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Investigation of Engineering Properties of Black Gram and Horse Gram for the Design of Hopper and Seed Plate of a Pneumatic Planter

Amit Kumar [a*] and Jayan P R [a]

[a] *Department of Farm Machinery and Power Engineering, KCAET, Tavanur, Kerala Agricultural University, Kerala-679573, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Authors have worked collectively to complete the objectives of the research study and have expressed that no competing interests exist. Both authors read and approved the final manuscript.

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ABSTRACT

Study presents an in-depth evaluation of the engineering properties of Black Gram (*Vigna mungo*) varieties VBN-6 and ADT-5, and Horse Gram (*Macrotyloma uniflorum*) varieties KS-2 and Paiyur-2. This is carried out for the design of a pneumatic seed metering unit viz., seed plate and the hopper. Emphasizing the importance of physical and engineering properties, the investigation on moisture content, axial dimensions, gravimetric properties, and key engineering characteristics such as density, porosity and frictional properties provides critical data for optimizing the design and functionality of the pneumatic seed metering unit, including the seed plate and hopper. For black gram, metering plates with 2.1 mm cell diameter were found optimal, whereas horse gram varieties

*Corresponding author: E-mail: amitchauhanarya1996@gmail.com; 2020-28-005@student.kau.in;

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require 3.5 mm diameter with 26 cells. Hopper of 9100 cm3 capacity made of mild steel of 2 mm thickness was developed according to the seed bulk density and flow characteristics. These properties made the pneumatic metering mechanism compatible with pulse seeds and helped to mechanize the pulse sowing.

Keywords: Black gram; horse gram; hopper; pneumatic planter; precision agriculture.

1. INTRODUCTION

As the population increased, people have been looking for ways to grow more food with less resources and make it sustainable. Precision farming is helping farmers to achieve this goal [1]. One important part of precision farming is using the right equipment for each crop. Among various operation sowing operation is crucial and important for the crop. Therefore, Planting machines need to be designed specifically for the seeds the plant. Pneumatic planters represent a significant innovation in this domain, offering precise seed placement and improved crop yields [2-4]. However, the effectiveness of these planters is contingent upon the design of their metering mechanism tailored to the physical and engineering properties of the seeds they dispense [5,6].

In the pneumatic meter mechanism, the following components viz., the casing, hopper, plate, air suction canal and air cut area were considered as important parts. The casing is designed to accommodate various types of seeds, ensuring versatility in planting applications. Through experiments, it has been found that maintaining pneumatic pressure between 2 to 6 kPa yielded satisfactory results for different seed types. However, the major optimizing performance lies in selecting the appropriate plate with the appropriate hole size and number, hopper, air suction canal and air cut area [7]. This study aims to address the connection between the characteristics of seeds and the design of hopper and plate for pneumatic seed metering mechanism, with a specific focus on pulses viz., black gram (*Vigna mungo*) and horse gram (*Macrotyloma uniflorum*) seeds. These pulses are essential food staples in many regions but pose unique challenges when it comes to mechanized planting. India stands as the leading global producer and consumer of black gram, contributing approximately 24.5 lakh tonnes annually from around 4.6 million hectares, reflecting an average yield of 533 kilograms per hectare in the 2020-21 period, as reported by the Ministry of Agriculture & Farmers Welfare. The cultivation of black gram occupies nearly 19% of the nation's overall pulse cultivation area, making up about 23% of the country's total pulse production. In India, horse gram is cultivated across approximately 5.07 lakh hectares, with a total output of 2.62 lakh tonnes and an average yield of 516 kilograms per hectare. Key contributors to horse gram production include Karnataka, leading with 28% of the national total, followed by Tamil Nadu contributing 18%, and Maharashtra, Orissa, and Andhra Pradesh each accounting for 10% [8].

An investigation of the physical and engineering properties of black gram (VBN-6, ADT-5) and horse gram (KS-2, Paiyur-2) seeds towards the design and development of the hopper and seed plate for the pneumatic meter mechanism suitable briefly explained.

