



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(3): 93-96
Received: 09-12-2025
Accepted: 10-02-2026

Karthik
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Sushilendra
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Sunil Shirwal
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Murali M
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Ananda N
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Corresponding Author:

Karthik
Department of Farm Machinery
and Power Engineering, College of
Agricultural Engineering, UAS,
Raichur, Karnataka, India

Engineering properties of finger and foxtail millet seeds for development of remote-operated millet planter

Karthik, Sushilendra, Sunil Shirwal, Murali M and Ananda N

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i3b.4996>

Abstract

Engineering properties of seeds constitute essential design parameters for the development and efficient operation of precision sowing equipment, particularly for small-seeded crops such as millets. The present study evaluated selected physical and frictional properties of finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*) seeds with specific reference to the design of a remote-operated precision planter. The properties analyzed included principal dimensions (length, width and thickness), geometric mean diameter, bulk density, angle of repose, and coefficients of internal and external friction, all determined using standardized experimental procedures. Finger millet seeds recorded mean dimensional values of 1.70 mm (length), 1.45 mm (width) and 1.33 mm (thickness), whereas foxtail millet seeds exhibited corresponding values of 2.24 mm, 1.53 mm, and 1.23 mm. The bulk density was found to be 708.2 kg m⁻³ for finger millet and 724.07 kg m⁻³ for foxtail millet. The angle of repose ranged from 27.08° to 31.85°, indicating satisfactory flowability suitable for hopper-based seed handling and delivery systems. The engineering data generated from this study provide a scientific basis for the rational design and optimization of seed hoppers, metering mechanisms and delivery units, thereby enhancing the precision, reliability and operational efficiency of remote-operated millet planters.

Keywords: Millets, engineering properties, precision planter, angle of repose, bulk density

1. Introduction

Millets are among the earliest domesticated cereal crops and are widely recognized for their high nutritional value, climate resilience, and adaptability to marginal agro-climatic conditions (Kiple, 2001) [8]. Globally, millet production exceeds 30 million tonnes annually, with India contributing approximately 38% of the total output across nearly 12 million hectares (FAO, 2023-24; APEDA, 2024) [3, 2]. In India, Rajasthan and Karnataka are major millet-producing states, together accounting for a substantial share of national production. Millets such as finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), pearl millet, and sorghum play a critical role in ensuring food and nutritional security, particularly in rainfed, tribal, and hilly regions.

Despite their agronomic importance, millet cultivation continues to exhibit low levels of mechanization, especially during sowing operations (Abhishek Pandey *et al.*, 2025) [1]. The small size, low weight, and irregular shape of millet seeds create significant challenges for achieving precise seed metering and placement when conventional planters designed for larger cereal grains are used. Consequently, traditional broadcasting and non-precision drilling methods remain prevalent, often resulting in uneven plant populations, poor crop establishment, and reduced productivity (Santosh *et al.*, 2024) [14].

Precision sowing with appropriately engineered planters can substantially enhance seed placement accuracy, crop uniformity, and field operational efficiency. The effective design and development of such equipment depend on accurate knowledge of the engineering properties of seeds, encompassing physical, gravimetric, and frictional characteristics. Key parameters such as seed dimensions, geometric properties, bulk density, angle of repose, and coefficients of friction directly govern the design and performance of critical components including seed hoppers, metering devices, and seed delivery systems (Mohsenin, 1986; Sahay and Singh, 2001) [9, 13]. A comprehensive understanding of these properties is essential for ensuring smooth seed flow,

minimizing mechanical damage, preventing clogging, and achieving uniform seed distribution during planting operations. Consequently, the systematic evaluation of seed engineering properties forms the scientific basis for optimizing planter design and improving the precision and reliability of sowing machinery.

Several researchers have documented the engineering properties of millet grains to support equipment design and post-harvest handling operations. Swami and Swami (2010) [16] reported that the geometric mean diameter of finger millet increased from 1.60 to 1.80 mm with rising moisture content. Ramappa *et al.*, (2011) [12] observed bulk density values for finger millet in the range of 731.67–733.60 kg m⁻³. Similarly, Powar *et al.*, (2018) [11] noted that the geometric mean diameter increased from 1.41 to 1.58 mm, whereas bulk density decreased from 749 to 665 kg m⁻³ as moisture content increased.

