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PHYSICAL PROPERTIES OF SORGHUM (SORGHUM BICOLOR) GRAINS AS A FUNCTION OF MOISTURE CONTENT

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ABSTRACT

Experiments were conducted to evaluate some moisture dependent physical properties of newly evolved variety of Sorghum (*Cv. Phule suchitra*) by MPKV Rahuri in the simulated moisture content range of 10.94 to 24.22 % (d. b.). The data on physical properties are essential to the design engineers for designing of various processing machineries. The sample of *Phule suchitra* was procured from AICRP on sorghum. Cleaned and graded sample was used for experimentation. The sample was conditioned with predetermined quantity of distilled water and was placed in polythene bag in refrigerator for 8 days. It was observed that length, breadth and thickness were increased linearly with increase in moisture content. Grain size was increased from 4.09 to 4.53 mm with corresponding increase in moisture content from 10.94 to 24.22 % (d. b.). Similar trend was observed for AMD, SMD and EQD. Sphericity was decreased from 81.79 to 79.63 % with increase in moisture content. Surface area, volume and thousand grain weight was linearly increased from 46.39 to 56.16 mm^2, 29 to 38 mm^3 and 42.47 to 45.21 g respectively. It was observed that bulk density and true density decreased with increase in moisture content in the simulated range. Bulk density was decreased from 775.85 to 699.69 kg/m^3. Whereas, true density was decreased from 1147.1 to 995.3 kg/m^3. The porosity value does not show any specific trend, it varied for every biological material. The values of angle of repose were increased from 26.75^0 to 29.31^0 with corresponding increase in moisture content. Values of Static coefficient of friction were found to be ranged between 0.58 to 0.66, 0.60 to 0.72 and 0.70 to 0.77 for glass, GI sheet and plywood surface, respectively. Minimum Static coefficient of friction was found for glass surface (0.58) whereas, maximum static coefficient of friction was found for plywood surface (0.70) at initial moisture content of 10.94 % (d. b.)

KEYWORDS: Physical properties, Sorghum, Bulk density, True density.

INTRODUCTION

Sorghum (sorghum bicolor) is one of the most important cereal crops widely grown for food, feed, fodder/forage, and fuel in the semi-arid tropics of Asia, Africa, the Americas and Australia. The global sorghum areas remained static as the increased area in Africa compensated the area loss in Asia. In spite of rapid decline in sorghum area in Asia due to competition from other remunerative crops, sorghum grain production levels have not declined at the same rate owing to adoption of high yielding hybrids.

The performance of threshing machines depends on machine variables such as frequency of sieve oscillations, amplitude of oscillation, sieve slope, length of sieve, width of sieve, sieve opening diameter, threshing speed, velocity of air, air stream pressure and density, angle of air stream and terminal velocity of particles(both for grains and other materials) and crop parameters such as crop variety, maturity stage, grain moisture content, straw moisture content, bulk density of grain, bulk density of straw, stalk length and grain diameter. (Simonyan, 2005). Materials obtained after threshing are heterogeneous mixture of grain and various component fractions (Hurburgh 1995) with different ranges of physical and aerodynamic properties. Physical properties have great influence on the behaviour of crops when subjected to forces. Physical properties of agricultural materials are needed to adequately design appropriate equipment and systems for planting, harvesting and post-harvest operations such as cleaning, conveying and storage (Asoegwu et al., 2006). The physical properties of sorghum such as weight, diameter, surface area, bulk density are

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required and necessary in the design and optimal performance of the grain threshing unit. The shape and size of agricultural materials had been found useful in understanding the problem of separating grains from undesirable materials. The size of grains represented by their equivalent diameter and sphericity is necessary to describe their shape (Asoegwu et al., 2006). The surface area is useful to calculate the rate of heat transfer and in the design of appropriate heating equipment. Material size is required for grading and packing (Singh et al., 2004) and in sieve separation and grinding operations (Wilhelm et al., 2004). Mohsenin (1980) reported that shape and size are considered when dealing with problems of stress distribution in the material under load, designing of sizing and grading machines. Density is needed in mathematical conversion of grain mass to volume and also in heat transfer operations. The bulk density gives the degree of kernel filling during growth and serves as the quality indicator for breakage susceptibility, hardness tests and baking quality (Chang, 1988) and it also determines the dielectric properties (Nelson and You,1989) and useful in dielectric mixture equations (Nelson,1980).

