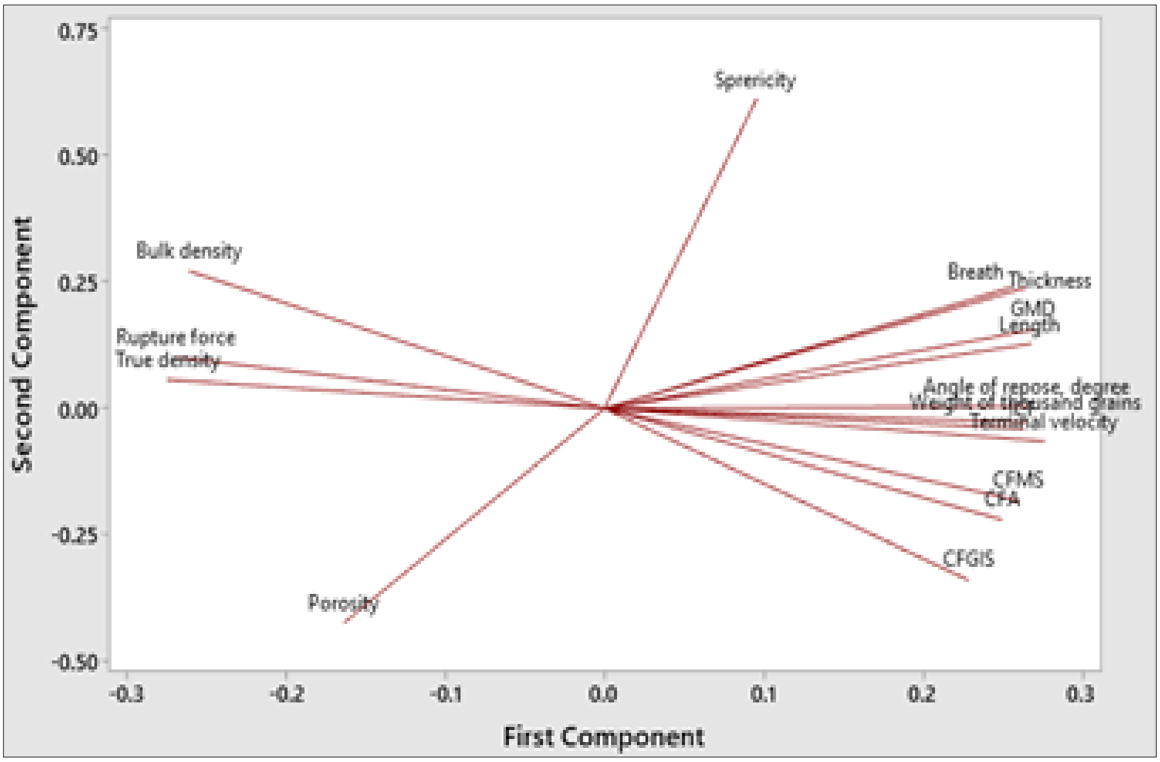
It was found that; the highest eigenvalue was 12.44 for PC1 (accounting for 77.8%) and the second high had 1.645 (counting for 10.3%) with both PCs achieving the total share of 88.1%.