For foxtail millet, Gouda *et al.*, (2019) [7] reported bulk density and angle of repose values of 724 kg m⁻³ and 24.30°, respectively. Gaurav *et al.*, (2021) [6] documented bulk density values for whole minor millets ranging from 527.34 to 738.20 kg m⁻³, with corresponding angle of repose values between 25.02° and 30.04°. Nethra *et al.*, (2022) [10] reported the geometric mean diameter and angle of repose of finger millet as 1.60 mm and 25.25°, respectively. Although these studies provide valuable insights into the physical characteristics of millet grains, most investigations have focused on individual crops or general handling properties, with comparatively limited attention to parameters directly applicable to planter design.

With the growing adoption of automation and remote-operated agricultural machinery—particularly suited to small and fragmented landholdings—the availability of crop-specific engineering data has become increasingly critical (Garg and Yadav, 2017; Felix *et al.*, 2024) [5, 4]. In this context, the present study was undertaken to determine selected engineering properties of finger millet and foxtail millet seeds relevant to the design and development of remote-operated precision planters.

2. Materials and Methods

2.1 Seed Material

Finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*) seeds were used for the study. The samples were cleaned manually to remove broken grains, dust and foreign matter prior to testing.

2.2 Determination of Physical Properties

2.2.1 Size

The length, width and thickness of randomly selected twenty seeds from each millet type were measured using a digital vernier caliper with an accuracy of ± 0.001 mm. The average values were recorded (Mohsenin, 1986) [9]. These parameters are fundamental for designing the seed metering mechanism. They determine:

- Size and shape of metering cells, holes, or grooves
- Clearance between seed plate and housing
- Selection of appropriate metering type (*e.g.*, inclined plate, vertical roller, or vacuum disc)
- Prevention of seed cracking and multiple seed pickup

For very small seeds such as millets, dimensional data help achieve single-seed metering, which is critical for precision sowing.

2.2.2 Geometric Mean Diameter

The geometric mean diameter was calculated using the relation

(Mohsenin, 1986) [9]:

$$D_g = (LBT)^{1/3}$$

Where,

D_g = Geometric mean diameter, (mm)

L = Longest intercept (Length), (mm)

B = Longest intercept normal to L (Width), (mm)

T = Longest intercept normal to L and B (Thickness), (mm)

This property represents the effective seed size and is widely used for:

- Designing orifice diameter of seed plates
- Determining seed tube diameter to prevent bridging
- Selecting sieve sizes for seed cleaning prior to planting
- Establishing optimal pickup hole size in pneumatic planters

Typically, the metering hole is designed slightly larger than the geometric mean diameter to ensure smooth release without allowing doubles.

2.2.3 Bulk Density

Bulk density was determined using a 100 ml measuring jar. The mass of seeds occupying the known volume was recorded and bulk density was calculated as the ratio of mass to volume (Mohsenin, 1986) [9].

$$B_d = \frac{M}{V}$$

Where,

B_d = Bulk density (kg m⁻³)

M = Mass of the seed sample (kg)

V = Volume of glass jar sampler (m³)

Bulk density is essential for calculating:

- Hopper capacity and volume requirements
- Structural strength of the hopper walls
- Seed load acting on the metering unit
- Calibration of seed rate (kg ha⁻¹)

It also helps estimate the total planter weight distribution for stable operation.

2.3 Determination of Frictional Properties

2.3.1 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 (2001) [13]. The apparatus consisted of a hopper filled with millet and a circular metal platform supported on three legs. Grains were allowed to flow freely from the hopper onto the platform, forming a heap on the circular iron plate. Using the measured height and diameter of the natural grain heap, the angle of repose as shown in Fig. 1 was calculated with the given formula.

$$\theta = \tan^{-1} \left(\frac{H}{r} \right)$$

Where,

θ = Angle of repose, (°)

H = Height of heap, (mm)

r = Radius of heap, (mm)



Fig 1: Measurement of angle of

Repose of Millet Seeds

This property governs seed flow behavior and is critical for hopper design:

- Determines the minimum hopper wall slope required for gravity flow
- Helps avoid bridging and rat-holing
- Guides selection of hopper geometry (conical or wedge-shaped)

Typically, hopper wall angles are designed 5-10° steeper than the angle of repose to ensure continuous seed movement.