Mohsenin (1980) and Vaughan et al., (1980) documented that crop separation from unwanted materials is based on differences in physical properties between the crop and materials. The process of cleaning sorghum requires that differences in the physical properties of sorghum grain be known. This study was undertaken to determine some moisture dependent physical properties of sorghum (Cv. Phule suchitra).

MATERIAL AND METHODS

Sorghum grains (cv. Phule suchitra) of quantity of sample was brought to the laboratory. The grains were thoroughly cleaned (manually by winnowing and hand sorting) to remove foreign materials such as dirt, stones, dust, immature grain, broken grains and unremoved chaffs.

The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relationship (Coşkun et al., 2005).

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

where,

Q = mass of water added, kg
W_i = initial mass of the sample, kg
M_i = initial moisture content of the sample, %(d. b.)
M_f = final moisture content of the sample, % (d. b.).

The samples were sealed in separate polythene bag (100 gauge) and stored in refrigerator at $7\,^0$ C ± 1^0 C for 8 days. Before each experiment, the required quantity of sample was taken out from the refrigerator and kept sealed in an ambient environment for 24 h. to reach equilibrium. The sample was kept in ambient environment in sealed conditions so that there is no loss or gain of in moisture.

The moisture content of sorghum grains was determined using American Society of Agricultural Engineers (ASAE) standard method (ASAE, 4). Predetermined quantity of grain samples were dried in a hot air oven and subsequently cooling in desiccators for one hour (AOAC, 2006) before taking a final weight. The process is continued till constant weight was obtained. Average of three replications was noted and reported as moisture content of the sample.

Length, breadth, thickness (L, B, and T)

For determination of L, B and T one thousand grains were randomly picked from each sample. The length (L), breadth (B) and thickness (T) were measured by using digital Vernier calliper (±0.01mm). The exact orientation of the sorghum grain during measurements of L, B and T are as shown in Fig. 1

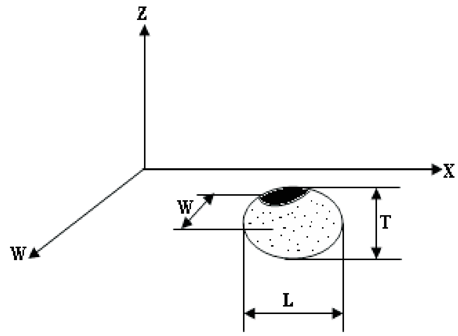

Fig. 1 Characteristic dimensions of sorghum grain

Grain size (D_m)

The average diameter of the grain was calculated by using arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter(*AMD*) geometric mean diameter (*GMD*), square mean diameter (SMD) and equivalent diameter (EQD) of the grains were calculated by using the following relationships (Mohsenin, 1986).

$$AMD = \frac{L+B+T}{3} \quad \ldots (2)$$

$$GMD = \sqrt[3]{LBT} \quad \ldots (3)$$

$$SMD = \sqrt{LB + BT + TL} \quad \ldots (4)$$

$$EQD = \frac{AMD+GMD+SMD}{3} \quad \ldots (5)$$

Sphericity (Φ)

Sphericity (**Φ**) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain and was determined using following formula (Mohsenin, 1986).

$$\Phi = \frac{LBT^{1/3}}{L} \quad \ldots (6)$$

where,

L= length of grain, mm
B= width of grain, mm
T= thickness of grain, mm

Volume (V)

The volume of the grain was determined by taking the dimensions of the two varieties of the grains in three axes of length, width, and thickness in 10 replications and then the volume was estimated using the relationship as described by Mohsenin (1986).

Angle of Repose (θ)

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus consisting of plywood box of 140 x 160 x 35 mm and plates fixed and adjustable. The box was filled with the sample from constant height (15 cm), and then the adjustable plate was inclined gradually allowing the grains to fall freely and assume a natural slope, this was measured as emptying angle of repose.

Thousand grain weight (M_{1000})

One thousand randomly selected sound grains of test sample at various moisture levels were collected and weighed on electronic top pan balance (Contech, India) having a least count of 0.01 g. This magnitude was termed as the thousand grain weight specific to the grain. The procedure described in IS: 4333 (Part IV) -1968 was adopted. Average of ten replications have been considered and reported as thousand grains weight of the sample. Effect of moisture content on thousand grain weight of sorghum was then attempted.

Bulk density (ρ_b)
Bulk density of the grain is ratio of its mass to bulk volume. Bulk density was measured using IS:4333 (Part III)-1967 method, in which a 500 mL cylinder was filled with grains from a height of 15 cm. The excess grains were removed by sweeping the surface of the cylinder and the grains were not compressed. Bulk density was then calculated as the ratio between the kernels weight and the volume of the cylinder.

