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Engineering Properties of Finger Millet (Eleusine coracana L.) Grains

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Abstract: ***Some physical properties of finger millet (Eleusine coracana) grains were determined at the moisture content of 13.43 per cent (w.b.). The size, sphericity, surface area, geometric mean diameter, test weight of grains, true density, bulk density and porosity were 1.672 mm, 0.95, 8.02 mm^2 , 1.60 mm, 2.91 g, 1.1561 g/ml , 0.8604 g/ml , and 25.49 %, respectively. The frictional properties of the finger millet grains viz., angle of repose, coefficient of static friction using different surfaces were also determined and the values were 25.25^o, 0.413(mild steel), 0.3713 (galvanized iron), 0.2899 (stainless steel) and 0.241(Perspex), respectively. The terminal velocity of the grains was 2.94 m/s.***

Keywords: Finger millet, Physical properties, size, shape, sphericity, Bulk density, True density

1. Introduction

Millets are a group of highly variable Small-seeded grasses, widely grown around the world as cereal crops or grains for human food and as fodder. Millets are important crops in the semi-arid tropics of Asia and Africa with 97% of millet production in developing countries. The production of millets in India during 2018 was about 11640000 tonnes in 9107000 hectares (FAO, 2018). Millet is the oldest human foods and believed to be the first domesticated cereal grains, cultivated over 7000 years ago. Millets belongs to the Poaceae (the grasses) family. Millet crops include Pearl millet, foxtail millet, kodo millet, little millet, proso millet, barnyard millet, finger millet, etc.

Ragi (*Eleusine coracana* L.) is also called finger millet and is widely cultivated in tropical and sub-tropical regions of India and Africa. Finger millet was introduced in India by the sea traders around 3000 B.C. Finger millet is one of the resilient crop, which is known for its drought tolerance, salanity and blast disease. Among the millets of the world, finger millet (Eleusine coracona) ranks fourth, after pearl millet (Pennisetum americanum L.), foxtail millet (Setaria italica), and proso millet (Panicum miliaceum) (Gupta, et al., 1989). Finger millet is the most widely grown small millet in the world. Finger millet, also known as ragi in India (Hulse et al., 1980) is a highly tillering annual grass, whose average height is a little over 1.0 m, but can reach as high as 1.6 m. The colour of grains may vary from white through orange red, deep brown, purple to almost black.

Physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in these processes involve knowledge of their physical and engineering properties (Irtawange, 2000). Bulk density, true density, and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies (Ghasemi et al., 2008). Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper wall's inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by gravity. The coefficient of static friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute.

2. Material and Methods

The raw material i.e. Finger Millet (Ragi), 'Vakula-PPR2700' variety was procured from Agricultural farm, Bapatla. Andhra Pradesh. The grains were cleaned manually to remove all foreign material like dust, dirt and stones etc., before conducting the experiments. The initial moisture content of grains was determined as per the method suggested by AOAC, 2000.The moisture content of sample was determined by hot air oven method. The samples were placed in a hot air oven maintained at 105° C for 3 hours. After taking out from the oven, the samples were cooled in desiccator and weighed. The average moisture content of the samples on wet basis was calculated using the following equation:

$$\text{Moisture content on wet basis (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,
W1 = Weight of sample before drying, g

W2 = Weight of sample after drying, g

The size (length, width and thickness) of randomly selected 50 grains was measured using a digital vernier calipers having the least count of 0.01 mm.

The sphericity (Φ) of Finger millet grains was calculated by using the following equation (Mohasenin, 1986).

$$\Phi = \frac{(LwT)^{\frac{1}{3}}}{L} \quad \ldots\ldots 3.1$$

Where,
L = Length of the grains
W = Width of the grains
T = Thickness of grains

The Geometrical mean diameter of Ragi was calculated by measuring their linear dimensions of randomly selected grains, using digital Vernier calipers with a least count 0.01 mm.

The GMD was calculated by using the following formula (Mohasenin, 1986).

$$Dg = (L \times W \times T)^{1/3} \quad \ldots\ldots 3.2$$

The surface area of finger millet was calculated using the following formula (Mohasenin, 1986).

$$\text{Surface area, } S = \pi D_g^2 \quad \ldots\ldots 3.3$$

Where,
Dg is the geometrical mean diameter.

For determination of test weight of grains, thousand ragi seeds, unbroken and sound grains, from three randomly drawn samples were hand counted and weighed using a digital balance (HTR-220E, Essae-Teraoka Pvt. Ltd., Bangalore), of accuracy 0.0001 g and their average weights were recorded. The mean values was reported.