2.3.2 Coefficient of Friction

2.3.2.1 Co-efficient of internal friction

The coefficient of internal friction represents the resistance created when grain kernels move against one another. To determine this, a wooden box measuring 10 × 10 × 10 cm³ was fastened with a cord that passed over a pulley and connected to a weight pan. A thin layer (1 cm) of millet was spread over the surface. Weights (W_1) were gradually placed in the pan until the empty box began to move on the millet surface. The box was then loaded with 200 g of millet (W) and the process was repeated by adding weights until the filled box started to slide, at which point the required weight (W_2) was noted and the average value was recorded (Shivabasappa *et al.*, 2012) ^[15].

$$\text{Co-efficient of internal friction } (\mu_i) = \frac{W_2 - W_1}{W}$$

Where,

W_1 = Weight to cause sliding of empty box, (g)

W_2 = Weight to cause sliding of millet filled box, (g)

W = Weight of millet inside box, (g)

Internal friction indicates resistance between seeds and is used to:

- Predict likelihood of arching or clogging inside the hopper
- Optimize agitator design (if required)
- Decide hopper outlet size

Higher internal friction demands larger outlet openings or agitation mechanisms.

2.3.2.2 Co-efficient of external friction

The coefficient of external friction refers to the resistance encountered when grains slide over a horizontal surface in contact with a wall as shown in Fig. 2. For millets, this property

was measured using a mild steel test surface. A box measuring 10 × 10 × 10 cm³ was connected to a cord that passed over a pulley, with a weight pan attached to the opposite end. Weights (W_1) were gradually added to the pan until the empty box began to move. The box was then loaded with 200 g of millet (W) and the procedure was repeated by adding weights until the filled box started sliding. The weight (W_2) required to initiate sliding of the filled box was recorded (Shivabasappa *et al.*, 2012) ^[15].

$$\text{Co-efficient of external friction } (\mu_e) = \frac{W_2 - W_1}{W}$$

Where,

W_1 = Weight to cause sliding of empty box, (g)

W_2 = Weight to cause sliding of millet filled box, (g)

W = Weight of millet inside box, (g)



Fig 2: Measurement of coefficient

Friction of Millet Seeds

This parameter affects interaction between seeds and construction materials (steel, aluminum, plastic) and is used for:

- Selecting hopper and seed tube materials
- Designing surface finishes to improve flow
- Reducing power requirement in mechanical metering systems

Materials with lower friction coefficients promote smoother discharge and improve metering consistency.

3. Results and Discussion

The engineering characteristics of millet seeds, including size, geometrical mean diameter, bulk density, angle of repose and coefficient of friction, were evaluated using standard testing methods as explained above. The results of these measurements are summarized in the Table 1 below.

3.1 Size

The physical dimensions of finger and foxtail millet seeds were measured, with finger millet seeds having a length of 1.70 ± 0.20 mm, width of 1.45 ± 0.06 mm and thickness of 1.33 ± 0.05 mm, while foxtail millet seeds measured 2.24 ± 0.20 mm in length, 1.53 ± 0.13 mm in width and 1.23 ± 0.10 mm in thickness.

3.2 Geometrical mean diameter

The geometrical mean diameter of the selected finger and foxtail millet seeds was measured to be 1.54 ± 0.03 mm and 1.48 ± 0.06 mm.

3.3 Bulk density

The bulk densities of finger and foxtail millet seeds were measured as 708.2 ± 11.52 kg m⁻³ and 724.07 ± 12.87 kg m⁻³, respectively.

3.4 Angle of repose

The angle of repose, which indicates the flowability of seeds, was measured for finger and foxtail millet seeds. The values recorded were $31.85 \pm 3.25^\circ$ for finger and $27.08 \pm 0.60^\circ$ for foxtail millets, reflecting their relative ease of movement during handling.

3.5 Coefficient of friction

The frictional properties of finger and foxtail millet seeds were determined to understand their flow behavior. The coefficient of internal friction was found to be 0.61 ± 0.02 and 1.25 ± 0.02 , while the coefficient of external friction measured against a surface was 0.49 ± 0.01 and 0.44 ± 0.02 .