True density(ρ_t)
The ratio of mass of sample to the true volume is termed as true density of the sample. True densities were measured at different moisture contents. It was determined with toluene displacement method. Grain sample of about 10 g was submerged in toluene in measuring cylinder having an accuracy of 0.1 mL. The increase in liquid volume due to pouring of sample was noted as true volume of the sample, which was then used to determine the true density of sample. Average of ten replications was considered as a true density value of the sample.

Porosity ($\in$)
It is the percentage of volume of voids in the test sample at given moisture content. It was calculated as the ratio of the difference in the true and bulk density to true density value and expressed in percentage with the following equation. Average of ten replications was considered as a per cent porosity value of the sample.

$$1-\frac{BD}{TD} \qquad \ldots(7)$$

Static coefficient of friction (μ)
The coefficient of friction between grain and wall is an important parameter in the prediction of grain pressure on walls. The coefficient of friction of the sorghum grain on three different surfaces such as glass, plywood and GI sheet were determined. These are common materials used for transportation, storage and handling operations of grains, pulses and grains, construction of storage and drying bins. A tilting platform of 400 × 200 mm was fabricated and used for experimentation. An-open ended PVC pipe having 63 mm diameter and 40 mm height was filled with the grain and placed on the adjustable tilting surface. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually with a screw jack, until the material started to flow and the angle of tilt was read from a graduated scale (Nimkar *et al.*, 2005). The coefficient of friction was calculated using the equation.

$$\mu = \tan\theta \qquad \ldots (8)$$

where,
μ = coefficient of friction; and
θ = angle of inclination of material surface.

Data Analysis
The result obtained were subjected to analysis of variance (ANOVA) and Duncan's test using SPSS 13 (SPSS Inc., USA) software and analysis of regression using Microsoft Excel 2007 (Microsoft Crop., USA).

RESULT AND DISCUSSION

Length breadth and thickness (L, B and T)
The data obtained for sorghum grain dimensions i.e. length, breadth and thickness of sorghum at different moisture levels are presented in Table 1 which revealed that the length, breadth and thickness were increased linearly with increase in moisture content. It was observed from Table 1 that the length of sorghum grain increased from 5.02 to 5.69 mm; breadth increased from 4.25 to 4.63 mm and thickness increased from 3.22 to 3.53 mm with the corresponding increase in moisture content from 10.94 % to 24.22 % (d. b.).

The increase in axial dimensions of sorghum grain with increase in moisture content is due to absorption of water by grains. These variations in grain size with moisture content of sorghum were significant at 5 % level of significance.

The increased values of length, breadth and thickness are in agreement with Simonyan *et al.*, (2007) for sorghum; Kenghe *et al.*, (2012) for soybean; Tavakoli *et al.*, (2009) for soybean and Mwithiga and Mark (2005) for sorghum.

The variation in properties with moisture content of grain could be represented by equations as shown in Table 4.

Grain size (D_m)

The data obtained for grain size of sorghum at different moisture levels are presented in the Table 1. which indicates that the grain sizes i.e. GMD AMD SMD and EQD were found to be increased linearly with increase in moisture content. It was observed from Table 1 that the GMD increased from 4.09 to 4.53 mm, AMD increased from 4.16 to 4.55 mm, SMD increased from 7.15 to 7.90 mm, while EQD increased from 5.14 to 5.67 mm with corresponding increase in moisture content from 10.94 to 24.22 % (d. b.).The increase in grain size was due to the moisture absorbed by the grains.

The variations in grain size with moisture content of grain could be represented by equation as shown in Table 4.

The results showed the increase in grain size with increase in moisture content were in conformity with the earlier findings for lathyrus (Kenghe *et al.*, 2011); for soybean (Kenghe *et al.*, 2012); and Mwithiga and Mark (2005) for sorghum.

Sphericity (Φ)

The values of sphericity were calculated individually by using the data on geometric mean diameter and the major axis of the grain sorghum and the result obtained are shown in Table 2 which indicates that sphericity was linearly decreased or remained fairly constant with decreasing trend of moisture content. Sphericity of the grains decreased from 81.79 to 79.63 % as the moisture content increased from 10.94 to 24.22% (d. b.).

Similar findings for shericity determination for various grains has been reported by Kenghe *et al.*, 2011 and Konak *et al.*, (2002).

