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Evaluating physical properties of green gram seeds for seed metering mechanism design

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Abstract
In 2022, a comprehensive research study was conducted at the Department of Agricultural Engineering, IARI, New Delhi, India. The primary focus of this study was to investigate essential physical properties related to the MH-421 variety of green gram seeds. These properties included size, sphericity, test weight, bulk density, true density, coefficient of static friction, and angle of repose. The green gram seeds were characterized by specific measurements: they had an average length of 5.08 mm, a breadth of 4.06 mm, a thickness of 3.99 mm, and a geometric mean diameter of 4.35 mm. The sphericity of these seeds was calculated to be 86%. Mean bulk density and true density were determined with values of 0.86 g/cc and 1.38 g/cc, respectively. The angle of repose, a crucial parameter, was measured at an average of 23.94°. Notably, the coefficient of static friction exhibited variations when tested against different materials: 0.50 (aluminum), 0.45 (mild steel), 0.47 (galvanized iron), and 0.60 (plywood). Furthermore, the average thousand-grain weight for the selected variety of green gram seeds was found to be 46.18 g.

Keywords: Physical properties, seed metering mechanism, geometric mean diameter, coefficient of static friction, angle of repose

Introduction

The population of India is experiencing rapid growth, necessitating an increase in agricultural productivity to meet the growing demand for food. India holds the position of being the world's leading producer (26%), consumer (27%), and importer (15%) of pulses. Pulses make up approximately 20% of the total food grain cultivation area and contribute 7-10% to the overall food grain production in the country (Bairwa *et al*., 2020) [2]. These pulses are cultivated in both the Kharif and Rabi seasons, with Rabi pulses accounting for over 60% of the total production (Bhat *et al*., 2022) [3]. The primary pulse crops grown in India include chickpea, pigeon pea, green gram (Mungbean), and black gram (Uradbean), with green gram covering 4.4 million hectares and yielding 2.56 million tonnes annually. A significant portion of pulse imports, including chickpeas, pigeon peas, mung beans, and urad beans, comes from Myanmar, Canada, and Australia. To reduce reliance on imports, there is a pressing need to boost pulse production, particularly within our country.

Seeding or planting represents a critical agricultural operation with a profound impact on crop production. The utilization of seed drills for pulses allows farmers to cover extensive areas in a relatively short time (Nassir *et al*., 2021) [7]. Moreover, seeding with a seed drill promotes uniform crop stands and row spacing, facilitating subsequent intercultural operations. However, conventional seed drills often fail to efficiently maintain seed rates and spacing between seeds, hindering the mechanization of subsequent operations (Madhusudan and Preetham, 2020) [5]. There is a demand for the development of efficient seed metering mechanisms for pulses that cater to the precision and affordability needs of farmers.

The physical characteristics of seeds, including size, shape, angle of repose, thousand-grain weight, and bulk density, play a pivotal role in designing seed metering units. These factors significantly influence the performance of seed metering mechanisms employed in planters or seed drills. Jayan and Kumar (2006) [4] conducted research on the physical characteristics of maize, red gram, and cotton seeds, finding that sphericity and roundness both affect seed flow through various planter components. Variations in average unit mass, volume, thousand-seed mass, bulk density, true density, bulk density, and porosity exist among seed varieties, impacting seed metering mechanism performance (Ramesh *et al*., 2015) [8]. In a study by Ajay *et al*. (2021) [1] focusing on three maize varieties (Rasi-3033, NMH-589, and KMH-2589), the investigation aimed to optimize seed metering unit design parameters, highlighting the significance of physical properties in developing efficient planter components for effective functionality. While several researchers have reported on diverse seed physical characteristics, there remains a gap in research exploring the relationship between these properties and metering system design, especially concerning green gram and black gram. To address these gaps, this study was conducted to examine the various physical properties of selected green gram seeds concerning the design of seed metering mechanisms.

