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Evaluation of physical properties of different varieties of sorghum grain

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Abstract
Some physical properties of different sorghum varieties *viz.*, Parbhani Jyoti, Parbhani Moti, Parbhani Super Moti, Dagadi, Parbhani Shakti were determined within moisture range formed 11.63 to 12.67 wb. Thousand-grain weight, moisture content, length (L), width (W) and thickness (T), angle of repose, bulk density, true density, porosity, colour L value, grain hardness (N), Equivalent mean diameter were the physical parameters measured. Result of investigation showed that the maximum physical parameters such as EQD (4.48 mm), sphericity (0.81), aspect ratio (0.906), surface area of single grain (41.25 mm^2), volume of single grain (24.48 mm^3), thousand grain weight (36.10 g), and bulk density (769.49 kg/m^3) were found for Parbhani Moti variety. The maximum physical parameters such as length (4.56 mm), width (3.99 mm), shape factor (4.51) and porosity (0.4267) were found for Parbhani Jyoti variety. The maximum physical parameter *i.e.* angle of repose (38^0 80') was found for Parbhani Shakti variety. The minimum physical parameters such as EQD (4.16 mm), surface area of single grain (35.71 mm^2), volume of single grain (19.69 mm^3), thousand grain weight (27.56 g), length (4.1 mm), and porosity (0.3839) were found for Parbhani Shakti variety. The minimum physical parameter *i.e.* sphericity (0.77) and aspect ratio (0.870) were observed for Parbhani Jyoti variety.

Keywords: Sorghum, hardness, bulk density, true density, porosity, shericity

1. Introduction

Millet crops or Nutri-Cereals are commonly known as poor man's crop; of late are termed as rich man's diet since they contain a lot of nutrients and vitamins and can tolerate adverse environmental conditions i.e. tolerance to moisture stress, resistant to water logging and grown in various soil conditions (Taylor, 2006) [3]. Sorghum [*Sorghum bicolor* (L.) Moench] popularly called as Jowar, is the "king of millets" and is the fifth in importance among the world's cereals after wheat, rice, maize and barley (Anglani, 1998) [1]. The grains of some varieties are now being used in the industries for the production of biscuits, confectionaries, beverages, pharmaceutical syrups and also for making of beer in beer industries. However, it has been reported that the major constraints in producing excellent food products from sorghum is the lack of consistent supply of good quality grain for processing as sorghum grain in existing markets are variable in different kernel size, colour and cleanliness (Rooney, 2003) [2].
The physical properties of sorghum grains, like other grains, are essential and important for designing the processing equipment for further handling and post-harvest processing. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of grains. Physical properties affect conveying characteristics of solid materials by air or water and cooling and heating loads of food materials. The knowledge on the physical properties of a crop is essential for proper design of processing equipment. The size distribution and characteristic dimensions of grain is important for the design of equipment for cleaning, sorting and separation (Kachru *et al*. 1994) [6]. The bulk density is used to determine the capacity of storage and transport, while the true density is useful to design proper separation equipment. Moreover, porosity of the grain mass determines the resistance to airflow during aeration and drying operation (Brooker *et al*. 1992; Kachru *et al*. 1994) [5, 6]. Frictional properties such as angle of repose and coefficient of friction are important properties for the design of grain containers and other storage structures (Vilche *et al*. 2003) [7]. These properties are affected by factors such as size, form and moisture content of the grain. The review of literature showed that there is a lack of information on physical properties of sorghum grains for different varieties. Hence, the knowledge of these physical properties are necessary for designing processing machines after harvesting like cleaner, grader and dehusker. 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) [8] and in sieve separation and grinding operations (Wilhelm *et al*., 2004) [9]. The milling quality of sorghum is determined by the kernel shape, density, hardness and structure (Rooney, 2003) [2]. Mohsenin (1980) [10] and Vaughan *et al*., (1980) [11] 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 physical properties of Sorghum grain of different variety which influence separation and cleaning.

