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Original Article

ENGINEERING PROPERTIES OF FOXTAIL MILLET GRAINS

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ABSTRACT

Design and development of post-harvest machinery needs information about various engineering properties. The present study focused to measure various engineering properties such as length, breath, thickness, geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, Length-breath ratio, sphericity, 1000 kernel mass, bulk density, true density, porosity, angle of repose, coefficient of static friction, coefficient of internal friction, hardness and terminal velocity of foxtail millet using standard methods. Raw foxtail millets after procured from local market was cleaned to remove dust and impurities. The engineering properties of foxtail millet was recorded at 10.9 % moisture (% db). The results of the study revealed that, the length, width and thickness of foxtail millet was found to be 1.878 ± 0.084, 1.467 ± 0.041 and 1.258 ± 0.061 mm respectively. Arithmetic mean diameter, geometric mean diameter and equivalent mean diameter of foxtail millet was found to be 1.534 ± 0.055, 1.513 ± 0.054, 1.516 ± 0.053 mm respectively. The sphericity, L/W ratio, thousand grain weight, terminal velocity and hardness of foxtail millet grains was found to be 0.806 ± 0.016, 1.28 ± 0.29, 3.126 ± 0.11 g, 3.82 ± 0.08 m/s and 22.383 N respectively. The bulk density, true density and porosity of foxtail millet was found to be 701.2 ± 16.27 (kg/m^3), 1385.2 ± 6.98 (kg/m^3) and 49.376 ± 1.33 % respectively. The frictional properties of foxtail millet were found to be angle of repose (29.66 ± 0.62 degree), coefficient static friction with mild steel (0.288 ± 0.02) and cast iron (0.31 ± 0.02) and coefficient of internal friction with mild steel (0.47 ± 0.03) and cast iron (0.512 ± 0.03). These engineering properties further will be used for development of pneumatic type millet dehuller.

KEYWORDS: Foxtail Millet, Terminal Velocity, Hardness, Length, Breath And Thickness.

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1. INTRODUCTION

A variety of small-seeded grasses known as millets are commonly cultivated as cereal crops and grains all over the globe. These are significant crops in Asia and Africa's semi-arid tropical regions, particularly in India and Nigeria. The millet crop is preferred because to its high productivity and short growing season, which, depending on the millet type, may be harvested in as few as 65 days in dry and hot circumstances. The majority of the time, millets crops are cultivated in rainfed settings in low-rainfall regions since ordinary cereals cannot withstand the dry agricultural conditions there (Amadou et al. 2014). Additionally, millets may thrive in less rich soils and are drought-tolerant crops (Amadou, Gounga, & Le, 2013; Geetha, Mishra, & Srivastav, 2014). (Geervani & Eggum, 1989). As a result, these millet crops became more crucial for food security and sustainable agriculture.

Major millets and small millets are the two primary categories into which millets fall. This division is mostly based on millet grain size. As of late, the categorization also indicates the area used for these crops' production. Other millets, such as foxtail millet, finger millet, barnyard millet, proso millet, kodo millet, and small millets, are classified as minor millets. Sorghum and pearl millet are major millets.

The most popular millet crops in India are sorghum and pearl millet. In that order, India grows finger millet, small millet, kodo millet, foxtail millet, barnyard millet, and proso millets, which are all significant crop species. Despite the fact that little millets are cultivated in practically every state and area of India, the distribution of each kind of millet varies. In Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Orissa, Bihar, Madhya Pradesh, and Maharashtra, the millets kodo, little, and foxtail are cultivated extensively. Kodo and small millet are both common in Madhya Pradesh, whereas foxtail millet is significant in Telangana, Andhra Pradesh, and Karnataka. Proso millet and barnyard millet are mostly farmed in the plains of North Bihar, Western Uttar Pradesh, Maharashtra, and the hills of Uttarakhand, Uttar Pradesh, and the North-Eastern area.

When taken, micronutrients like vitamins and minerals from millets have a significant positive impact on one's health. It is well acknowledged that among the people who use these grains as a staple meal, the prevalence of diabetes mellitus and illnesses connected to the gastrointestinal system is quite low. A significant portion of the population is made up of gluten intolerant (celiac) individuals who are sensitive to gliadin, a prolamin unique to wheat and several other popular cereals. Millets are devoid of gluten, making them potential dietary cereals.

