

RESEARCH ARTICLE

Engineering Properties of Little Millet and Barnyard Millet based on Moisture Content

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ABSTRACT

At five moisture levels of 8.70, 11.51, 15.76, 18.37, and 20.82% (dry basis), the physical qualities of little millet and barnyard millet were examined. Progressive absorption of moisture led to a steady increase in grain size and associated characteristics. The length, width, and thickness rose from 1.70 to 2.03 mm, 1.07 to 1.90 mm, and 1.06 to 1.28 mm, respectively. Similarly, arithmetic mean diameter (0.65–1.68 mm), geometric mean diameter (1.24–1.71 mm), surface area (7.52–7.76 mm²), sphericity (77.57–79.49%), thousand grain mass (1.43–2.36 g) and angle of repose (27.00°–34.33°) rose along with moisture content. Similar trends were seen in barnyard millet, where grain length rose from 1.91 to 1.98 mm, and thickness from 1.09 to 1.46 mm, and thickness from 1.09 to 1.46 mm. As moisture content rose, increases were also noted in geometric mean diameter (1.54–1.75 mm), arithmetic mean diameter (1.22–1.82 mm), surface area (12.53–15.42 mm²), sphericity (77.70–85.03%), thousand grain mass (2.06–4.80 g), and angle of repose (25.66°–42.33°). By contrast, porosity, bulk density, and true density showed a diminishing trend with increasing moisture levels for both millet kinds, showing lower density from grain swelling.

Keywords: *Barnyard millet Grain morphology Little millet Physical properties Storage*

INTRODUCTION

Belonging to the family Poaceae (Gramineae), millets are little-seeded edible grains categorized as coarse grains. They span ten genera and around twenty species. Collectively, millets refer to a collection of yearly grass crops grown mostly for grain, particularly in arid and semi-arid areas across temperate, subtropical and tropical regions. These plants thrive in poor settings with little inputs (Singh *et al.*, 2012). Millets were long overlooked and often called “lost crops” because of little attention in agriculture and

dietary practices, even though they are suitable as climate-resilient alternative crops. Millets have better nutritional qualities than do big cereals, including significant levels of zinc, calcium, and iron, proteins of good biological quality (Hassan *et al.*, 2021), great dietary fibre, and necessary macronutrients. Their nutritional content is said to be up to five times that of commonly eaten grains like rice and wheat. Though millets account for almost 10% of India’s total grain production, totaling roughly 18 million tonnes yearly,

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their intake remains far below that of wheat and rice (Rizwana *et al.*, 2023).

Efficient design and optimization of post-harvest activities including cleaning, grading, handling, processing, and storage, requires the evaluation of physical, mechanical and aerodynamic characteristics of grains. The form and size of grains are absolutely vital for impurity separation and are major influences in the creation of grading and sorting machinery. Additionally important for the design of appropriate bulk handling systems and storage buildings are properties such as porosity, bulk density, and true density (Singh *et al.*, 2010).

Panicum sumatrense, commonly referred to as little millet, is a minor cereal crop recognized for its diverse therapeutic and nutritional benefits, which are largely driven by its rich profile of bioactive nutraceutical constituents. (Kashim *et al.*, 2025). Little millet (*Panicum sumatrense*) is indigenous to the Indian subcontinent and is presumed to have originated from the wild species *Panicum psilopodium* (Patel *et al.*, 2025). Historically considered a “cooling food,” little millet is frequently consumed during the summer months for its reputed ability to lower body temperature. It’s a great repository of natural antioxidants, phenolic chemicals, and resistant starch. Through antioxidant action (Neelayathatchi *et al.*, 2023), phytates retained in little millet have been shown to help prevent metabolic diseases, including diabetes and cancer. Nutritional profiling further shows that small millet is characterized by high protein and carbohydrate content, thereby increasing its potential as a functional cereal (Srilekha *et al.*, 2019).

Mostly grown in Asian nations, including China, India, Korea, and Japan, barnyard millet (*Echinochloa* spp.) is a classic grain crop cultivated in moderate and warm agro-climatic zones. The crop is distinguished by a brief development cycle and the capacity to flourish in a range of environmental settings, even when water is scarce, while remaining tolerant of a broad spectrum of biological and ecological stresses. Apart from its agricultural benefits, barnyard millet is prized for its excellent nutritional value and low production costs compared with major cereals like rice, wheat, and maize. It offers a rich supply of carbohydrates, dietary fiber, and protein; it is especially rich in essential micronutrients, including zinc (Zn) and iron (Fe) (Renganathan *et al.*, 2020).