2. Materials and Method

Procurement and preparation of sample

The experiments were carried out at the Department of Agricultural Process Engineering, VNMKV Parbhani. For this investigation, a bulk sample of 5 kg each of different varieties of sorghum grain, namely Parbhani Joyti, Parbhani Moti, Parbhani Super Moti, Dagadi, and Parbhani Shakti, were procured from Sorghum Research Station, VNMKV Parbhani. The sorghum grains were cleaned, graded, packed and stored in a cool and dry place, in the laboratory till experimentation. The important engineering properties studied were: physical properties (Length, width, thickness, arithmetic mean diameter, equivalent mean diameter, square mean diameter, geometric mean diameter, sphericity, weight of 1000 grains, bulk, true density and porosity), aspect ratio, shape factor, surface area of single grain, volume of single grain, grain hardness, colour, frictional properties (Angle of repose and coefficient of friction) for sorghum. The initial moisture contents of these samples were found out following the standard hot-air oven method (Singh & Sahay, 1994) [4].

Determination of Physical Properties of different sorghum varieties

Shape and size: The size of the sorghum grain was determined by measuring the linear *Dimensions-length* (L), width (W) and thickness (T) measured using a digital calliper having the least count of 0.001 mm. The average size of the sorghum grains was calculated from randomly selected 10 grain samples.

Grain size (Dm)

The average diameter of the grain was calculated by using arithmetic mean and the geometric mean of the three axial dimensions. The arithmetic mean diameter (*AMD*), geometric mean diameter (*GMD*), square mean diameter (SMD), equivalent diameter (EQD), degree of sphericity (Sp), aspect ratio (AR), shape factor (λ) and unit volume of the grains were calculated by using the following relationships (Mohsenin, 1986) [13].

$$AMD = (L+B+T)/3 \quad \ldots (1)$$

$$GMD = (LBT)^{1/3} \quad \ldots (2)$$

$$SMD = \sqrt{(LB + BT + TL)} \quad \ldots (3)$$

$$EQD = (AMD+GMD+SMD)/3 \quad \ldots (4)$$

Sphericity: The sphericity is used to describe the shape of the grain. The sphericity was calculated using the relationship (Mohsenin, 1986) [13]

$$S_p = \frac{GMD}{L}$$

Aspect ratio (Ra): Is the ratio of longer diameter to shorter diameter, was calculated by using the relationship given.

$$AR = \frac{W}{L}$$

Surface area: Major dimensions were used to calculate the surface area (S) of single grain (Jain and Bal, 1997) [17] as details below.

$$S = \frac{\pi \times GMD \times L^2}{2L - GMD}$$

Unit volume: The unit volume of single grain (Jain and Bal, 1997) [17] was calculated as

$$V_t = \frac{\pi \times GMD^2 \times L^2}{6(2L - GMD)}$$

Where, V_T: unit volume, L: length (mm) and GMD: geometric mean diameter.

Shape factor (λ): based on unit volume and surface area of grain was determined (Mc. Cabe and Smith, 1984) as

$$\lambda = \frac{b}{a}$$

$$a = \frac{Vt}{W^4} \quad b = \frac{S}{6W^2}$$

Where, V_T: unit volume (mm^3), W: width (mm), S: surface area (mm^2).

True Density: 50 ml of toluene was taken in a measuring cylinder. A known weight of grain sample was poured to the measuring jar and rise in the toluene level was recorded. The true density of the grain was calculated by using the following formula (Mohsenin, 1986) [13].

$$\text{True density kg/m3} = \frac{\text{weight of grain}}{\text{volume of grain excluding void space}}$$

Bulk density: Bulk density was determined by using a container of known volume. The sample was taken into the container for the known volume and weighed. The bulk density was determined using the formula (Mohsenin, 1986) [13].

$$\text{Bulk density kg/m3} = \frac{\text{weight of grain}}{\text{volume of grain including pore space}}$$

Porosity (ε): is the ratio of the volume of internal pores in the particle to its bulk volume. It was calculated as the ratio of the difference in the true density and bulk density to the true density and expressed by Kakde *et al.* (2019) [19].

$$\varepsilon = \frac{\rho t - \rho b}{\rho t} \times 100$$

Where, (ε) was the Porosity, ρt was the true density and ρb was the bulk density.

Density ratio: It is the ratio of bulk density to true density. Calculated by the formula.

$$\text{Density ratio} = \frac{\text{Bulk density}}{\text{True density}}$$

Weight of 1000 grains

One thousand grains were randomly selected and weighed using an electronic balance with an accuracy of 0.1 g. ten replications was weighed and the mean weight of one thousand grains was calculated.

Colour

The Colour (L*, a, b value) of the samples was determined by using a Hunter Lab colorimeter.