2. MATERIALS AND METHODS

This research investigated the physical and engineering properties of Black Gram (*Vigna mungo*) varieties VBN-6 and ADT-5, and Horse Gram (*Macrotyloma uniflorum*) varieties KS-2 and Paiyur-2. These two varieties were selected because, the varieties are mostly used in the southern part of the India especially in the states like Tamil Nadu, Kerala and Karnataka. These varieties are easily available locally and suitable for local soil and climatic condition. The motive behind the study was to mechanize the pulse sowing using precision planter. The seeds were collected from the Regional Agricultural Research Station at Pattambi, one of the major research station of Kerala Agricultural University. In this study, the moisture content of the seeds using the oven drying method and all the physical properties were determined at this moisture content [9], (Pathak et al*.,* 2020). Dimensions measured as suggested by Pandiselvam et al. [10], Nimkar et al*.* [11] included axial dimensions, arithmetic mean diameter (Da), geometric mean diameter (D), aspect ratio (R), sphericity (ϕ), and roundness (R) These evaluations provided insights into the seeds handling characteristics, used for optimizing storage and transportation systems. Additionally, bulk density and porosity were determined to understand the seeds storage.

Further, the study delved into engineering properties (the angle of repose to gauge how these seeds interact with surface of different materials). Additionally, evaluated the coefficient of friction between the seeds and various surfaces, informing the design of hoppers and material suitable for grain movement.

2.1 Moisture Content

Moisture content in the seed samples was determined using the oven drying method at 105 ± 2°C for 5 hours, following AOAC [12] guidelines. The moisture content was calculated as a percentage on a dry basis using a specific formula.

$$M = \frac{w_1 - w_2}{w_2} \times 100 \tag{1}$$

Where, 'M' represents the moisture content (%), 'W_1' denotes the initial weight of the seeds (g), and 'W_2' represents the weight of the oven-dried sample (g).

2.2 Axial Dimensions

Axial dimensions are critical for determining the size and shape characteristics of seeds, which influence their behavior during mechanical handling and sowing. Accurate measurements of length, width, and thickness are essential for designing appropriately sized components in seed metering and planting equipment to ensure efficient and precise seed distribution.

2.2.1 Size of black gram and horse gram seeds

The size of black gram and horse gram seeds was determined using digital Vernier calipers with a precision of 0.01mm (Mitutoyo of Japan) for the following:

a. Length (L)
b. Width (W)
c. Thickness (T)

For each variety, measurements were taken on 100 seed samples, and the mean values were calculated.

2.2.2 Arithmetic mean diameter (D_a)

Calculated as per Kiani Deh Kiani et al*.* [13] and Mohsenin [14], this diameter is a fundamental size measurement of the seeds.

$$D_a = \frac{L+W+T}{3} \tag{2}$$

Where, 'D_a' represents the arithmetic average diameter of the black gram and horse gram seeds, 'L' denotes the major diameter of the seeds, 'W' signifies the intermediate diameter of the seeds, and 'T' represents the minor diameter of the seeds.

2.2.3 Geometric Mean Diameter (D)

This diameter was derived using length, width, and thickness measurements, based on the relationship outlined by Pradhan et al*.* [15].

$$D = (L \times W \times T)^{\frac{1}{3}} \tag{3}$$

2.2.4 Aspect Ratio (R)

Representing the width to length ratio, the aspect ratio was calculated following Mohsenin's method [16].

$$R = \frac{W}{L} \times 100 \tag{4}$$

2.2.5 Sphericity

Defined by Mohsenin [16] as a measure of seed roundness, sphericity compares the seed's surface area to that of a sphere with the same volume.

ϕ = (Surface Area of Sphere) / (Surface Area of Seed)

Where, 'ϕ' represents the sphericity of the seed.

Surface area of a sphere was calculated using the formula, $A = 4\pi R^2$, where 'R' is the radius of the sphere. For the seed, the projected area was determined through image processing using a flatbed scanner to acquire images, followed by analysis using ImageJ software to estimate surface area.

2.2.6 Roundness

As described by Maduako & Hamman, [17] and Manoharan [18], roundness measures the corner sharpness of the seeds and was determined using a specific mathematical expression.

$$R = \frac{Ap}{Ac} \tag{5}$$

Where, 'Ap' represents the largest projected area of the seed in its natural rest position (mm^2), and

'Ac' represents the area of the smallest circumscribing circle (mm^2). It is also analyzed by using ImageJ software.