An experiment was carried out to assess how the moisture contents of 8.70, 11.51, 15.76, 18.37, and 20.82% (dry basis) affected the physical and geometric characteristics of little millet and barnyard millet. The main aim of the research was to evaluate moisture-dependent changes in selected physical properties, including arithmetic and geometric mean diameters, sphericity, surface area, thousand-grain mass, angle of repose, porosity, bulk density, and true density, of both millet types. For the effective design and optimization of millet processing machinery, including dehullers, storage bins, milling units, grain separators, and drying systems, knowledge of how these characteristics vary with different moisture levels is critical.

MATERIALS AND METHODS

Moisture Content

The standard hot-air oven method was used to measure millet grain moisture content. The samples were dried for twenty-four hours at 105 °C till a constant weight was attained. Millet samples were conditioned to achieve the desired moisture levels by adding a fixed amount of distilled water. Using the following formula, the volume of water needed for moisture correction was calculated (Singh *et al.*, 2025) (eq. 1).

$$Q = W_i \left(\frac{m_f - m_i}{100 - m_f} \right) \quad (\text{eq. 1})$$

Where,

Q is the weight of water that needs to be added (g); W_i is the initial weight of the sample (g); m_i is the initial moisture content of the sample (% d.b.) and m_f is the final moisture content of the sample (% d.b.).

The equilibrated moisture contents of both little millet and barnyard millet were found to be 8.70, 11.51, 15.76, 18.37, and 20.82% d.b. Five moisture content levels, ranging from 8.70% to 20.82% (dry basis), were used to evaluate all physical properties; each level was tested five times.

Arithmetic and Geometric Mean Diameter

Three main dimensions were length (L) as the longest axis, width (W) as the intermediate axis, then thickness (T). The shortest axis was determined for thirty representative grains. The arithmetic mean diameter (Da) and geometric mean diameter (Dg) is computed using eq. 2 and eq. 3 respectively (Khatoniar *et al.*, 2020).

$$D_a = \frac{L+W+T}{3} \quad (\text{eq. 2})$$



$$D_g = (LWT)^{1/3} \quad (\text{eq. 3})$$

Sphericity

Sphericity (Φ) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain which had been calculated using the following expression (Sabar et al., 2020) (eq. 4).

$$\Phi = \frac{(L \cdot W \cdot T)^{1/3}}{L} = \frac{D_g}{L} \quad (\text{eq. 4})$$

Surface Area

Using Eq. 5 (Singh et al., 2010), the surface area (mm^2) of small millet and barnyard millet was computed.

$$A_s = \pi (D_g)^2 \quad (\text{eq. 5})$$

Thousand Grain Weight

For analysis, ten evenly split portions of a 1 kg millet sample were taken. From every portion, 1,000 grains were randomly chosen and weighed with a digital balance. Five times the procedure was performed, and the average value was computed and noted.

Bulk Density

Bulk density (ρ_b) is calculated by grain mass per unit volume (kg/m^3) using a 500 ml container with a height of 15 cm, which was filled with millets (Sabar et al., 2020) $\rho_b = \frac{W_s}{V_s}$ (eq. 6).

Where, W_s is the weight of the sample (g); V_s is the volume of the sample occupied by the grain in ml^3 .

True Density

ive to their true volume produced the true density (ρ_t). Millet grains hardly absorb any toluene (C_7H_8); the toluene displacement approach was utilized. 50g grains were delicately introduced into a graduated measuring cylinder with 100 ml of toluene, and the rise in liquid level was documented to calculate the volume of liquid displaced by the grains (Sabar et al., 2020) (eq. 7).

$$\rho_t = \frac{M_s}{V_t} \quad (\text{eq. 7})$$

Where, M_s is the mass of the millet grain (g) and V_t is the volume of toluene displaced by grains (ml^3).