Grain hardness: The textural properties (Hardness and Crispiness) of sorghum popped samples were evaluated using a texture analyzer (TA.XT. Plus Texture Analyzer, Stable Micro System, UK). The hardness value was considered as the mean peak compression force (Bourne, 2002) [12]. The setting of texture analyzer a pre-test speed of 1mm/s, probe P_{35}, test speed of 10mm/s, distance of 50% strain, data aquiation rate 400 pps, testing force 0.05N Bourne *et al*., (2002) [12].

Frictional properties

Angle of repose: Angle of repose is the angle between base and slope of the cone formed on a free vertical fall of grains on to a horizontal plane. It was determined by following the procedure described by Sahay and Singh (1994) [4]. It was found by measuring the height (H, mm) and diameter (D, mm) of the grains heaped in natural piles by using the expression:

Angle of repose, θ (degree) = $\tan^{-1}[2H/D]$

3. Results and Discussion

3.1 Physical properties of sorghum cultivar

In order to characterize sorghum grain, different visual physical parameters which are presented in following Table 1.

Table 1: Physical properties of sorghum grain of different varieties

Sr. No.	Grain	MC, Wb %	Length mm	Width mm	Thickness mm	AMD mm	GMD Mm	SMD mm	EQD mm	SP	AR	S (mm^2)	VT (mm^3)	LAM
1	PJ[1]	12.36	4.56	3.99	2.41	3.65	3.52	6.22	4.46	0.77	0.875	41.17	24.20	4.51
2	PM[2]	12.49	4.37	3.96	2.61	3.64	3.56	6.24	4.48	0.81	0.906	41.25	24.48	4.40
3	PSM[3]	12.57	4.32	3.76	2.59	3.55	3.47	6.09	4.37	0.805	0.870	39.50	22.89	4.06
4	DG[4]	11.71	4.16	3.66	2.52	3.44	3.37	5.91	4.24	0.810	0.879	37.06	20.83	3.97
5	PSH[5]	12.63	4.1	3.59	2.46	3.38	3.30	5.79	4.16	0.806	0.875	35.71	19.69	3.89
SE(mean)		0.04	0.03	0.016	0.02	0.02	0.03	0.02	0.004	0.006	0.48	0.39	0.05	0.04
SD		0.45	0.18	0.17	0.08	0.12	0.10	0.19	0.14	0.016	0.014	2.48	2.09	0.27
CD at 5%		0.16	0.11	0.047	0.07	0.06	0.11	0.08	0.012	0.018	1.44	1.17	0.16	0.16

Sr. No.	Thousand grain weight (g)	Bulk density (kg/m^3)	True density (kg/m^3)	Density ratio	Colour L value	Grain hardness (N)	porosity	Angle of repose
PJ[1]	33.97	757.70	1321.73	0.573	67.10	68.62	0.4267	$34^0 65'$
PM[2]	36.10	769. 49	1310.07	0.587	64.34	73.15	0.4126	$34^0.32'$
PSM[3]	31.61	746.24	1251.33	0.597	65.09	73.47	0.4038	$35^0 47'$
DG[4]	30.77	732.19	1240.72	0.590	63.70	84.45	0.4098	$36^0 85'$
PSH[5]	27.56	700.04	1219.66	0.573	65.86	116.72	0.4260	$38^0 80'$
SE (mean)	0.72	5.57	9.48	0.01	0.032	8.48	0.002	0.41
SD	3.24	29.58	44.57	0.004	0.296	19.43	0.01	1.83
CD at 5%	2.84	16.49	29.58	0.014	0.877	25.20	0.008	1.21

Table 2: Visual physical parameter of sorghum grain of different varieties

Variety	Color	Size	Shape
Parbhani Jyoti	Pearly white	Bold	Round
Parbhani Moti	Creamy white	Bold	Round
Parbhani super Moti	Pearly White	Medium Bold	Round
Dagadi	Creamy White	Medium Bold	Round
Parbhani Shakti	Milky White	Small size	oblong

3.1.1 Comparision of physical characteristics of different sorghum varieties

The length, width and thickness of different sorghum cultivars ranged from 4.56 to 4.10 mm, from 3.99 to 3.59 mm and from 2.61 to 2.41 mm, respectively. The maximum length of 4.56 mm for Parbhani Jyoti followed by Parbhani Moti (4.37 mm) and Parbhani Super Moti (4.32 mm) and the minimum length was obtained for Parbhani Shakti which was 4.10 mm. Similar results were reported by Sabar *et al.* (2020) [20], Patekar *et al.* (2017) [24] and Simonyan *et al.* (2007) [22] regarding the length, width and thickness of sorghum.