Material and Methods

The physical characteristics of seeds, including size, shape, bulk density, angle of repose, and thousand-grain weight, play a crucial role in the performance of the seed metering mechanism. These properties were thoroughly examined and the data is used for the design of an efficient seed metering system. The size property was used to determine the groove length, depth, and the number of seeds required on the groove surface. The shape property ensured the smooth and uniform flow of selected pulse seeds from the groove. The bulk density and true density values aided in designing the appropriate seed hopper volume and thickness. The angle of repose and coefficient of friction were considered to establish the optimal slope for the free flow of selected pulse seeds from the hopper. The coefficient of static friction was measured to select a suitable hopper material that allows uniform and free flow of seeds. Additionally, the thousand-grain weight played a key role in calculating the number of seeds needed per meter area to achieve the desired seed rate.

All experiments were conducted in the laboratory of the Division of Agricultural Engineering at IARI, New Delhi, using an experimental set-up to determine the aforementioned physical properties. The experimental procedure for determining the aforementioned physical properties of the selected seed varieties is outlined below.

i) Size and shape

The size and shape of green gram seeds were two significant factors that influences the determination of the shape and size of the seed metering plate. To accomplish this, a random sampling of seeds was conducted, and their length (*l*), breadth (w), and thickness (t) were measured in three mutually perpendicular directions using a digital vernier caliper with a least count of 0.01 mm (Plate 1(a). The size of the seed is expressed as the geometric mean dimension (Dg), determined using the relationship proposed by Mohsenin (1986) [7].

Geometrical mean = $\sqrt[3]{l \times b \times t}$

Where,
l = length of seed, mm
b = breadth of seed, mm
t = thickness of seed, mm

Sphericity (∅) plays a significant role in ensuring the smooth and even flow of pulse seeds from the groove surface of the metering plate. Sphericity serves as the parameter to define the shape of the seed. The calculation of sphericity (∅) follows the method proposed by Mohsenin (1986) [7].

$$\emptyset = \frac{\sqrt[3]{(l \times b \times t)}}{l}$$

ii) Bulk density

Bulk density and true density measurements are utilized in the design of the seed hopper. To determine the bulk density, a jar of known volume was used. The jar was filled with green seeds without any compaction, and the weight of the seeds inside the jar was subsequently measured (Plate 1(b). The bulk density was calculated by dividing the weight of the seeds by the volume of the jar, using the following relationship.

$$\rho = \frac{W}{V}$$

Where,
ρ = Bulk density, g cc^{-1}
W = Weight of the seed, g
V = Volume of the sample, cc

iii) True density

The true density of pulse seeds was determined using the Hexane displacement method (Mohsenin, 1986) [7]. The volume and true density were assessed for 10 samples of seeds, with the weight of each sample being recorded. Each sample was immersed in a jar filled with hexane liquid (Plate 1(c)), and the volume of displaced hexane was measured for each sample. The true density was then calculated as the ratio of the weight of each sample to its corresponding volume.