Porosity

The proportion of the total grain volume taken up by air spaces rather than the grain material itself is expressed as Porosity (ϵ) using Eq. 8 it was calculated considering actual density and bulk density readings (Rajendran et al., 2023).

$$\epsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (\text{eq. 8})$$

Angle of Repose

The height and base diameter of a spontaneously formed conical pile of grains were measured to estimate the angle of repose, which was evaluated using eq. 9.

$$\text{Angle of repose } (\theta) = \tan^{-1} \frac{2h}{d} \quad (\text{eq. 9})$$

Where θ is the angle of repose in degrees; h is the height of the cone formed on the circular plate and d is the diameter of the circular plate.

Statistical Test:

Statistical evaluation of the experimental values was performed using Analysis of Variance (ANOVA) and the Duncan test, performed in SPSS version 20.0.

RESULTS AND DISCUSSION

Grain Dimension

Tables 1 and 2, respectively, show the average values of the three main dimensions of tiny millet and barnyard millet measured at five different moisture levels. The findings suggest that as humidity levels rose from 8.70 to 20.82% (dry basis), the axial dimensions of both millet grains grew gradually. With rising moisture content, the average grain length, breadth, and thickness in little millet increased from 1.70 to 2.03 mm ($P < 0.05$) and from 1.07 to 1.90 mm ($P < 0.001$), respectively. Similarly, in barnyard millet, the comparable dimensions grew from 1.91 to 1.98 mm ($P < 0.01$), 1.75 to 1.87 mm ($P < 0.001$), and 1.09 to 1.46 mm ($P > 0.05$) as the water content climbed from 8.70 to 20.82% (dry basis).

With increasing moisture content, the arithmetic and geometric mean diameters of little millet rose dramatically, ranging from 0.65 to 1.68 mm ($P < 0.001$) and 1.24 to 1.71 mm ($P < 0.001$), respectively, as moisture levels rose from 8.70 to 20.82% (dry basis). Barnyard millet showed a similar trend; its arithmetic mean diameter rose from 1.22 mm ($P < 0.05$) to 1.82



Table 1. Engineering properties of little millet at various moisture contents

Moisture content (% d.b.)	Axial dimensions (mm)			Average diameters (mm)	
	Length, L	Width, W	Thickness, T	Arithmetic mean, Da	Geometric mean, Dg
8.70	1.7±0.1 ^a	1.07±0.03 ^a	1.06±0.33 ^a	0.65±0.05 ^a	1.24±0.34 ^a
11.51	1.73±0.12 ^{ab}	1.7±0.1 ^b	1.13±0.33 ^{ab}	1.12±0.13 ^b	1.49±0.054 ^b
15.76	1.93±0.03 ^{abc}	1.7±0.1 ^b	1.13±0.06 ^{ab}	1.25±0.12 ^b	1.55±0.05 ^{bc}
18.37	1.97±0.33 ^{bc}	2±0.45 ^c	1.21±0.11 ^{ab}	1.49±0.15 ^{cd}	1.64±0.55 ^{cd}
20.82	2.03±0.33 ^c	1.9±0.33 ^c	1.28±0.04 ^c	1.68±0.05 ^d	1.71±0.016 ^d

*Different lowercase letters represent significant differences between the interaction of moisture content and the grain dimension of little millet.

mm, and the geometric mean diameter from 1.54 mm ($P < 0.05$) over the same moisture range. Grain expansion due to moisture absorption can explain the observed increase in mean diameters. Improved paddy rice cultivars have shown similar results, with all three main characteristics growing with moisture level from 10 to 30% (dry basis) (Adebawale *et al.*, 2011). Similar arithmetic and geometric mean diameters expansion in *Detarium microcarpum* Seeds was noted by Aviara *et al.*, 2015 with increase in moisture content from 8.2 to 28.5% (dry basis).