One of the minor millets, foxtail millet (Setaria italica L.), is said to have originated in China around 8000 years ago (Lu et al., 2009; Zhang & Liu, 2015). Due to its short growth season and minimal rainfall needs, it is particularly well-liked in Japan, Bangladesh, and India (Pawar & Machewad, 2006). Foxtail millets are renowned for having a long storage time and for being pest-resistant while being stored (Anju & Sarita, 2010). In terms of the overall output of millets worldwide, foxtail millet comes in second. Additionally, the foxtail millet grains come in a range of hues from light yellow, red, and brown to black (FAO, 1995). Conversely, it was discovered that foxtail millet lowers the risk of type 2 diabetes, cardiovascular disease, and atherosclerosis (Choi et al., 2005). The husk part of millets must be removed from the millet grains in order to produce edible food items from them. Dehulling operation refers to the process of removing the millet husk. Additionally, the bran component contains a lot of oil, and owing to long-term storage, the grain's and flour's quality diminishes as a result of rancidity. Additionally, the quantity of antinutritional material in bran is much higher than that in endosperm. Therefore, removing the bran from millets helps to increase the digestion of millet grains or flours as well as their storage stability. The process of polishing brown millet involves removing the bran.

On the other hand, engineering characteristics of grains are quite important when constructing any apparatus for post-harvest processing. Creating hoppers will benefit from angle of repose, designing screens or separating equipment will benefit from dimensional qualities, and conveying and dehulling equipment will benefit from frictional and terminal velocities, among other features.

2. MATERIAL AND METHODS

2.1 Sample Preparation

Following the acquisition of the foxtail millets, the grain sample underwent a thorough cleaning to get rid of dirt, rocks, dried straws, and any other foreign objects or contaminants. Using the hot air oven technique, the original moisture content of cleaned foxtail millet was calculated, and it was discovered to be 10.90.5%. (w.b). In order to prevent moisture exchange and insect infestation from the environment, these cleaned grains were packed in polythene bags and kept in an airtight environment in the refrigerator.

2.2 Measurement of Moisture Content

With a few minor adjustments, the hot air oven technique was used to measure the moisture content of the grains in accordance with the Association of Official Analytical Chemists' (1995) approved practices. A 5 g sample was ground and stored in an oven set at 105°C for around 24 hours. The grains were taken out of the oven after 24 hours, let to cool in a desiccator, and then weighed. Based on the discrepancies between beginning weight and final weight, the loss in grain weight was calculated. Using the following equation, the moisture content of wet basis (w.b.) was determined.

Moisture content (% w.b) = $\frac{W_2 - W_3}{W_2 - W_1}$ x 100

Where:

W1 = weight of empty crucible (g)

W2 = weight of crucible + grain before drying (g)

W3 = weight of crucible + grain after drying (g)

2.3 Dimensional Properties

Thirty foxtail grains in total were chosen at random, and the length (major axis), width (intermediate axis), and thickness (minor axis) of each were measured using a vernier calliper, with a minimum count of 0.01 mm.

2.4 Geometric Mean Diameter

The measured length, breadth, and thickness of foxtail millet samples were used to estimate the geometric mean diameter (mm) using following equation (Mohsenin, 1986).

Geometric mean diameter (GMD) = $(L \times W \times T)^{1/3}$

Where:

L = Major principal axis, length (mm)

W = Intermediate principal axis, width (mm)

T = Minor principal axis, Thickness (mm)

2.5 Arithmetic Mean Diameter

The arithmetic mean diameter (mm) of foxtail millet samples was calculated based on the measured measurements of length, breadth, and thickness (Mohsenin, 1986).

$$\text{Arithmetic mean diameter (AMD)} = \frac{(L + W + T)}{3}$$

Where:

L = Major principal axis, length (mm)

W = Intermediate principal axis, width (mm)

T = Minor principal axis, Thickness (mm)

2.6 Equivalent Mean Diameter

The equivalent mean diameter (mm) of foxtail millet samples was calculated based on the measured length, breadth, and thickness of the samples.

$$\text{Equivalent mean diameter (EMD)} = \sqrt[3]{\frac{L*(W+T)^2}{4}}$$

Where:

L = Major principal axis, length (mm)

W = Intermediate principal axis, width (mm)

T = Minor principal axis, Thickness (mm)

2.7 Sphericity

The following equation was used to calculate sphericity based on the observed length, breadth, and thickness of foxtail millet samples (Mohsenin, 1986).