2.3 Gravimetric Properties

2.3.1 Bulk density

Bulk density of black gram and horse gram seeds was determined using a 10×10×10 cm box. Seeds were filled in the box, and their weight measured with an electronic scale (precision: 0.01 g). This process was repeated 10 times with different seed. Bulk density was calculated as the average seed weight divided by the box volume.

$$\rho_b = \frac{M}{V} \tag{6}$$

Where, ρ_b represents the bulk density of the seeds (g cm^{-3}), M is the total weight of the seeds measured in grams, V is the volume in cm^{-3}.

2.3.2 True density

True density (ρt) representing mass per unit volume without empty spaces, was measured using the toluene displacement method [19]. This method involves immersing seeds in toluene using pycnometer to calculate their volume based on the displaced liquid, chosen over water due to toluene low surface tension and non-absorbency by the grains [20,21]. The process included immersing a known quantity of seeds in toluene and measuring the volume displaced, allowing for the calculation of true density.

$$\rho_t = \frac{W_s}{V_s} \tag{7}$$

Where, ρ_t represents the true density of seeds in kilograms per cubic meter (kg m^{-3}), Ws refers to the weight of seeds in kilograms (kg), and Vs denotes the true volume of seeds in cubic meters (m^3).

2.3.3 Porosity

Calculated using the relationship between bulk density and true density as described by Mohsenin [16]. This calculation helps to determine the void spaces within the grains.

$$\rho = \frac{(\rho_T - \rho_B)}{\rho_T} \tag{8}$$

Where, ρ_b represents the bulk density of the grains (kg m^{-3}), ρ_t represents the true density (kg m^{-3}).

2.4 Frictional Properties

2.4.1 Angle of repose

When any given grain material is allowed to fall freely the material will heap up forming a cone. To determine the angle of repose apparatus used that consists of a funnel like feed hopper, the bottom of which can be opened or closed. At the bottom of the funnel shaped hopper, iron discs of varying diameters like 100, 150 and 200 mm are placed. This is mounted on a stand. There is a pointer to measure the height. The entire device is placed in a trough [22]. The given grain material was filled in the feed hopper. Below the feed hopper the given disc of known diameter was placed. The funnel was opened and the grain was allowed to heap freely. The grain heap took the form of a cone. The height and diameter of the cone was measured [23,24]. This method is called filling type angle of repose. From this, the angle of repose was calculated using formula

$$\theta = \tan^{-1}\frac{2H}{D}$$

2.4.2 Coefficient of friction

The coefficient of external friction for black gram and horse gram grains against various surfaces (plywood, aluminum, mild steel, stainless steel, and GI sheet) was measured using a specific setup. Testing the friction of seeds on different surfaces helps pick the best materials and designs for hoppers. This ensures seeds flow smoothly and don't get stuck. A box containing a 250-gram sample of the seeds was pulled across these surfaces using a wire and pulley system [25]. The frictional force required to move the box was recorded, and the static coefficient of friction (μ_e) was calculated as the ratio of this frictional force to the normal force. This experiment was repeated 10 times for each grain variety to determine the average value.

$$\mu_e = \frac{F}{W}$$

Where, 'μ_e' represents the coefficient of external friction, 'F' denotes the weight required to slide the box, 'W' represents the weight of the grains

3. RESULTS AND DISCUSSION

This study revealed variations in the axial dimensions of black gram and horse gram, with horse gram typically larger than black gram. Mean, variance, and standard deviation were used to assess size diversity, particularly in black gram varieties like VBN-6, showed notable size variability. Aspect ratio and sphericity analyses highlighted distinct shape characteristics between the two seed types, with horse gram showing a lower aspect ratio but similar sphericity to black gram. The roundness parameter averaged around 0.52 for all varieties, indicating consistent seed shape across types.

All parameters investigated were carried out at the moisture content of about 11%, with a standard deviation of ±0.50%. This uniform moisture level is crucial as it significantly impacts the seeds physical, gravimetric, and friction properties as shown in Table 1.