Sphericity

Figure 1 shows the change in sphericity as a function of water content. For both millet types, sphericity steadily rose as humidity content grew from 8.70 to 20.82% (dry basis). Over the same moisture range, sphericity values increased from 77.57 to 79.49% ($P < 0.01$) in little millet, while barnyard millet showed a more notable rise from 77.70 to 85.03% ($P < 0.001$). These results indicate that the sphericity of barnyard millet was more affected by moisture

content than that of little millet. The observed trend is consistent with prior studies that reported an increase in sphericity with rising moisture levels, as in cowpea, where sphericity rose from 0.783 to 0.803 as moisture content grew from 5 to 22.5% (dry basis) (Baryeh *et al.*, 2002)

Surface Area

Figure 2 depicts the variation in surface area of millet grains as a function of moisture content. The results demonstrate an increasing trend in surface area with rising moisture levels for both millet varieties. As moisture content increased from 8.70 to 20.82% (dry basis), the surface area of little millet increased marginally from 7.52 to 7.76 mm² ($P > 0.05$), whereas a statistically significant increase was observed in barnyard millet, where surface area increased from 12.53 to 15.42 mm² ($P < 0.001$). The relatively greater change in barnyard millet suggests a stronger response of grain morphology to moisture absorption. Similar trends have been reported by Deshpande *et al.* (1993) for soybean and Tekin *et al.* (2006) for bean.

Table 2. Engineering properties of barnyard millet at various moisture contents

Moisture content (% d.b.)	Axial dimensions (mm)			Average diameters (mm)	
	Length, L	Width, W	Thickness, T	Arithmetic mean, Da	Geometric mean, Dg
8.70	1.91±0.01 ^a	1.75±0.01 ^a	1.09±0.01 ^a	1.22±0.01 ^a	1.54±0.01 ^a
11.51	1.93±0.01 ^{ab}	1.77±0.01 ^a	1.13±0.33 ^a	1.29±0.03 ^a	1.57±0.02 ^a
15.76	1.94±0.01 ^b	1.81±0.01 ^b	1.18±0.02 ^{ab}	1.39±0.02 ^a	1.61±0.01 ^a
18.37	1.95±0.01 ^b	1.82±0.01 ^b	1.16±0.02 ^{ab}	1.39±0.03 ^a	1.61±0.01 ^a
20.82	1.98±0.01 ^c	1.87±0.01 ^b	1.46±0.21 ^b	1.82±0.25 ^b	1.75±0.07 ^b

*Different lowercase letters represent significant differences between the interaction of moisture content and grain dimension of barnyard millet.

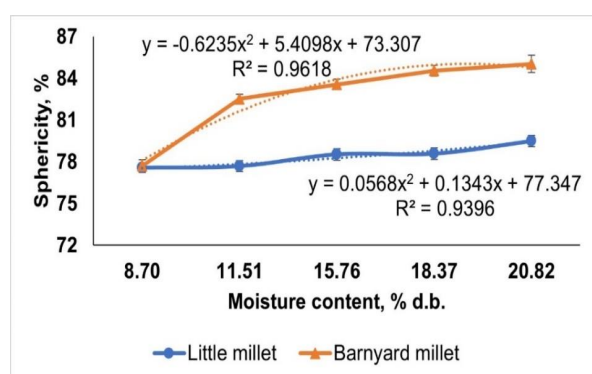


Figure 1: Effect of moisture content on sphericity of little millet and barnyard millet

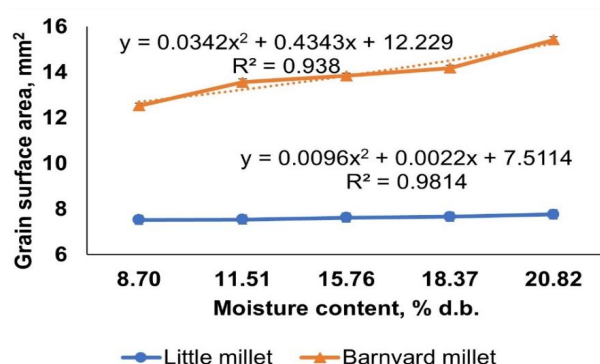


Figure 2: Effect of moisture content on surface area of little millet and barnyard millet

Thousand Grain Weight

Figure 3 shows how both tiny millet and barnyard millet grew dramatically in their thousand-grain weight with rising moisture content. As moisture content rose from 8.70 to 20.82% (dry basis), the thousand-grain mass of little millet increased from 1.43 to 2.36 g ($P < 0.01$), while barnyard millet exhibited a more pronounced increase from 2.06 to 4.80 g ($P < 0.001$). Kernels absorbing moisture is thought to be responsible for the seen rise in grain mass. Other cereal crops have seen a comparable moisture-dependent rise in reported thousand-grain weight. Maize (PMH-1) also described with supporting data that thousand grain weight increased from 258.1 to 287.9 g when moisture content was increased from 10–18% wet basis (w.b.). (Bhise et al., 2014)