$$\text{Sphericity} = \frac{D_g}{L} = \frac{(L*W*T)^{\frac{1}{3}}}{L}$$

Where:

L = Major principal axis, length (mm)

W = Intermediate principal axis, width (mm)

T = Minor principal axis, Thickness (mm)

2.8 Bulk Density

The mass of the sample divided by the volume of the sample is known as bulk density (kg/m3) (Vanrnamkhasti et al., 2008). It was calculated by gently tapping foxtail grains into a 500 mL measuring cylinder to fill it, then using an electric weighing balance to estimate the weight of the grains (0.01g accuracy). Using the following equation, the foxtail millet grains' bulk density was determined.

$$\text{Bulk density } (\frac{\text{kg}}{m^3}) = \frac{Sample\ weight\ (kg)}{Volume\ (m^3)}$$

2.9 True Density

Using a top loading balance and the liquid displacement technique, the true density (kg/m3) was calculated. Five grammes (g) of foxtail millet seeds were added to a graduated beaker of toluene. Utilizing, the displacement of toluene was measured. Equation was used to calculate the actual density of the foxtail grains (Karababa and Cokuner, 2013).

$$True\ density\left(\frac{kg}{m^3}\right)=\frac{Weight\ of\ the\ grain\ taken\ for\ analysis\ (kg)}{Change\ in\ volume\ of\ toulene\ due\ to\ addition\ of\ grains}$$

2.10 Porosity

Porosity (%) is defined as the fraction of the space in bulk grain that is not occupied by the grain (Sangamithra *et al*., 2016). It was calculated using following equation

$$\text{Porosity (\%)} = (\frac{\rho_b - \rho_t}{\rho_b}) * 100$$

Where,

$\rho_{b-Bulk\ density}\left(\frac{kg}{m^3}\right)$

$\rho_{t-True\ density}\left(\frac{kg}{m^3}\right)$

2.11 Thousand Grain Mass

Approximately 1 kg of foxtail millets were divided into five groups. 100 grains were randomly picked from each group and weight of the grains measured with analytical type precision balance (0.01 g).

2.12 Terminal Velocity

The air speed at which grain stays hung in a vertical pipe is known as terminal velocity. The development of separation and conveying equipment heavily depends on the terminal velocity. The current work was aiming to build pneumatic type millet dehuller where the terminal velocity is beneficial for sustaining the input air velocity. The terminal velocity apparatus, which is a vertical, clear acrylic pipe linked to a blower, was used to measure the terminal apparatus. The blower speed was controlled by a regulator. Adequate number of foxtail millet grains was inserted in acrylic tube and air velocity (using blower) was maintained in such a manner that the 90% of grain hang in air. Terminal velocity, which was determined using an anemometer, is the speed at which 90% of the material is hung.

2.13 Grain Hardness

Hardness of grains plays important role in calculating force required for performing dehulling or polishing operation. The hardness of foxtail millet was measured using hardness tester as shown in

2.14 Angle of Repose

When building hoppers for different post-harvest machines, angle of repose is crucial. Using angle of repose equipment, the angle of repose of foxtail millets was measured. The foxtail grains were liberally poured into the apparatus's circular part, where they were permitted to stand on a platform with a steep angle. Equation was used to determine the foxtail millet's angle of repose (Sreenarayanan et al., 1988).

$\theta = \tan^{-1}(h/r)$

Where

θ - angle of repose, degree.

h - heightoftheheap, cm.

r - radiusoftheplatform,cm.

2.15 Coefficient of Static Friction

While moving within the machine, the materials come into contact with the metal bodies' surface. It is crucial to research the coefficient of static friction in order to understand how it affects machine design (Stewart et al., 1969). A loading pan, pulley, thread, and open-ended sample storage container were utilised in an experimental setup to measure the coefficient of static friction between the foxtail millet grains and the surface. Once the sample holder began to move beyond the static friction created by the foxtail millet grains and the sheet surface, the static frictional force was measured. The foxtail millet grains were placed into the sample holder (Ns), and incremental weight was added to the loading pan (Fs). Different test surfaces made of mild steel and cast iron were used in the experiment. The following equation was used to compute the coefficient of static friction (s) (Sreenarayanan et al., 1988).