iv) Angle of repose

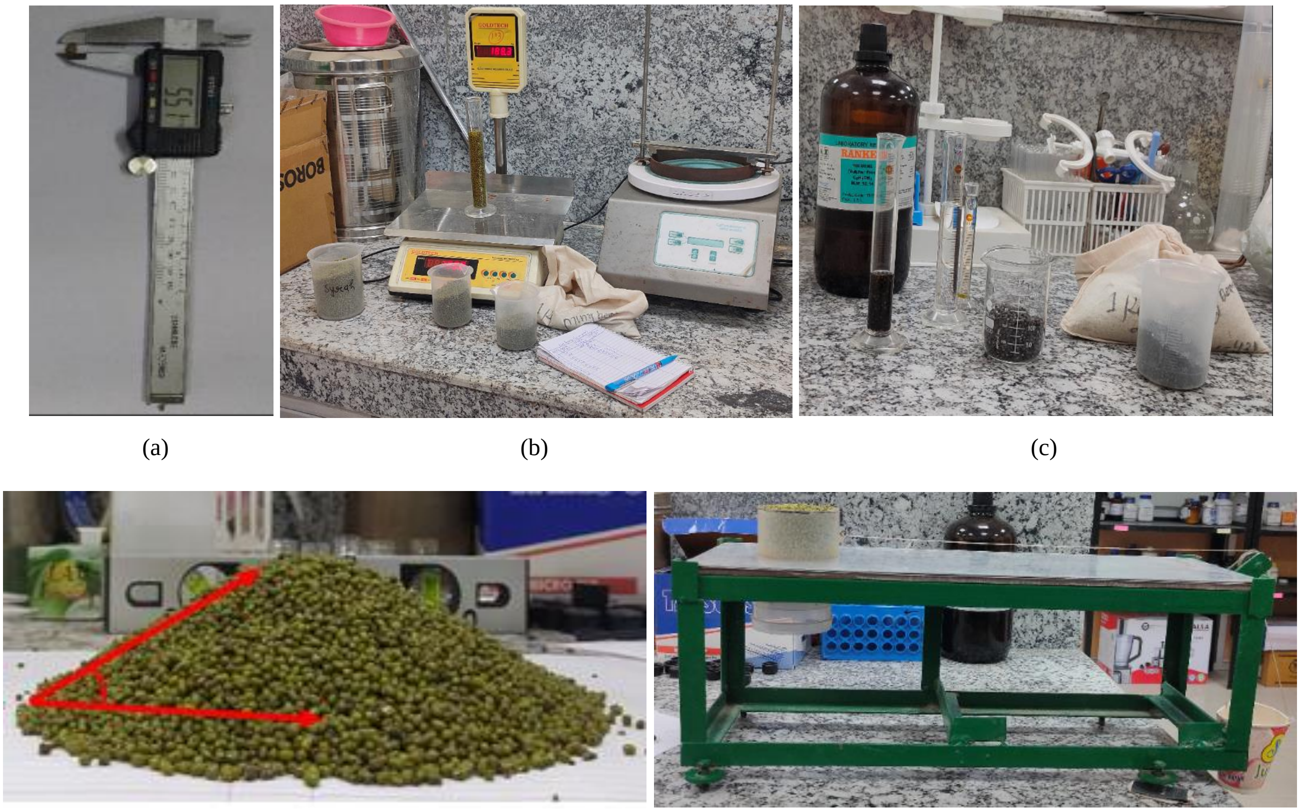
The equipment used to measure the dynamic angle of repose comprised a funnel with a throat opening that could be adjusted, and it was mounted on a stand (Plate 1(d). Inside the funnel, there was a circular plate with centering arms positioned above the adjustable throat. To begin the measurement, the funnel was filled with seeds, while keeping the adjustable throat closed. Then, the throat was fully opened, allowing the seeds to flow freely over and around the plate inside the funnel. This resulted in the formation of a heap of seeds on the plate. The diameter of the base and the height of the heap were measured. The angle of repose was calculated using the following equation:

$$\theta = tan^{-1}\left(\frac{2H}{D}\right)$$

Where,
Θ = Angle of repose, degrees
H = height of cone, cm
D = base diameter, cm

v) Coefficient of static friction

The inclined plane method (Plate 1(e)) was utilized to measure the coefficient of static friction for green seeds. The procedure involved placing the material on a horizontal surface and gradually increasing the slope. The angle (α) at which the seeds were on the verge of sliding was recorded. The coefficient of static friction was then determined as tanα. This process was repeated twenty times, and the mean value was calculated.



(a) (b) (c)

(d) (e)

Plate 1: Measurement of (a) seed size (b) bulk density (c) True density (d) Angle of repose and (e) Coefficient of static friction

vi) Thousand-grain weight

The key factor used to determine the desired seed rate of green gram seeds was the weight of one thousand seeds. Ten random samples, each containing one thousand seeds, were selected from chosen seed varieties. These samples were then weighed using an electronic balance, and the average weight was calculated.