Bulk Density

Figure 4 depicts the fluctuation in the bulk density of little millet and barnyard millet with moisture content. The data clearly show that for both millet types, bulk density decreases as moisture levels rise. Little millet's bulk density decreased from 764.33 to

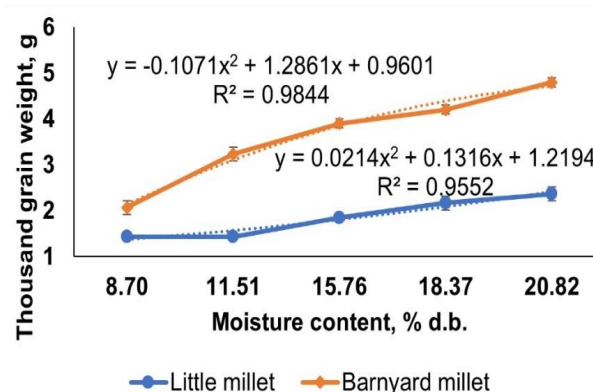


Figure 3: Effect of moisture content on thousand-grain mass of little millet and barnyard millet

721.00 kg m^{-3} ($P < 0.001$) as moisture content rose from 8.70 to 20.82% (dry basis), but barnyard millet showed a more dramatic decrease from 682.66 to 566.33 kg m^{-3} ($P < 0.001$). The cause of this fall might be that the increase in bulk volume due to moisture-induced grain swelling exceeded the equivalent increase in mass (Pradhan et al., 2008). Baryeh and Mangope (2003) have recorded comparable decreases in bulk density with rising moisture level for pigeon pea (variety QP38). Kingsly et al. (2006), by contrast, found an upward trend in bulk density in dried pomegranate seeds, therefore implying that the impact of moisture content on bulk density may differ among crop types. The disproportional association between moisture-related weight increase and grain volumetric expansion (Kenghe et al., 2013) can explain the drop in bulk density at greater moisture levels. Hayford et al. (2019) found that Opeaburoo and Abontemma maize cultivars exhibited a nonlinear rise in bulk density with diminishing moisture content.

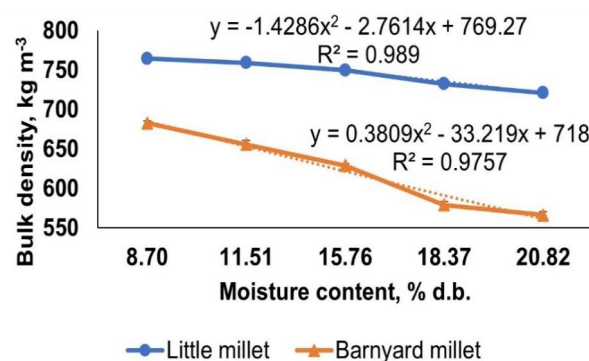


Figure 4: Effect of moisture content and bulk density of little millet and barnyard millet

True Density

Figure 5 shows how the actual densities of little millet and barnyard millet vary across various moisture levels. For both millet types, as moisture content increased, actual density declined. In small millet, true density fell considerably from 1133.66 to 970.66 kg m⁻³ (P<0.01), but barnyard millet showed a reduction from 1177.33 to 1130.66 kg m⁻³ (P<0.001) as moisture content rose. This decline implies that the volumetric expansion of the grains resulting from moisture absorption exceeded the equivalent increase in weight (Balasubramanian *et al.*, 2010). Mollazade *et al.* (2009) reported an increase in true density in cumin seeds, where true density grew from 917.8 to 1030.64 kg m⁻³ as moisture content increased from 7.24 to 21.38% (dry basis), contrasting the current findings, indicating that moisture effects on true density may vary depending on grain structure and composition.