Table 4: Eigenvector for variables on PC1 and PC2

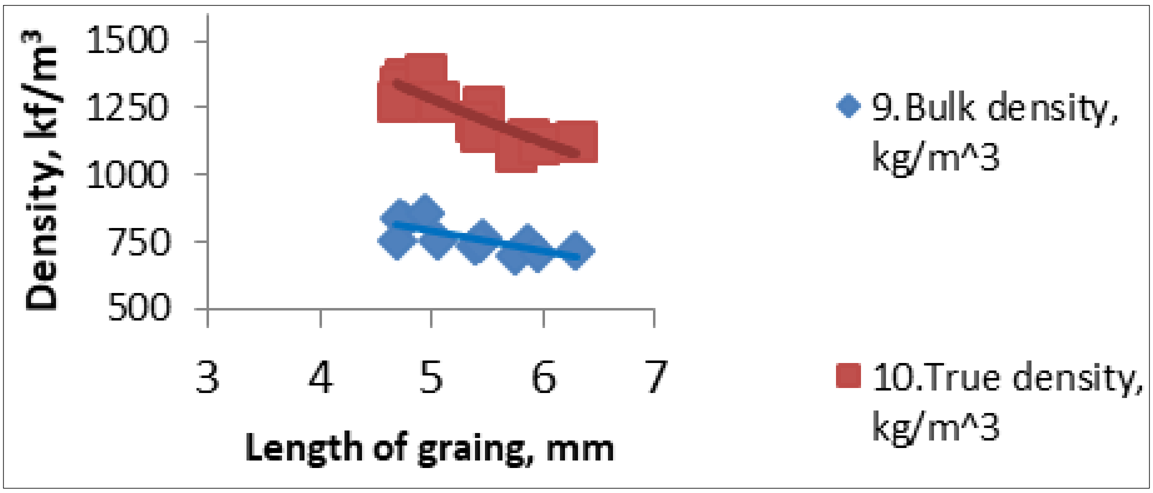
Variable	PC1	PC2
1. Length, L	0.268	0.128
2. Breath, B	0.255	0.239
3. Thickness, T	0.265	0.239
4. Geometric mean Diameter	0.270	0.156
5. Sphericity	0.096	0.612
6. Bulk density	-0.261	0.271
7. True density	-0.275	0.057

8. Porosity	-0.163	-0.424
9. Weight of thousand grains,	0.264	-0.028
10. ICF	0.263	-0.040
11. CFGIS	0.229	-0.340
12. CFMS	0.260	-0.182
13. CFAl	0.249	-0.220
14. Angle of repose	0.265	0.004
15. Terminal velocity	0.276	-0.065

The negative and positive signs shown in the eigenvectors table 4 depict the contrast among the green gram grain properties and the correlation trend along the principal components. For example the signs of bulk density, true density and porosity show that they are inversely correlated with PC1. It was shown that with respect to gravimetric properties there was positive correlation with PC1illustrated on figure 6 (a). The frictional coefficients showed that they are directly correlated with PC1. Therefore from PC1, it can be deduced the contrast between the gravimetric properties (density and porosity) and the displacement properties (friction coefficient and terminal velocity). For PC2 all's the displacement properties have the same sign which is indicative of their opposite stand in comparison to the gravitational and size related variables. The load of the variable towards the main components were illustrated in table 4 and graphically shown in figure 6 (a).



(a)



(b)

Fig 6: The loading plot of variables (a) and the correlation among variable

The results shown in the on the loading plot are good indicators of correlation among the tested properties. It is shown that the density and length are inversely related as it is illustrated on the figure 6(b). The analysis of Pearson coefficient of correlation showed that there a significant effect the change of density at $p>0.05$. The negative correlation were observed between of length and the bulk (r=-0.775, p=0.003) and between length and the true density (r=0.883, p=000). The high positive correlation is found between length and frictional properties becoming 0.803, 0.701, 0.843, 0.922 and 0.879 for, respectively, ICF, CFGIS, CFMS, CFAl and angle of repose. In the same manner the correlation pattern among other variables can be easily drawn.