Results and Discussion

The design of the seed metering mechanism involved an assessment of the physical characteristics of selected seed varieties, including green gram seeds. These characteristics encompassed size, shape, bulk density, angle of repose, and coefficient of static friction. The resulting observations are as follows:

Table 1 displayed the spatial dimensions of green gram seeds. The mean length of the chosen seeds was 5.08 mm, with an average breadth of 4.06 mm and an average thickness of 3.99 mm. Additionally, the geometric mean diameter was 4.35 mm (Table 1). To assess their shape, the sphericity of the pulse seeds was examined, revealing that the sphericity of green gram seeds was 86% (Table 1).

Table 1: Variations in size dimensions of green gram seeds

Crop	Descriptive Statistics	Length (mm)	Breadth (mm)	Thickness (mm)	Geometric mean diameter (mm)	Sphericity (%)
Green gram	Range	4.07-5.83	3.49-4.60	3.47-4.48	3.75-4.83	79-94
	Mean	5.08	4.06	3.99	4.35	86
	CV (%)	10	8	8	8	6

The angle of repose for green gram ranged from 22.40° to 24.90° (Table 2), with a mean value of 23.94°. In all cases, the coefficients of variation were under 3%. The mean coefficients of static friction for aluminum, mild steel (MS), galvanized iron (GI), and plywood were 0.50, 0.45, 0.47, and 0.60, respectively, for green gram seeds. Overall, the coefficient of friction was lowest for MS compared to aluminum, GI, and wood. Consequently, MS was chosen as the material for seed hopper fabrication, ensuring the maximum angle for the selected material to facilitate the free flow of seeds.

Table 2: Angle of repose and frictional properties of green gram seeds

Crop	Descriptive Statistics	Angle of repose (degree)	Coefficient of static friction			
			Aluminum	Mild steel	Galvanized Iron	Plywood
Green gram	Range	22.40-24.72	0.47-0.51	0.43-0.49	0.45-0.49	0.58-0.64
	Mean	23.94	0.5	0.45	0.47	0.6
	CV (%)	3	2	4	3	3

The mean thousand-grain weight of green gram seeds was determined to be 46.18 g. This weight is essential for calculating the seed rate and determining the number of seeds to be distributed along the rows.

Design values of the seed metering mechanism: The average dimensions of length, breadth, and thickness of pulse seeds played a crucial role in the seed metering plate's design. Based on the respective average geometric mean diameter ranges of 3.75-4.83 mm for green gram, the optimal plate groove diameter was determined to fall within the 5 to 6 mm range, ensuring precise seed release per hill. The coefficients of friction, ranging from 0.45 to 0.49 when in contact with mild steel material, influenced the material selection process. This led to the choice of mild steel for the hopper's design due to its lower frictional properties with the seeds. The average angle of repose for green gram ranged from 22.40 to 24.72 degrees. These angle of repose values were instrumental in determining the appropriate slope of the hopper to facilitate uninterrupted, free flow of pulse seeds. Consequently, a minimum angle of 24.72 degrees was selected for the hopper's design.

Conclusion

Assessing the physical properties of selected seed varieties is essential for designing a seed metering unit. A size range of 5 to 6 mm determined the plate groove diameter. Sphericity values, ranging from 0.79 to 0.94 for green gram, influenced the slope design of the seed transfer cup to enable free seed movement. The lowest coefficient of friction, 0.45, was associated with mild steel material, guiding its selection for hopper design. Using angle of repose values, a suitable hopper slope was determined for unrestricted seed flow, with observed angles between 22.40 and 24.72 degrees for green gram seeds. The bulk density values of the selected varieties ranged from 0.86 to 0.87 g/cc, serving as the basis for calculating the hopper's volume.

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