$$\mu_s = \frac{F_s}{N_s}$$

Where

μ_s - Coefficient of static friction, dimensionless

F_s - Frictional force for static friction, g

N_s - Normal force for static friction, g

2.16 Coefficient of internal friction

Using a horizontally split cylinder as the measuring tool, the coefficient of internal friction was measured (Thajudhin Sheriff, 1996). The top half was detachable and the bottom piece was permanent; they were joined by a loading pan. In order to calculate the force (Ni) needed to slide the minor millet grains contained in the top section of the cylinder against the minor millet grains in the bottom cylinder, foxtail millet grains were poured into the cylinder without being compacted. The equation presented by Sreenarayanan et al. (1988) and Thompson et al. allowed for the determination of the internal frictional coefficient I (1983).

$$\mu_i = \frac{F_i}{N_i}$$

Where,

μ_i = Coefficient of internal friction

F_i = Frictional force (g)

N_i = Normal force (g)

3. RESULTS AND DISCUSSION

When constructing post-harvest equipment, engineering features are crucial. During this study, the engineering characteristics of foxtail millet were measured, including length (mm), width (mm), thickness (mm), arithmetic, geometric, and equivalent mean diameters; sphericity; L/W ratio; hardness; 1000 grain weight; bulk, true, and porosity densities; angle of repose; angle of internal friction; coefficient of static friction; and terminal velocity. Table 1 summarizes the findings of 30 randomly chosen foxtail grains (moisture content 10.9 0.1% w.) from five randomly separated groups. The findings showed that foxtail millet had dimensions of 1.878 mm in length, 1.467 mm in breadth, and 1.258 mm in thickness, respectively. It was discovered that the foxtail millet's arithmetic mean diameter, geometric mean diameter, and equivalent mean diameter were each 1.534 0.055, 1.513 0.054, and 1.516 0.053 mm. It was discovered that the foxtail millet grains' sphericity, L/W ratio, thousand grain weight, terminal velocity, and hardness were each 0.806 0.016, 1.28 0.29, 3.126 0.11 g, 3.82 0.08 m/s, and 22.383 N, respectively. Foxtail millet has been discovered to have the following densities: 701.2 16.27 kg/m3, 1385.2 6.98 kg/m3, and 49.376 1.33 %, respectively. The angle of repose, coefficient of static friction with mild steel (0.288 0.02) and cast iron (0.31) 0.02, and coefficient of internal friction with mild steel (0.47) 0.03 and cast iron (0.512 0.03) were all determined for foxtail millet. The findings from this research are consistent with those from Balasubramanian et al. (2010), Subramanian et al. (2003), and Subramanian et al. (2007). The cultivar of foxtail millet utilized in various research may account for the modest difference in engineering qualities of foxtail millet between this study's findings and those published in the literature

Table 1: Engineering Properties of Foxtail Millets at 10.9±0.1 (% w.b)

S.No.	Parameter	Value
1	Length (mm)	1.878±0.084[a]
2	Width (mm)	1.467±0.041[a]
3	Thickness (mm)	1.258±0.061[a]
4	Arithmetic mean diameter (mm)	1.534±0.055[a]
5	Geometric mean diameter (mm)	1.513±0.054[a]
6	Equivalent mean diameter (mm)	1.516±0.053[a]
7	Sphericity	0.806±0.016[a]
8	Length/width ratio	1.280±0.29[a]
9	1000 grain weight (g)	3.126±0.11[b]
10	Bulk density (kg/m^3)	701.2±16.27[b]
11	True density (kg/m^3)	1385.2±6.98[b]
12	Porosity (%)	49.376±1.33[b]
13	Angle of repose (degree)	29.66±0.62[b]
14	Coefficient of static friction	
	Mild steel	0.288±0.02[b]
	Cast iron	0.31±0.02[b]
15	Coefficient of internal friction	
	Mild steel	0.47±0.03[b]
	Cast iron	0.512±0.03[b]
16	Hardness (N)	22.383±1.339[a]
17	Terminal velocity (m/s)	3.82±0.08[b]

Values represented as Mean ± Standard deviation (Superscripts: a- sample size 30; b- sample groups 5)

CONCLUSIONS

Engineering properties plays an important role in designing post-harvest machinery for agriculture produce. The study was aimed to measure the various engineering properties of foxtail millets. The study reported the engineering properties of the foxtail millet grains. The engineering properties further can be used for designing any post-harvest machinery for foxtail millets.

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