The bulk density (BD) was determined by using measuring cylinder of volume 1000 ml. The finger millet grains were filled into the measuring cylinder and the top of the cylinder was levelled off. The grains were then weighed using a digital electronic balance. The bulk density of Ragi grains was calculated using the following formula:

$$Bulk\ density\ \left(\frac{g}{mL}\right) = \frac{Weight\ of\ grains, g}{Volume\ of\ grains\ including\ void\ space, mL} \quad \ldots\ldots 3.4$$

The apparatus used for measuring true density of grains consisted of 250 ml jar and digital weighing balance. 100 ml of toluene was taken in to the measuring cylinder and a known weight of grain sample was poured into the measuring cylinder. The displacement of the toluene level was recorded as the true volume of the grains without void space. The true density was measured using the following formula (Mohasenin, 1986).

$$True\ density\ \left(\frac{g}{ml}\right) = \frac{Weight\ of\ grains, g}{true\ Volume\ of\ grains\ without\ void\ space, ml} \quad \ldots\ldots 3.5$$

Porosity of grains was calculated by using the following formula:

$$\%\ Porosity = \left(1 - \frac{Bulk\ Density}{True\ Density}\right) \times 100 \quad \ldots\ldots 3.6$$

Angle of repose is important in designing a structure for storage of food grains in bulk. When a granular material is allowed to flow freely from a point into a pile, the angle which the side of the pile makes with horizontal plane is called angle of repose. (IS: 6663-1972) It is influenced by size, shape, moisture content and orientation of the particles. Angle of repose of grains was calculated using an apparatus consists of a circular platform immersed in a box filled grains. The equipment is supported by three legs and is surrounded by a metal funnel leading to a discharge hole. The grain are allowed to escape from the box.

The angle of repose,ϕ, is calculated by using the following formula:

$$\phi = \tan^{-1}\left(\frac{2H}{D}\right) \quad \ldots\ldots 3.7$$

Where,
Φ= Angle of repose, degrees
H= Height of the ragi pile formed, mm
D= Diameter of the circular disc, mm

Coefficient of static friction on three different surfaces, namely mild steel, Galvanised iron, Perspex and stainless steel, was measured by the inclined plane method (Singh and Goswami, 1996). Grains were kept on an adjustable tilting plate and the slope was increased gradually. The angle at which the material just started to move downward was recorded (α). Coefficient of static friction was calculated from the following relationship.

$$\mu = \tan \alpha \quad \ldots\ldots 3.8$$

Where,

μ= Coefficient of static friction
α= Angle of tilt, degrees

Air is used as a carrier in handling and processing of agricultural products for transport or for separating the desirable product from the unwanted materials. Terminal velocity plays a vital role in design of pneumatic systems.

The wind tunnel consists of a 0.25 hp centrifugal blower, plenum chamber, vertical Perspex tube, air flow control ring and inlet pipe. The vertical Perspex tube of 923 mm length of 40 mm internal diameter was fixed at the top of the plenum chamber with the help of three screws and a height of 500 mm was marked on the tube. At the top of the vertical tube, the opening was closed with Perspex sheet and covered with air control ring which was graduated around its periphery. The ring opening was closed upto 23 mm with Perspex sheet. By operating the ring, the air flow rate in the tube was controlled. The air velocity is measured using a digital anemometer at top end of a Perspex tube.

3. Results and Discussions

The lateral diameter and longitudinal diameters of Ragi sample of 50 grains were selected and measured. Sphericity, geometrical mean diameter and surface area were calculated and presented in **Table**. It was observed that the mean and standard deviation values of ragi grains for lateral and longitudinal diameters, GMD, sphericity and surface area are found to be 1.5736 ± 0.09 mm, 1.6726 ± 0.0799 mm, 1.5736 ± 0.097 mm, 1.568 ± 0.10 mm, 1.5959 ± 0.08 mm, 0.9511 ± 0.02 and 8.0156 ± 0.7941 mm^2 , respectively. These findings of the grains make a distinct role for the suitable design and development of crop-processing machines such as sorting, grading, grinding, drying and extraction equipments (Mahbobeh et al., 2011).

The frictional properties helps in the designing of storage structures like bins, godowns etc. The mean values of frictional properties of the millets like angle of repose, coefficient of static friction were calculated and found to be 25.49 ^{o}, 0.413(mild steel), 0.3713 (galvanized iron), 0.2899 (stainless steel) and 0.241(Perspex), respectively. The frictional properties such as the angle of repose and the coefficient of static friction are recognized by engineers as important properties concerned with rational design of seed bins and other storage structures including the compressibility and flow behaviour of materials (Mirzaee et al., 2009; Gharibzahedi et al., 2010). The average terminal velocity of finger millet required for suspending the grains was 2.94 ms^{-1}. This result is in accordance with Singh et al. (2010) for barnyard millet. This data of terminal velocity can be used in designing an aspiration unit. The millets are gaining the tremendous demand in the production of value added products. Hence, the technical data obtained in this study may be useful in the design of machines for handling and processing of finger millet grains (Mahbobeh et al., 2011).

Physical properties	Units	No. of observations	Mean value	Maximum	Minimum	Std. dev
Moisture content	%	10	13.43	13.88	13.02	0.33
Diameter	Mm	50	1.672	1.79	1.38	0.079
Sphericity	%	50	0.95	0.99	0.901	0.02
Surface area	mm^2	50	8.02	9.614	5.103	0.7941
Geometric mean diameter of grains	mm^3	10	1.60	1.749	1.274	0.08
True density	g/ml	10	1.1561	1.2048	1.0989	0.0445
Bulk density	g/ml	10	0.8604	0.868	0.855	0.0054
Porosity	%	10	25.49	29.035	22.013	2.8216
Test weight of grains	G	10	2.9108	2.991	2.786	0.0738

Frictional properties	Units	No.of observations	Mean value	Maximum	Minimum	Std. dev
Angle of repose	Degrees	5	25.259	26.565	23.749	1.070
Coefficient of static friction		10				
Terminal velocity	m/s	10				

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