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# Engineering Properties of Finger Millet

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***Abstract:*** Engineering properties of grain play a vital role in designing crop production, material handling and processing equipment. A study was conducted to determine the engineering properties of finger millet at different moisture content in the range of 6.0 - 17.5% (w.b.). In this moisture range, the sphericity of finger millet increased while bulk density, true density and porosity decreased with an increase in moisture content. The values for sphericity, angle of repose & porosity for finger millet varied from 0.540 to 0.668, 21.344 to 23.517 degrees, and 40.4 to 37.4 respectively. The angle of repose also increased with an increase in moisture content. Bulk density and true density for finger millet varied from 795 kg/m$^3$ to 755 kg/m$^3$.

***Keywords****:* Engineering properties, Finger millet, moisture content, surface area, volume, true density, bulk density, porosity, angle of repose, sphericity

## INTRODUCTION

Millets are a species of small-seeded grasses in the family Poaceae. The word Millet has been taken from the French word "Mille". The word "Mille" means "thousand", meaning that a handful of millet can hold up to a thousand grains (Rao et al., 2022). It is also known as "Nutri- Cereals" one of the traditional grains that have been used for food, animal feed and fodder. It is mostly consumed as a staple food in the arid part of tropical Africa, particularly in the semi-arid region of West Africa (Purseglove, 1988) Millet is the sixth cereal crop in terms of world agriculture production.

The 21$^{st}$ Century brought many challenges like climate change, water scarcity, increasing world population, rising food prices, and other socioeconomic impacts. These are expected to greatly threaten agriculture and food security worldwide, especially for the poorest people in arid and sub-arid regions (Saleh et al., 2013). Hence there is a need for alternative nutritive food sources and Millet is one of that alternative food sources. Millet has some unique properties, making it a "future Crop". It is favoured due to its productivity and short growing season under dry, high-temperature conditions. It can survive even in areas with less seasonal rainfall as 300 mm. Finger Millet is also known by the name "Ragi". It is widely cultivated in India and Africa's tropical and sub-tropical regions. It is known for its drought tolerance, salinity and blast disease. The most grown small millet in the world is finger millet.

Engineering properties of small millets will provide important and essential data in the design of machines, structures, processes and controls in analysing and determining the efficiency of a machine. These are also required in developing a new product or in evaluating the quality of the final product. This basic information should be viable not only to engineers but also to food scientists because they can exploit these properties to find new uses (Balasubramanian et al., 2014). It is also important to know how these properties are affected by the moisture content of the grain. Thus, keeping in this view a study

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was focused on determining the engineering properties of finger millet as affected by moisture content of the millet grains.

## MATERIALS AND METHODS

The experiments were carried out to study the engineering properties of millet at the Department of Processing and food engineering, college of Agricultural Engineering and Technology, RPCAU, Samastipur, Bihar. The grains of finger and foxtail millets were procured from the Small Millet Storage, TCA, Dholi and were developed at the University (RPCAU, Pusa). The measurement of different engineering properties of these millets such as size, sphericity, geometric mean diameter, surface area, bulk density, true density, porosity, angle of repose and coefficient of friction are described as follows:

### Determination of Moisture Content

The moisture content of finger millet was determined by the standard oven dry method by placing about 10 g of the sample at 100 ±2°C for 24 h. The moisture content on a wet basis (w.b.) was determined by using the following formula (Singh and Sahay, 2001),

$$\text{Moisture content (w.b.)} = \frac{W_d}{W_i} \quad (1)$$

Where, $W_d$ is the drop in weight of the sample (Initial weight – final weight), g

$W_i$ is the initial weight of the sample, g

### 1. Determination of Physical Properties

#### 1. *Sphericity*

The Sphericity of Finger was determined with the help of projection of grain and by using the following relationship (Singh and Sahay, 2001),

$$\text{Sphericity } (\phi) = \frac{D_i}{D_c} \quad (2)$$

Where,

$D_i$ is the diameter of the largest inscribing circle, mm

$D_c$ is the diameter of the smallest circumscribing circle, mm

#### 2. *Bulk Density*

The bulk density was determined by using a 100 mL graduated cylinder and weighing balance. The glass cylinder was weighed, then filled with the grain up to 100 mL and measured the weight grain occupied. The experiment was repeated thrice for each millet and the average value was recorded. The following expression was used to determine the bulk density for finger and foxtail millet (Mohesenin, 1986),

$$\text{Bulk density} \left(\rho_b\right) = \frac{w}{v_t} \quad (3)$$

Where,

W is the weight of the sample poured into the graduated cylinder, g

$V_t$ is the volume of the sample with the void space, mL

$\rho_b$ is the bulk density, g/mL

#### 3. *True Density*

The true density was measured by using the water displacement method but in this method, toluene was used in place of water. The following relationship was used to determine the true density of the millet (Mohesenin, 1986),