Table 1: Engineering properties of selected millet seeds for millet planter

Sl. No.	Properties		Millet values	
			Finger	Foxtail
1.	Size, mm	Length	1.70 ± 0.20	2.24 ± 0.20
		Width	1.45 ± 0.06	1.53 ± 0.13
		Thickness	1.33 ± 0.05	1.23 ± 0.10
2.	Geometric Mean Diameter, mm		1.54 ± 0.03	1.48 ± 0.06
3.	Bulk Density, Kg m^{-3}		708.2 ± 11.52	724.07 ± 12.87
4.	Friction	Internal Friction	0.61 ± 0.02	1.25 ± 0.02
		External Friction	0.49 ± 0.01	0.44 ± 0.02
5.	Angle of Repose $^\circ$		31.85 ± 3.25	27.08 ± 0.60

4. Conclusion

The study determined key engineering properties of finger and foxtail millet seeds relevant to the development of a remote-operated planter. Finger millet seeds recorded a geometric mean diameter of 1.54 mm, bulk density of 708.2 kg m^{-3} and angle of repose of 31.85° , while foxtail millet seeds exhibited corresponding values of 1.48 mm, 724.07 kg m^{-3} and 27.08° . The coefficients of internal friction were 0.61 for finger millet and 1.25 for foxtail millet, with external friction values ranging from 0.44 to 0.49. These quantified properties provide essential inputs for the design of seed hoppers, selection of metering mechanism and delivery systems. The results can support the development of efficient, crop-specific precision planters for millet cultivation.

References

- Pandey A, Chaudhary S, Shukla P, Upadhyay A, Chouhan P, Kumar A, *et al.* Mechanization of millet cultivation: status, technological innovations and future directions. *International Journal of Research in Agronomy*. 2025;8(5):383-395.
- Agricultural and Processed Food Products Export Development Authority (APEDA). Millet export. 2024. https://apeda.gov.in/apedawebsite/SubHeadProducts/eCatalogue_Milletsexport.htm
- Food and Agriculture Organization (FAO). Millets 2023. 2023-2024. <https://www.fao.org/millets2023/en>
- Felix OA, Raphael BS, Kehinde AO, Joshua AAO. Design and implementation of robotic controlled beans planter using mobile app. *Trends in Applied Sciences Research*. 2024;19(1):112-125.
- Garg R, Yadav R. Agricultural robotics: a comprehensive review. *Journal of Robotics*. 2017;2017:1-15.
- Gaurav A, Pradhan RC, Mishra S. Comparative study of physical properties of whole and hulled minor millets for equipment designing. *Journal of Scientific and Industrial Research*. 2021;80(8):658-667.

- Gouda GP, Sharanagouda H, Udaykumar N, Ramachandra CT, Nagaraj N, Ananda N, *et al.* Studies on engineering properties of foxtail millet (*Setaria italica*). *Journal of Farm Sciences*. 2019;32(3):340-345.
- Kiple KF. The Cambridge world history of food. Vol. 2. Cambridge: Cambridge University Press; 2001. p. 761-777.
- Mohsenin NN. Physical properties of plant and animal materials. 2nd ed. New York: Gordon and Breach Science Publishers; 1986.
- Nethra V, Someswara Rao C, Edukondalu L, Ashok Kumar A. Engineering properties of finger millet (*Eleusine coracana* L.) grains. *International Journal of Science and Research*. 2022;11(7):1476-1478.
- Powar R, Aware V, Shahare P, Sonawane S, Dhande K. Moisture-dependent physical properties of finger millet grain and kernel. *Journal of the Indian Society of Coastal Agricultural Research*. 2018;36(1):48-56.
- Ramappa KT, Batagurki SB, Karegoudar AV, Sharnakumar H. Physical properties of finger millet (*Eleusine coracana*). *International Journal of Agricultural Engineering*. 2011;4(1):13-15.
- Sahay KM, Singh KK. Unit operations of agricultural processing. New Delhi: Vikas Publishing House; 2001.
- Santosh, Devanand M, Vijayakumar P, Anand N. Engineering properties of foxtail millet seeds for development of planter for millet crop. *Journal of Scientific Research and Reports*. 2024;30(10):236-241.
- Shivabasappa S, Roopa Bai RS, Sridevi S, Sharanagouda H, Udaykumar N. Engineering properties of finger millet (*Eleusine coracana* L.) grains. *International Journal of Agricultural Engineering*. 2012;5(2):178-181.
- Swami S, Swami S. Physical properties of finger millet (*Eleusine coracana*). *International Journal of Agricultural Engineering*. 2010;3(1):156-160.