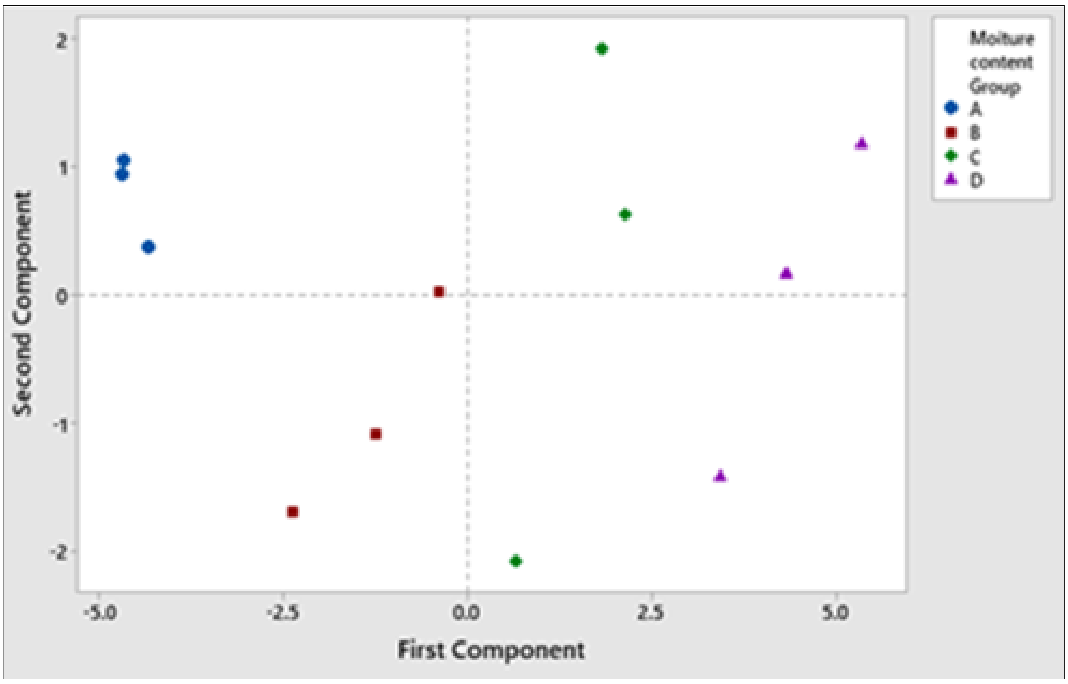


Fig 7: Score plot of groups on the PCs

The principal components analysis of the data distribution depicted the effect of moisture content as the values are grouped in distinctively visible pattern with respect to the moisture contents visualized on the figure 8. In the score plot, groups A, B, C and D are, respectively, the levels of 11.1%, 16.3%, 21.9%, 28.2% MC_{db}. These results show that the moisture contents should be the basis for treatment and handling of grain as the engineering properties adhere to them naturally. These results corroborate the ones found on Sorghum [4].

Conclusion

The investigation was done on the effect of MC ranging from 11.1 to 28.2 (MC_{db}.) of green gram on the engineering properties. The physical properties of the seeds from tested crop are useful for the design of agricultural processing machines such as threshers, pearler, blower, cleaning unit and conveyors. It can be concluded that geometric mean diameter, sphericity, grain volume, surface area, mass of 1000 grains, angle of repose, internal coefficient of friction and static coefficient of friction over different plate material terminal velocity, increase in direction of MC. However the bulk density, true density, porosity and rupture force decreased with the increase in MC. The statistical analysis of the data showed that there is a statistical difference among the properties at the various MC levels at 5% level of significance. The PCA have shown that 77.8% of the date revolves around the PC1 while 10.3% on PC2. PCA illustrated, also, the pattern among manifest variables and the effect of the groups/treatments on the array trend of the variables with respect to CPs. In the design of various parts of handling equipment; the maximum size and minimum size show the top sieve hole diameter and mosquito sieve hole size while the sphericity help in the shape of the hole. The angle of repose and coefficients of friction are considered in the design of chutes, hoppers and their slopes. The density and terminal velocity is important to design of the aerodynamic separation and conveyance the rupture point is considered in the design of threshing drums ad mills. The PCA features would permit to locate the driving variables and their relative effect on various treatments towards the grains.

Acknowledgement

The author acknowledges the ICAR-IARI for providing the support in materials and laboratory.