$$\text{True density } \left(\rho_t\right) = \frac{w}{v}$$

Where,

W is the weight of the sample, g

V is the true volume of the sample, mL

$\rho_t$ is the true density, g/mL

#### 4. *Porosity*

It is generally expressed in percentages. The porosity of millet was determined using the parameters like bulk density and true density. The following relationship was used to calculate the porosity of the millet as mentioned by Mohesinen (1986)-

$$Porosity\ (\epsilon) = \left[1 - \frac{\rho_b}{\rho_t}\right] \times 100 \quad (5)$$

Where, $\rho_b$ is the bulk density, g/mL

$\rho_t$ is the true density, g/mL

## 2. Determination of frictional properties

### 1. *Angle of Repose*

Angle of repose is the angle between the base and slope of the cone formed on a free vertical fall of grain onto a horizontal plane. The apparatus that is used to determine the angle of repose was a beaker of 250 mL and scale. The Angle of repose was determined by measuring the height and average diameter of that heap which is formed by the free vertical fall of the grain. The angle of repose for finger and foxtail millet was calculated by using the following formula (Singh and Sahay, 2001),

$$\text{Angle of Repose } (\Theta) = tan^{-1}\, 2H/D \qquad (6)$$

Where,

H is the height of the heap formed by the free vertical falling of grains, cm

D is the average diameter of the heap formed by free vertical falling of grains, cm

Φ is the angle of repose, radian.

### 2. *Coefficient of Friction*

The coefficient of friction was measured against the five material surfaces namely cardboard, ply, rubber, steel, and wood. It was determined by the surface method. The experiments were repeated at least three times to obtain an average value. The following formula was used to determine the coefficient of friction of finger millet (shivabasappa et al., 2012),

$$\text{Coefficient of friction } (\mu) = (W_2/W_1) \qquad (7)$$

Where,

$W_1$ is the weight of the box filled with the sample, g

$W_2$ is the weight to cause the sliding of the filled box, g

## RESULTS AND DISCUSSION

### 1. Physical Properties of Finger Millet

The physical and frictional properties of finger millets were determined at different moisture contents ranging from 7.8% to 17.2% shown in Tables 1 & 2, respectively. The sphericity of finger millet varied from 0.540 to 0.668, respectively shown in Table-1. The sphericity of finger millet increases linearly with an increase in moisture content from 7.8% to 13.2%, after that there is a gentle decrease with an increase in moisture content. Swami and Swami, 2010 have obtained a similar trend of sphericity for finger millet.

The bulk density decreased from 795 to 755 kg/m$^3$ with the increase in moisture content and the porosity and true density of finger millet were also found to be decreased with the increase in moisture content (shown in table-1). This indicates that there is a higher grain volume increase (increase in intergranular space) in comparison to its mass. True density's minimum and maximum values were 1333 and 1208 kg/m$^3$. The Porosity of Finger Millet ranged from 36.0 % to 40.4 %. The plotted curve for bulk density and true density with respect to moisture content is shown in Fig. 1 and Fig. 2

A similar decreasing trend in the bulk density of finger millet was found by Divate and Sawant, 2016. Sirsat and Patel, 2008 also have been reported a decreasing trend in bulk density with an increase in moisture content for Kodo millet. Balasubramanian and Visvanathan, (2010) also found a decreasing trend in true density with an increase in moisture content for finger millet. They also found out that the porosity of finger millet was decreased non-linearly with an increase in moisture content. It was obtained that the angle of repose increases with an increase in moisture content ranging from 23.313$^0$ to 23.517$^0$. The trend of the angle of repose for finger millet is shown in Fig. -5. An increase in moisture content resulted in the increase of angle of repose, as reported by Divate and Sawant , 2016.

**Table 1: Physical Properties of Finger Millet**

| *Physical properties* | *Moisture I (7.8%)* | *Moisture II (13.2%)* | *Moisture III (17.2%)* |
|---|---|---|---|
| Sphericity | 0.540 | 0.662 | 0.668 |
| Bulk density (kg/m$^3$) | 795 | 783 | 755 |
| True density (kg/m$^3$) | 1333 | 1236 | 1208 |
| Porosity (%) | 40.4 | 36.0 | 37.4 |
| Angle of repose ($^0$) | 21.344 | 21.799 | 23.517 |