3.1.2 Comparision of arithmetic mean diameter of different sorghum varieties

For the different varieties of raw sorghum, the arithmetic mean diameter ranged from 3.38 to 3.65 mm. The maximum arithmetic mean diameter of 3.65 for Parbhani Jyoti, followed by Parbhani Moti (3.54 mm), and Parbhani Super Moti (3.55 mm) and minimum arithmetic mean diameter was obtained for Parbhani Shakti which was 3.38 mm. Similar trends were reported for sorghum seeds by Sabar *et al.* (2020) [20] and Patekar *et al.* (2017) [24].

3.1.3 Comparision of geometric mean diameter of different sorghum varieties

For the different varieties of raw sorghum, the geometric mean diameters ranged from 3.56 to 3.30 mm. The maximum geometric mean diameter of 3.56 for Parbhani Moti followed by Parbhani Jyoti (3.52 mm), Parbhani Super Moti (3.47 mm), and minimum geometric mean diameter was obtained for Parbhani Shakti which was 3.30 mm. Similar results were reported by Sabar *et al.* (2020) [20], Patekar *et al.* (2017) [24] and Simonyan *et al.* (2007) [22] regarding the geometric mean diameter of sorghum.

3.1.4 Comparision of square mean diameter of different sorghum varieties

For the different varieties of raw sorghum, the square mean diameter ranged from 6.24 to 5.79 mm. The maximum square mean diameter of 6.24 for Parbhani Moti, followed by Parbhani Jyoti (6.22 mm), Parbhani Moti (6.09 mm) and minimum square mean diameter was obtained for Parbhani Shakti which was (5.79 mm). Similar results were reported by (Sabar *et al.* 2020) [20], Patekar *et al.* (2017) [24], for regarding square mean diameter of sorghum.

3.1.5 Comparision of equivalent diameter of different sorghum varieties

For the different varieties of raw sorghum, the equivalent mean diameter ranged from 4.48 to 4.16 mm. The maximum equivalent mean diameter of 4.48 for Parbhani Moti, followed by Parbhani Jyoti (4.46 mm), Parbhani Super Moti (4.37 mm) and minimum equivalent mean diameter was obtained for Parbhani Shakti which was (4.16 mm). Similar results were reported by Sabar *et al.* (2020) [20], Patekar *et al.* (2017) [24], Simonyan *et al.* (2007) [22] for regarding equivalent mean diameter of sorghum.

3.1.6 Comparision of sphericity of different sorghum varieties

For the different varieties of raw sorghum, the sphericity ranged from 0.81 to 0.77. The maximum sphericity of 0.81 for Parbhani Moti, followed by Parbhani Shakti (0.806), Parbhani Super Moti (0.805) and minimum sphericity was obtained for Parbhani Jyoti which was 0.77. Similar results were reported by Sabar *et al.* (2020) [20] regarding shericity of sorghum.

3.1.7 Comparision of aspect ratio of different sorghum varieties

For the different varieties of raw sorghum, the Aspect ratio ranged from 0.875 to 0.906. The maximum aspect ratio of 0.906 for Parbhani Moti, followed by Parbhani Shakti & Jyoti (0.875), Dagadi (0.879) and minimum aspect ratio was obtained for Parbhani Super Moti which was 0.87. Similar results were reported by Adinoyi *et al.* (2017) [14] regarding shericity of sorghum.

3.1.8 Comparision of surface area of single grain of different sorghum varieties

For the different varieties of raw sorghum, the surface area of single grain ranged from (41.25 to 35.71 mm^2). The maximum surface area of single grain of (41.25 mm^2) for Parbhani Moti, followed by Parbhani jyoti (41.17 mm^2), Parbhani Super Moti (39.50 mm^2) and minimum surface area was obtained for Parbhani Shakti which was (35.71 mm^2). Similar results were reported by Adinoyi *et al.* (2017) [14], Kokane *et al.* (2021) [23] regarding shericity of sorghum.