Volume (V)

The data obtained for volume of sorghum at different moisture levels are presented in Table 2; which indicated that volume was increased linearly with increase in moisture content; it was observed that the volume increase from 29 to 38mm^3 with corresponding increase in moisture content from 10.94 to 24.22% (d. b.).

These variations in volume with moisture content of sorghum where significant at 5% level of significance. The increase in volume was due to moisture absorbed by grain. The increased values of volume are in agreement with Simonyan *et al.*, (2007) for sorghum; and Konak *et al.*, (2002) for chickpea.

Thousand Grain Weight (M_{1000})

The results are shown in Table 2 which revealed that thousand grain weight was increased linearly with increase in moisture content. It was observed that thousand grain weight increased from 42.47 to 45.21 g when moisture content was increased from 10.94 to 24.22 % (d. b.).

These variations in thousand grain weight with moisture content of sorghum were significant at 5 % level of significance. The increase in thousand grain weight was due to moisture absorbed by the grains. The increased values of thousand grain weight are in agreement with Kenghe *et al.*, (2012)for soybean; Tavakoli *et al.*, (2009) for soybean and Mwithiga and Mark *et al.*, (2005) for sorghum.

Bulk Density (ρ_b)
The bulk density was decreased linearly with increase in moisture content. The bulk density was decreased from 775.05 to 699.69 kg/m^3. These variations in bulk density with moisture content of sorghum were significant at 5 % level of significance.

The result showing decreased in bulk density with increase in moisture content were in conformity with the earlier findings for soybean (Kenghe *et al.,* 2012); for gram (Chaudhary *et al*., 2001) and for soybean grains (Tavakoli *et al.,* 2009).

True Density (ρ_t)
It was observed from Table 2 that true density was linearly decreased with increase in moisture content. The true density was decreased from 1147.1 to 995.3 kg/m^3. The variation in true density with moisture content of sorghum were significant at 5% level of significance.

The decreased values of true density are in agreement with Simonyan et al.(2007) for sorghum; Mwithiga and Mark (2005) sorghum grains and Kenghe et al., (2012) for soybean.

Porosity (Ɛ)
The experimental results for porosity with elevated moisture content are as shown in Table 2. It was observed that the value of porosity does not follow the specific trend as like other properties. The porosity values may be different for different bio-logical material.

Angle of Repose (θ)
The results are shown in Table 2 which indicates that angle of repose linearly increases with increase in moisture content. It was observed that angle of repose increased from 26.75º to 29.31º when moisture content increased from 10.94 to 24.22 % (d. b.)

The increasing trend of angle of repose with moisture content occur because surface layer of moisture surrounding particle hold the aggregate of grain together by surface tension (Pradhan *et al.*, 2008). The variation in angle of repose with moisture content of sorghum was in significant at 5 % level of significance.

The increased values of angle of repose are in agreement with Mwithiga and Mark (2005) for sorghum; Kenghe *et al.,* (2012) for soybean and Tavakoli *et al.,* (2009) for soybean.

Static Coefficient of Friction (μ_{stat})
The static coefficient of friction for sorghum grains determined with respect to three different structural surfaces in the moisture range of 10.94 to 24.22 % (d.b.) are given in Table 3 . It was observed that the static coefficient of friction increased linearly with moisture content for all contact surfaces.

The values of static coefficient of friction of sorghum were found in the range of 0.58 to 0.66 for glass, 0.60 to 0.72for galvanized iron and 0.70 to 0.75 for plywood. The increased in values of the static coefficient of friction are in agreement with Tavakoli*et al.,* (2009) for barley grains; Kenghe *et al.,* (2012) for soybean and Chudhary *et al.,* (2001) for gram.

CONCLUSIONS
Based on the results discussed following conclusions could be drawn:

1. Length, breadth and thickness were found to be increased from 5.02 to 5.69 mm, 4.25 to 4.63 and 3.22 to 3.53 mm.
2. The grain size was found to be increased from 4.09 to 4.53 mm.
3. The values of AMD, SMD and EQD were increased from 4.16 to 4.62 mm, 7.15 to 7.90 mm and from 5.14 to 5.69 mm respectively.
4. Sphericity was decreased from 81.79 to 79.63 %.
5. The surface area was increased from 46.39 to 56.16 mm^2.
6. The volume was linearly increased from 29 to 38 mm^3
7. Thousand grain weight was increased from 42.47 to 45.21 g

8 Bulk density was decrease from 775.85 to 699.69 kg/m^3
9 True density was decrease from 1166 to 1104 kg/m^3.
10 The values of Angle of repose was increase from 26.75^0 to 29.31^0
11 Porosity does not follow any specific trend with increase moisture content
12 Values of static coefficient of friction was found ranged between 0.58 to 0.66, 0.60 to 0.72 and 0.70 to 0.77 for glass, GI sheet and plywood surfaces respectively
13 The regression equations developed showing the relationship between various physical properties and moisture content could be used exploited for predicting physical properties within the experimental range.