3.1 Dimension

In terms of length, black gram varieties VBN-6 and ADT-5 range from 2.32 mm to 3.88 mm and 3.85 mm to 4.49 mm, respectively. Comparatively, horse gram varieties KS-2 and Paiyur-2 tend to be larger, with lengths varying between 6.02 mm and 6.27 mm for KS-2, and 5.64 mm to 6.00 mm for Paiyur-2. This difference in size has been documented by Harshavardhan et al*.* [26] and Vashishth et al*.* [27]. Moving on to width, black gram varieties VBN-6 and ADT-5 exhibit significant variation, ranging from 1.99 mm to 3.65 mm and 3.10 mm to 3.53 mm, respectively. Similarly, horse gram varieties KS-2 and Paiyur-2 also show notable width differences, with measurements falling between 4.10 mm and 4.35 mm for KS-2, and 3.65 mm to 3.96 mm for Paiyur-2. As for thickness, there is comparatively less variation. Black gram varieties VBN-6 and ADT-5 display thickness ranging from 1.56 mm to 2.07 mm and 2.96 mm to 3.29 mm,

Table 1. Comparative analysis of axial dimension properties of black gram and horse gram varieties for pneumatic planter design

Parameter	Measure-ment	Black Gram		Horse Gram	
		VBN-6	ADT-5	KS-2	Paiyur-2
Length (mm)	Min	2.32	3.85	6.02	5.64
	Max	3.88	4.49	6.27	6.00
	Mean	3.12	4.21	6.14	5.83
Width (mm)	Min	1.99	3.10	4.10	3.65
	Max	3.65	3.53	4.35	3.96
	Mean	2.90	3.31	4.23	3.80
Thickness (mm)	Min	1.56	2.96	2.16	1.96
	Max	2.07	3.29	2.45	2.16
	Mean	1.85	3.14	2.31	2.06
Arithmetic Mean D (mm)	Min	1.95	3.30	4.09	3.75
	Max	3.20	3.77	4.36	4.04
	Mean	2.62	3.55	4.22	3.90
Geometric Mean D (mm)	Min	1.92	3.24	3.71	3.38
	Max	3.05	3.69	4.00	3.66
	Mean	2.53	3.48	3.86	3.53
Aspect Ratio (%)	Min	85.69	76.59	67.96	64.28
	Max	99.68	80.50	69.50	66.14
	Mean	92.62	78.64	68.88	65.17
Sphericity (%)	Min	78.34	76.34	61.43	58.06
	Max	85.12	83.21	67.86	64.95
	Mean	83.61	80.44	63.68	61.23
Roundness	Min	0.45	0.46	0.33	0.34
	Max	0.57	0.53	0.42	0.39
	Mean	0.53	0.49	0.38	0.36

respectively. Meanwhile, horse gram varieties KS-2 and Paiyur-2 show thickness measurements ranging from 2.16 mm to 2.45 mm for KS-2, and 1.96 mm to 2.16 mm for Paiyur-2.

3.2 Arithmetic and Geometric Mean Diameter

Black gram varieties have smaller mean diameters compared to horse gram, influencing plate hole design.

3.3 Aspect Ratio, Sphericity, and Roundness

Black gram shows more variability in aspect ratio, indicating seed elongation differences. Sphericity and roundness are more consistent across varieties, with sphericity ranging from 58.06% to 85.12% and roundness from 0.33 to 0.57, impacting seed plate and flow mechanism design in pneumatic meter mechanism.

3.4 Bulk Density

The bulk density of the seeds plays a pivotal role in determining the volumetric design of the seed hopper, guiding its capacity and informing how many kilograms of seed it can hold at any given time. The bulk density of black gram varieties, VBN-6 and ADT-5, ranges from 800.00 to 814.00 kg m^{-3} and 812.00 to 834.00 kg m^{-3}. For horse gram varieties, KS-2 and Paiyur-2 show a slightly higher range as shown in Fig. 1. Theertha et al. in 2014 reported analogous findings.

3.5 True Density

True density values offer insight into the compactness of the seeds. Fig. 2. Depicted that Black gram's VBN-6 and ADT-5 have true densities with means at 1433.50 kg m^{-3} and 1458.33 kg/m^3. In contrast, horse gram's KS-2 and Paiyur-2 have slightly lower ranges with means at 1387.933 kg m^{-3} and 1359.40 kg m^{-3}.