Porosity

Porosity is a derived property that is directly dependent on bulk density and true density. As shown in Figure 6, porosity decreased with increasing moisture content for both millet varieties. In little millet, porosity decreased significantly from 41.48 to 24.74% (P < 0.001), whereas barnyard millet showed a reduction from 63.60 to 32.62% (P < 0.001) as moisture content increased from 8.70 to 20.82% (dry basis). The observed decline in porosity may be attributed to moisture-induced alterations in grain structure, including changes in grain mass, volume, and internal packing. Similar reductions in porosity with increasing moisture content have been reported for soybeans, and chickpeas by Shirkole *et al.* (2011), and Eissa *et al.* (2010), respectively.

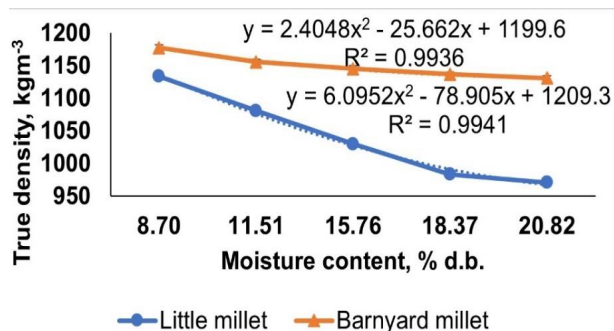


Figure 5: Effect of moisture content on true density of little millet and barnyard millet

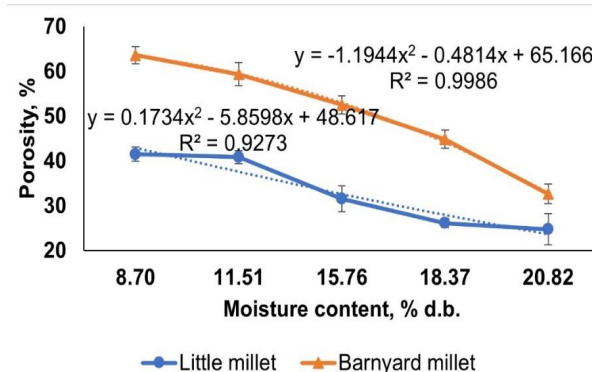


Figure 6: Effect of moisture content on porosity of little millet and barnyard millet

Angle of Repose

The angle of repose is defined as the inclination angle formed between the sloping surface of a freely accumulated heap of granular material and the underlying horizontal plane (Peng *et al.*, 2022). Figure 7 shows how the angle of repose of small millet and barnyard millet changes with moisture level. For little millet, the angle of repose rose dramatically from 27.00 to 34.33° (P<0.001); for barnyard millet, it increased from 25.66 to 42.33° (P < 0.001) as moisture content rose from 8.70 to 20.82% (dry basis). Surface moisture enhances interparticle cohesion, thereby increasing adhesive forces via surface tension (Pradhan *et al.*, 2008), thereby explaining the increase in angle of repose with escalating moisture levels.

CONCLUSION

In this work, vital engineering features of little millet and barnyard millet—namely length, width, thickness, arithmetic mean diameter, sphericity, surface area, thousand-grain mass, porosity, bulk density, true density, and angle of repose—were examined. Designing and optimizing postharvest processing equipment requires knowledge of these physical characteristics under different conditions, as it increases the efficiency of operations such as threshing, drying, and sorting while reducing mechanical damage and postharvest losses. The data showed that arithmetic and geometric mean diameters, sphericity, surface area, thousand-grain mass, and angle of repose of both millet cultivars increased directly with moisture content (dry basis), which increased from 8.70 to 20.82%. Conversely, porosity, bulk density, and true density fell as moisture content rose.

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Ethical Approval

This study does not involve human or animal subjects; therefore, ethical approval is not applicable.

Originality and Plagiarism

Authors confirm that this manuscript is an original work. No parts of the manuscript have been previously published and proper citations have been provided. There is no known plagiarism in any form in this article.

Consent to Participate

Not applicable, as no human participants were involved.

Consent to Publish

All authors agree to the content of the article and its publication in this journal.

Competing Interests

Authors have no potential conflicts of interest, financial or otherwise, that could affect the research or its interpretation.

Data availability

All the data are present in the graph.

Author Contributions

Sindhu G: Investigation, data curation, writing original draft. Sharon. E.M: conceptualization, supervision, validation. Nithyalakshmi. V: conceptualization, supervision, validation. Geetha. P: conceptualization, supervision, validation.

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