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Table 2 Physical properties of sorghum grain

Property/Moisture content, % (d.b.)	**10.94**	**18.23**	**21.58**	**24.22**
Sphericity (%)	81.79* (±3.60)	80.83 (±3.82)	80.08 (±2.21)	79.63 (±2.33)
Surface area, mm^2	46.39 (±5.47)	48.6 (±5.23)	51.61 (±3.81)	56.16 (±5.14)
Volume, mm^3	29.00 (±2.02)	31.00 (±3.02)	34.00 (±1.02)	38.00 (±1.02)
1000 grain weight (g)	42.47 (±1.39)	43.52 (±0.54)	44.48 (±1.02)	45.21 (±0.72)
Bulk density (kg/m^3)	775.05 (±4.09)	741.15 (±5.61)	716.14 (±3.21)	699.69 (±4.75)
True density (kg/m^3)	1147.1 (± 0.96)	1092.4 (± 0.07)	1043.6 (± 0.12)	995.3 (± 0.05)
Angle of repose, degree	26.75(±2.02)	27.39(±2.09)	28.82(±1.02)	29.31 (±1.28)
Porosity (%)	35.7 (± 0.05)	37.7 (± 0.04)	36.8 (± 0.02)	35.9 (± 0.05)

Values in the parenthesis indicates standard error * Average determinations of three replications

Table 3 Effect of moisture content on static coefficient of friction

Moisture content % (d. b.)	Coefficient of static friction		
	Glass	G.I. Sheet	Plywood
10.94	0.58	0.60	0.70
18.23	0.63	0.64	0.73
21.58	0.65	0.68	0.75
24.22	0.66	0.72	0.77

Table 4 Representation in variation of physical properties

Physical property	**Equation**	**R^2**
Grain size, (mm)	D_m= 0.0309M + 3.7112	0.874
	D_a = 0.0284M + 3.8176	0.916
	D_s = 0.0530M + 6.5013	0.882
	D_e = 0.0375M + 4.6804	0.877
	D_m= 0.0309M + 3.7112	0.874
Sphericity (%)	Φ = 0.1632M + 83.64	0.986
Volume (mm^3)	V= 0.6297M + 21.199	0.855
1000 grain weight (g)	M_{1000}= 0.2034M + 40.108	0.967
Bulk density (kg/m^3)	ρ_b = -5.6713M + 839	0.988
True density(kg/m^3)	ρ_t =-13.283M + 1415.2	0.935
Angle of repose degree	θ = 0.1973M + 24.37	0.896
Static coefficient of friction	μ_{gl} =0.0062M + 0.5145	0.991
	μ_{gi} =0.0087M + 0.4968	0.940
	μ_{pl} =0.0051M + 0.6412	0.979

Table 1. Physical properties of sorghum grains at different moisture contents

Moisture content (%) d. b.	Axial dimensions, mm			Average diameters, mm			
	Length (L)	Width (B)	Thickness (T)	Arithmetic Mean Diameter (AMD)	Geometric Mean diameter (GMD)	Square Mean Diameter(SMD)	Equivalent Diameter (EQD)
10.94	5.02* (±0.44)	4.25 (±0.27)	3.22 (±0.21)	4.16 (±0.27)	4.09 (±0.26)	7.15 (±0.45)	5.14 (±0.33)
18.23	5.20 (±0.32)	4.29 (±0.25)	3.33 (±0.27)	4.27 (±0.21)	4.20 (±0.22)	7.34 (±0.37)	5.27 (±0.27)
21.58	5.42 (±0.18)	4.44 (±0.19)	3.40 (±0.21)	4.42 (±0.14)	4.34 (±0.15	7.59 (±0.28)	5.45 (±0.18)
24.22	5.69 (±0.23)	4.63 (±0.24)	3.53 (±0.25)	4.62 (±0.14)	4.53 (±0.20)	7.99 (±0.33)	5.69 (±0.24)

Average determination of three replications