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Engineering properties of sorghum

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Abstract
The engineering properties of sorghum (*Sorghum bicolor* (L.) Moench) were determined at moisture content of 9.15% (wb). The mean values obtained for length, width and thickness were 4.39, 4.20 and 2.64 mm, respectively. The average value for geometric mean diameter, sphericity, weight of thousand grains, bulk density and true density were 3.64 mm, 0.834, 35.16 g, 812.4 kg/m^3 and 1448.39 kg/m^3 respectively. The angle of repose mean value was 35º. The co-efficient of static friction on three types of structural material were found to be 0.20 (steel), 0.0.23 (galvanised iron sheet) and 0.24 (wooden).

Keywords: Sorghum, aerodynamic properties, frictional properties, mechanical properties

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench], a tropical plant belonging to the family of Poaceae, is one of the most important crops in Africa, Asia and Latin America (Anglani, 1998) [2]. Sorghum is a major cereal crop, being grown extensively in tropical and subtropical regions of the world. Sorghum is the world fifth most important cereals and widely grown both for food and as a feed grain production. Roughly 90% of world sorghum area lies in the developing countries. India has the largest share (32.3%) of the world's area under sorghum and ranks second in production after the United State. The sorghum grain production of India in 2017-18 was 4.57 Million metric tonnes from an area of 5.10 Million hectares (Anonymous, 2018) [1].

The vast majority of the population in Africa and Central India is depending on it for their dietary and micro-nutrient requirements. It is an important food crop for a large section of people in Africa and Asia. It ranks third in area and production after rice and wheat. The major sorghum growing areas include Great Plains of North America; sub Saharan Africa, North Eastern China, India, Argentina, Nigeria, Egypt and Mexico. It is the second largest grain crop in India till the green revolution, presently occupies third place among food grains in terms of acreage and production. It is a staple food grain in many Indian states. The recent crop trends in India have indicated that there is a steep decline in sorghum cropped area. However, sorghum continues to be the main staple food for poor and marginal farmers of India. The crop has huge potential and also been identified as one among the climate resilient crops that can adapt quickly under changing climatic conditions.

Knowledge of the engineering properties is important, useful and necessary in the design of processes, machines, structures and controls. These properties are used in analyzing and determining the efficiency of the machine and operation or process as well as determining quality or studying the behavior of the product during agricultural processing unit operations. Basic information on these engineering properties is of great importance and help engineers towards efficient process and equipment development.

The physical properties such as size, shape, surface area, volume, density, porosity, color and appearance are important in designing a particular equipment or determining the behaviour of the product for its handling. It is quite important to have an in depth knowledge of the physical and mechanical properties of oil bean seed which is considered an essential engineering data needed in the design of machine, storage structures, processing and quality control. Design of these equipment without putting these physical and mechanical properties into consideration may yield poor results (Oluka *et al*., 2010).

Basic information on these engineering properties is of great importance and help engineers towards efficient process and equipment development. The engineering properties like size, shape, geometric mean diameter, surface area, volume, sphericity, 1000 seed mass, true density, bulk density, porosity, angle of repose, coefficient of static friction, coefficient of internal friction, hardness and terminal velocity for different millets at different moisture content have been studied and determined by many researchers (Balasubramanian and Vishwanathan, 2010, Singh *et al*., 2010, Ramappa *et al*., 2011) [12, 9].

Materials and Methods

The experiments were carried out at the Department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The local variety of Sorghum (*Rabi* Jowar) was procured from the local market. The important engineering properties studied were: physical properties (Length, width, thickness, geometric mean diameter, sphericity, weight of 1000 grains, bulk and true density), frictional properties (Angle of repose and coefficient of friction) for sorghum.

Determination of Physical Properties

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.

Geometric Mean Diameter: The geometric mean diameter was calculated by using the relationship (Mohesenin, 1986) [6].

Geometric mean diameter, $Dm= [LBT]^{1/3}$

Where, L= longest intercept (Length), B= longest intercept normal to L (Width) and T= longest intercept normal to L and B (Thickness).

Sphericity: The sphericity is used to describe the shape of the grain. The sphericity was calculated using the relationship (Mohesenin, 1986) [6].

Sphericity, $\Phi = Dm/ L$

Where, Dm= Geometric mean diameter and L= longest intercept (Length).

True Density: 50 ml of toluene was taken in a measuring jar. 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) [6]

$$\text{True density, kg/m}^3 = \frac{\text{Weight of grains (kg)}}{\text{Volume of grains excluding void space (m}^3\text{)}}$$

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) [6]

$$\text{Bulk density, kg/m}^3 = \frac{\text{Weight of grains (kg)}}{\text{Volume of berries including pore space (m}^3\text{)}}$$

Porosity: Porosity of sorghum grains was calculated from the bulk density and true density values (that were found earlier) by using the following formula (Mohesenin, 1986) [6]:

$$\text{Porosity, \%} = 1- \frac{\text{Bulk density}}{\text{True density}} \times 100$$

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 were weighed and the mean weight of one thousand grains was calculated.