3.1.9 Comparision of volume of single grain of different sorghum varieties

For the different varieties of raw sorghum, the volume of single grain ranged from (24.48 to 19.69 mm^3). The maximum volume of single grain of (24.48 mm^3) for Parbhani Moti, followed by Parbhani Jyoti (24.20 mm^3), Parbhani Super Moti (22.89 mm^3) and minimum volume was obtained for Parbhani Shakti which was (19.69 mm^3). Similar results were reported by (Sabar *et al.* 2020) [20], (Kokane *et al.* 2021) [23] regarding shericity of sorghum.

3.1.10 Comparision of shape factor of different sorghum varieties

For the different varieties of raw sorghum, the shape factor was ranged from 4.51 to 3.89. The maximum shape factor of 4.51 for Parbhani Jyoti followed by Parbhani moti (4.40), Parbhani Super Moti (4.06), Dagadi (3.97 mm) and minimum shape factor was obtained for Parbhani Shakti which was 3.89. Similar results were reported by (Kokane *et al.* 2021) [23], for regarding shericity of sorghum.

3.1.11 Comparision of thousand grain weight of different sorghum varieties

For the different varieties of raw sorghum, the thousand grains weight ranged from (27.56 to 36.10 g). The maximum thousand grain weight of 36.10 g for Parbhani Moti, followed by Parbhani jyoti (33.97g), Parbhani Super Moti (31.61g), Dagadi (30.77g) and Minimum thousand grain weights was obtained for Parbhani Shakti which was 27.56 g. thousand grain weight of Parbhani Shakti variety was found minimum because of its small seed size. Similar result reported (Sabar *et al.* 2020) [20], Patekar *et al.* (2017) [24], Simonyan *et al.* (2007) [22] for thousand grain weight of sorghum.

3.1.12 Comparision of bulk density and true density of different sorghum varieties

For the different varieties of raw sorghum, the bulk density ranged from (700.04 to 769.49 kg/m^3). The maximum bulk density of (769.49 kg/m^3) for Parbhani Moti (769.49 kg/m^3), followed by Parbhani Jyoti (757.70 kg/m^3), Parbhani Super Moti (746.24 kg/m^3) and minimum bulk density was obtained for Parbhani Shakti which was (700.04 kg/m^3).

For the different varieties of raw sorghum, the true density was ranged from (757.70 to 1321.73 kg/m^3). The maximum true density of (1321.73 kg/m^3) for Parbhani jyoti followed by Parbhani Moti (1310.07 kg/m^3), Parbhani Super Moti (1251.33 kg/m^3) and minimum True density was obtained for Parbhani Shakti which was (1219.66 kg/m^3).

For the different varieties of raw sorghum, the porosity was ranged from 0.3839 to 0.4162. The maximum porosity of 0.4267 for Parbhani Jyoti, followed by Parbhani Shakti 0.4260, Parbhani moti (0.4126), Dagadi (0.4098) and minimum porosity was obtained for Parbhani Super Moti (0.3882), which was 0.4098. Similar results were reported by (Sabar *et al*. 2020) [20], Patekar *et al*. (2017) [24], Simonyan *et al*. (2007) [22], Kokane *et al*. (2021) [23] for (bulk, true) density and porosity of sorghum.

3.1.13 Comparision of Angle of repose of for different sorghum varieties

For the different varieties of raw sorghum, the Angle of repose was ranged from 34^0.32’ to 38^{0}80’. The maximum Angle of repose of 38^{0}80' for Parbhani Shakti, followed by Dagadi 36^0.85’, Parbhani Super Moti (35^{0}47') and minimum Angle of repose were obtained for Parbhani moti which was 34^{0}32'. Similar results were reported by Sabar *et al.* (2020) [20], Shashikumar *et al.* (2018) [21], for angle of repose of sorghum.

3.1.14 Comparision of Grain hardness, colour L value, Density of for different sorghum varieties

For the different varieties of raw sorghum, the grain hardness (N) ranged from 68.62N to 116.72N. For the different varieties of raw sorghum, the colour L value ranged from 63.70 to 67.10.

In conclusion, of present study provides a comprehensive basic information about the engineering, frictional and aerodynamic properties of sorghum grain for designing small scale post-harvested machinery especially a sorghum thresher for small scale and marginal farmers which include the angle of repose for designing hopper and feeding chute, and grain size (AMD, GMD, SMD, & EQD) for designing of sieve openings, size of holes and concave clearance.

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