Reference

1. Bashir AA, Sakharam IN. Moisture-dependent engineering properties of SML-668 variety of green gram. 2018;6(3):1330-1336.
2. Tavakoli H, Rajabipour A, Mohtasebi SS. Moisture-Dependent Some Engineering Properties of Soybean Grains. Agric Eng Int CIGR J. 2009, 0(0).
3. Pandiselvam R, Venkatachalam T, Kothakota A, Baskaran K. Important Engineering Properties of Green Gram Vigna radiate. 2017.
4. Gely MC, Pagano AM. Effect of moisture content on engineering properties of sorghum grains. Agric Eng Int CIGR J. 2017;19(2):200-209.
5. Kenghe RN, Nimkar PM, Shirkole SS. Moisture dependent physical properties of lathyrus. J Food Sci Technol. 2013;50(5):856-867. doi:10.1007/s13197-011-

0428-7.
6. Surpam T, Pardeshi I, Rokade H. Engineering properties of sorghum. 2019;7(5):108-110.
7. Soyoye BO, Ademosun OC, Agbetoye LAS. Determination of some physical and mechanical properties of soybean and maize in relation to planter design. Agric Eng Int CIGR J. 2018;20(1):81-89.
8. Sangani VP, Davara PR. Moisture dependent physical properties of pigeon pea grains. Int J Postharvest Technol Innov. 2013;3(1):51-62. doi:10.1504/IJPTI.2013.051989
9. Powar RV, Aware VV, Shahare PU, Sonawane SP, Dhande KG. Moisture-Dependent Physical Properties of Finger Millet Grain and Kernel (*Eleusine coracana* (L.) Gaertn). J Indian Soc Coast Agric Res. 2018;36(1):48-56.
10. Chavoshgoli E, Abdollahpour S, Abdi R, Babaie A. Aerodynamic and some physical properties of sunflower seeds as affected by moisture content. Agric Eng Int CIGR J. 2014;16(2):136-142.
11. Singh KP, Mishra HN, Saha S. Moisture-dependent properties of barnyard millet grain and kernel. J Food Eng. 2010;96(4):598-606. doi:10.1016/j.jfoodeng.2009.09.007
12. Tarighi J, Mohtasebi SS, Seyfi M. Some mechanical and physical properties of corn seed (VAR. DCC 370). African J Agric Res. 2011;6(16):3691-3699. doi:10.5897/AJAR10.521
13. Altuntas E, Demirtola H. Effect of moisture content on physical properties of some grain legume seeds. New Zeal J Crop Hortic Sci. 2007;35(4):423-433. doi:10.1080/01140670709510210
14. Mohsenin NN. Physical Properties of Plant and Animal Materials. New York (USA) Gordon and Breach. 1986.
15. Stroshine R. Physical Attributes: Shape, Volume, Density, Porosity and Particle Size Distribution. 1998.
16. Hillel Daniel. Introduction to Environmental Soil Physics. 1st Edition. 2003.
17. Gupta RK, Arora G, Sharma R. Aerodynamic properties of sunflower seed (*Helianthus annuus* L.) Aerodynamic properties of sunflower seed (*Helianthus annuus* L.). 2007-2020. doi:10.1016/J. J food eng. 2006.03.010
18. Ricci C, Baumgartner J, Wentzel-viljoen E, Smuts M. Food or nutrient pattern assessment using the principal component analysis applied to food questionnaires. Pitfalls, tips and tricks. Int J Food Sci Nutr. 2019;0(0):1-11. doi:10.1080/09637486.2019.1566445
19. Baryeh EA, Mangope BK. Some physical properties of QP-38 variety pigeon pea. J Food Eng. 2003;56(1):59-65. doi:10.1016/S0260-8774(02)00148-6
20. Gebreselassie TR. Effect of moisture on physical properties of dekoko (*Pisum sativum var. abyssinicum*) seed. Agric Eng Int CIGR J. 2014;16(2):143-150.
21. Işik E, İzli N. Effects of moisture content on some physical properties of the yellow lentil. Tarim Bilim Derg. 2016; 22(2):307-316. Doi: 10.1501/tarimbil_0000001389