Frictional Properties:

Co-efficient of friction: Coefficient of friction was determined against three material surfaces namely steel sheet, wooden and galvanised iron sheet by surface method. The static angle of friction was recorded when the grain just began to slide on the test surface (Mohsenin, 1986) [6].

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). 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) = $\tan^{-1}[2H/D]$

Aerodynamic properties: Aerodynamic properties of agricultural products are important and required for design of air conveying systems and the separation equipment (Sahay and Singh, 1994).

Terminal velocity: Terminal velocity is required to decide the velocity of winnowing air blown to separate a lighter material (Sahay and Singh, 1994). Terminal velocity is equal to air velocity at which the particle remains in suspended state in a vertical pipe. In this study, only terminal velocity of sorghum was measured using an air column. For each test, a sample was dropped into the air stream from the top of the air column and air was blown up the column to suspend the material in the air stream. The air velocity near the location of the sample suspension was measured by digital anemometer having a least count of 0.1 m/s (Gharibzahedi *et al*., 2010).

Results and Discussion

The results of the physical properties are presented in Table 1. The mean of individual sorghum length, width and thickness were 4.398, 4.204 and 2.645 mm, respectively. The values of length, width and thickness of the grains varied from 4.17-4.62 mm, 4.12-4.27 mm and 2.57-2.74 mm. The average geometric mean diameter was 3.648 mm and it varied between 3.55-3.71 mm. The projected area of the particle is used for the measurement of the sphericity.

Table 1: Physical Properties of Sorghum

Property	No. of observation	Minimum Value	Maximum Value	Mean	SD	C.V
Moisture content (%wb)	10	9.12	9.25	9.158	0.04196	0.458
Length (mm)	10	4.17	4.62	4.398	0.1426	0.0324
Width (mm)	10	4.12	4.27	4.204	0.0568	0.0135
Thickness (mm)	10	2.57	2.74	2.645	0.0643	0.0243
Geometric mean diameter (Dm)	10	3.55	3.717	3.648	0.0573	1.573

Sherisity ϕ	10	0.80	0.85	0.834	0.01642	1.968
True Density (kg/m^3)	10	1433.42	1460.42	1448.39	8.1054	0.560
Bulk Density (kg/m^3)	10	808.32	817.3	812.4	2.7166	0.334
Weight of 1000 grains(g)	10	35.10	35.22	35.163	0.030	0.001

The sphericity values observed were in the range of 0.80-0.85 and the mean sphericity value is 0.834. The average thousand-grain weight of sorghum was 35.163 g. The bulk density and true density were in the range 808.32-817.3 kg/m^3 and 1433.42-1460.42 kg/m^3 respectively. The mean of bulk density and true density were 812.4 kg/m^3 and 1448.396 kg/m^3 respectively.

The results of frictional properties are shown in Table 2. The mean value of angle of repose of millet was 27.1°. The angle of repose is important for determining the maximum angle of a pile of grain in the horizontal plane, and is important in the filling of a flat storage facility. The average values of static coefficient of friction against steel and galvanized iron sheet and wooden plate were 0.20, 0.238 and 0.24 respectively.

Table 2: Frictional Properties of Sorghum

Property	No. of observation	Minimum Value	Maximum Value	Mean Value	Std Deviation	C.V
Angle of Repose	10	24.6	29.6	27.1	1.05	0.022
Static coefficient of sorghum						
Steel	10	0.16	0.25	0.2	0.029	0.145
GI	10	0.22	0.26	0.238	0.012	0.052
Wooden	10	0.22	0.26	0.24	0.013	0.056

The aerodynamic property measured was ranging from 3.37 to 3.73 m/s. The mean value was 3.54 m/s (Table 3).

Table 3: Aerodynamic Property of Sorghum

No. of observations	Minimum Value	Maximum Value	Mean Value	Std Deviation	C.V
10	3.37	3.73	3.54	0.12961481	0.037

Conclusion

The engineering properties of sorghum were measured at 9.12% (w.b). The mean of individual sorghum length, width and thickness were 4.398, 4.204 and 2.645 mm, respectively. The average value for geometric mean diameter, sphericity, thousand grain weight, bulk density and true density were 3.648 mm, 0.834, 35.163 g, 812.4 kg/m^3 and 1448.396 kg/m^3 respectively. The mean value of angle of repose of millet was 27.1°. The average values of static coefficient of friction against steel and galvanized iron sheet and wooden plate were 0.20, 0.238 and 0.24 respectively. The mean value of aerodynamic property was found 3.54 m/s. These properties can be used for design of equipment for handling and processing of the sorghum.

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