Values are average of 3 replications

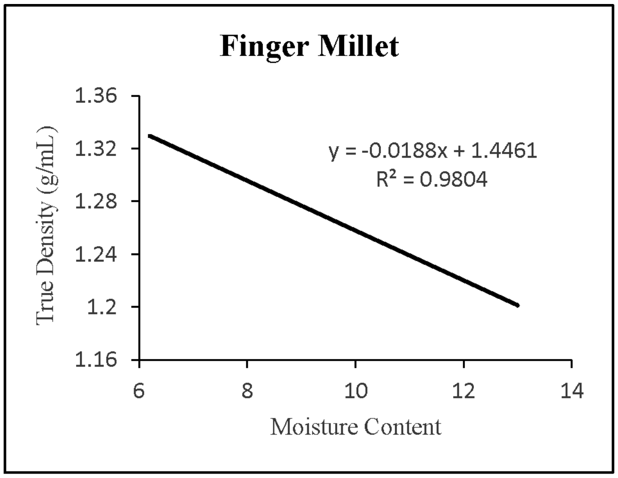


**Fig. 1: Effect of Moisture on True Density**

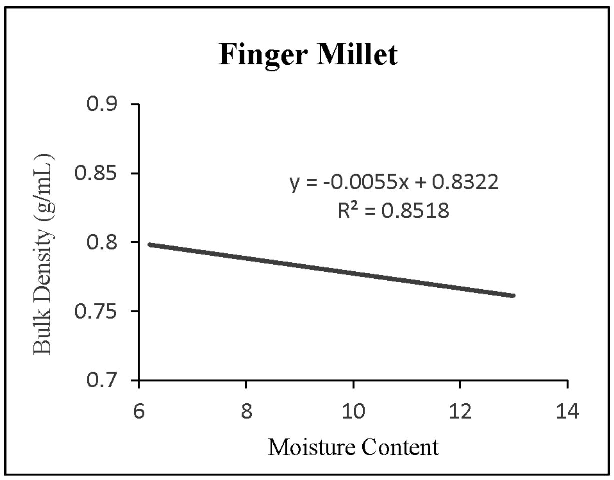


**Fig 2: Effect of Moisture Content on Bulk Density**

The coefficient of friction for finger millet at different surfaces was determined at different moisture content (7.8%, 13.2%,17.2%). The obtained results are shown below in Table-2. The coefficient of friction for finger millets was maximum on the wood surface at 7.8% moisture content and it was maximum on the rubber surface at 17.2% moisture content.

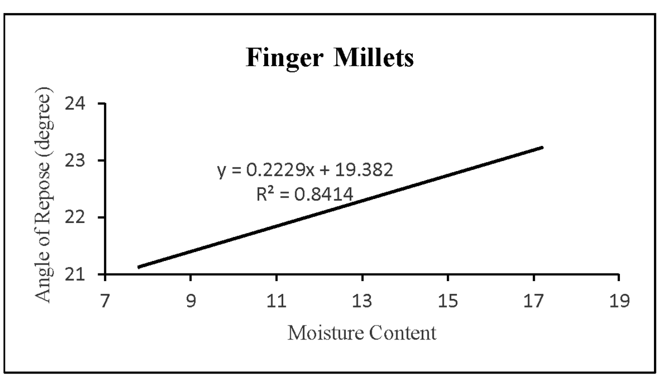


**Fig. 3: Effect of Moisture Content on Angle of Repose**

**Table 2: Frictional Properties of Finger Millets**

| *Materials* | *Moisture I* | *Moisture II* | *Moisture III* |
|---|---|---|---|
| | 7.80% | 13.20% | 17.20% |
| Cardboard | 0.507 | 0.648 | 0.614 |
| Plywood | 0.509 | 0.671 | 0.729 |
| Rubber | 0.603 | 0.659 | 0.671 |
| Steel | 0.419 | 0.474 | 0.494 |
| Wood | 0.654 | 0.564 | 0.700 |

The coefficient of friction with respect to moisture content at different surfaces (cardboard, plywood, rubber, steel and wood) can be expressed by following the linear equations:

At Cardboard,

$$\mu = 0.444 + 0.012 \text{ M.C. } (R^2 = 0.9059) \quad (8)$$

At plywood,

$$\mu = 0.332 + 0.0239 \text{ M.C. } (R^2 = 0.9673) \quad (9)$$

At Steel,

$$\mu = 0.3601 + 0.008 \text{ M.C. } (R^2 = 0.9651) \quad (10)$$

At Rubber,

$$\mu = 0.3318 + 0.0239 \text{ M.C. } (R^2 = 0.9673) \quad (11)$$

At wood,

$$\mu = 0.6139 + 0.0048 \text{ M.C. } (R^2 = 0.9878) \quad (12)$$

Edward, 2002 has reported that the coefficient of friction of millet (obtained from Ghana) increased with an increase in moisture content for plywood, mild steel and galvanized iron.

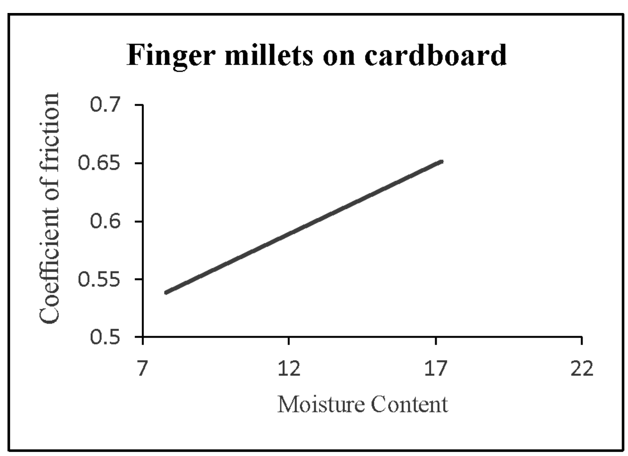


**Figure 4: Effect of moisture on μ of finger millet**

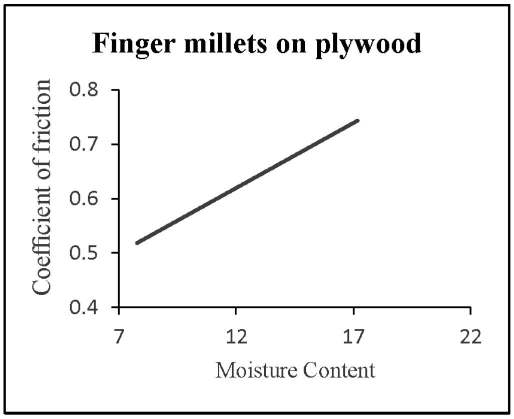


**Figure 5: Effect of moisture on μ of finger millet**

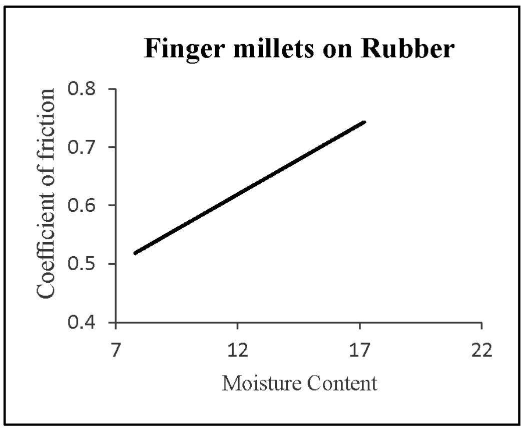


**Figure 6: Effect of moisture on μ of Finger millet**

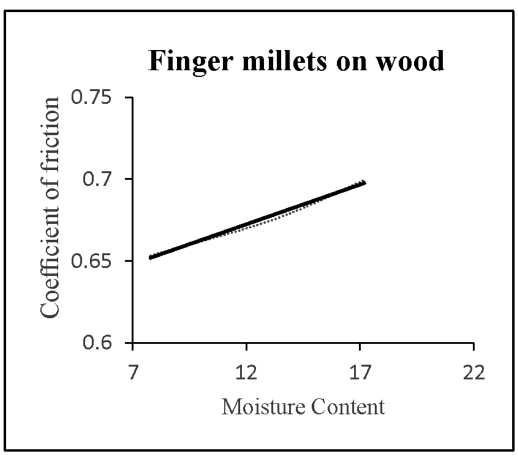


**Figure 7: Effect of moisture on μ of finger millet**

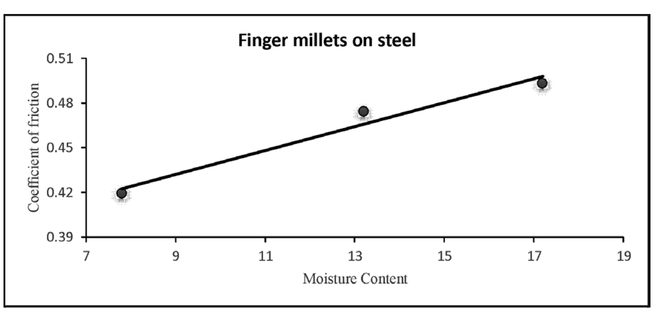


**Figure 8: Effect of moisture on Coefficient of Friction of finger millet**

## CONCLUSION

It was observed that the bulk density for finger millet was decreased and true density for finger millet was increased with an increase in moisture content. The coefficient of friction of finger millet at different surfaces (cardboard, plywood, rubber, steel and wood) increased with an increase in moisture content except at cardboard. These values of some engineering properties of finger millet would be useful for designing various equipment intended to be used for crop production, material handling and processing.

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