3.6 Porosity

Porosity, which affects how seeds interact with air and moisture, shows VBN-6 and ADT-5 with porosities averaging at 43.71% and 43.52%. Horse gram KS-2 and Paiyur-2 have slightly lower porosities with means at 33.29% and 33.13 percent. In 2013, Liny et al. discovered results akin to those for the geometric and gravimetric characteristics of Black Gram. Porosity impacts how seeds move in the hopper, how air flows through it, and how well it keeps seeds dry. Porous seeds may necessitate smoother hopper surfaces or the use of agitation mechanisms to prevent clumping and clogging.

3.7 Analysis of Angle of Repose and Coefficient of Friction in Black Gram and Horse Gram Varieties on Various Surfaces

Engineering properties like the coefficient of friction and angle of repose showed notable variations for black gram and horse gram varieties on different surfaces. For black gram, VBN-6 had an angle of repose ranging from 25.01° to 25.31° (mean 25.18°), and coefficients of friction between 0.52 and 0.29 on various surfaces. Similar findings were reported by Sharon et al. [28]. ADT-5 showed a slightly higher angle of repose (25.51° to 25.88°, mean 25.71°) and coefficients of friction ranging from 0.57 to 0.32. Horse gram KS-2 exhibited an angle of repose from 23.41° to 25.06° (mean 24.45°) and friction coefficients from 0.61 to 0.31, while Paiyur-2 had an angle of repose from 20.03° to 23.67° (mean 22.06°) and friction coefficients from 0.57 to 0.29 as shown in Fig. 3. These findings, consistent with Sonawane et al. [29], are essential for selecting materials for planter hoppers and seed plates, ensuring optimal seed interaction with planter components.

3.8 Optimizing Plate and Hopper Design Based on Seed Properties

The design of a seed plate for vacuum seed metering system for black gram and horse gram seeds involved several critical considerations:

Seed plate openings: The circular holes in the seed plate were chosen based on their effectiveness in seed placement, as per Barut and Özmerzi [30].

To ensure a single-seed release, the seed plate holes were designed with a conical shape and an optimal angle of 120°, as recommended by Singh et al. [31]. Additionally, the diameter of the openings was determined to be less than 50% of the seeds' geometric mean diameter. This design approach ensures precise and efficient seed metering, preventing multiple seeds from being released simultaneously and thus enhancing the overall effectiveness of the pneumatic seed metering unit.

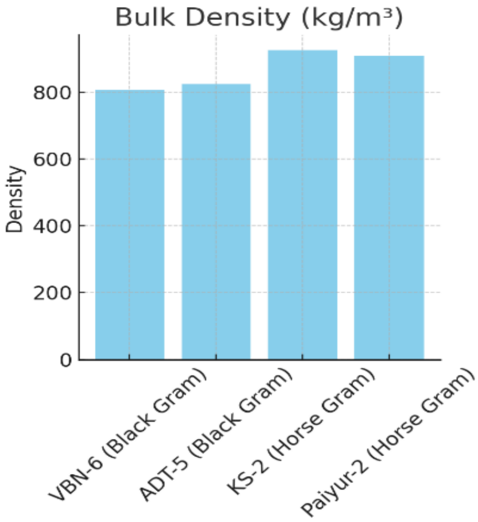

Fig. 1. Comparative Mean Bulk Density of Black Gram and Horse Gram Varieties

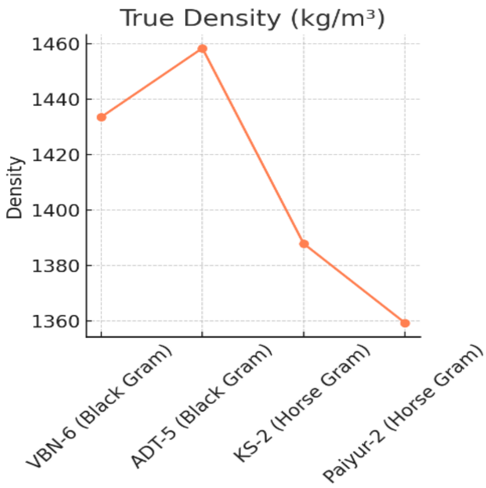

Fig. 2. Variation in Mean True Density Across Black Gram and Horse Gram Varieties

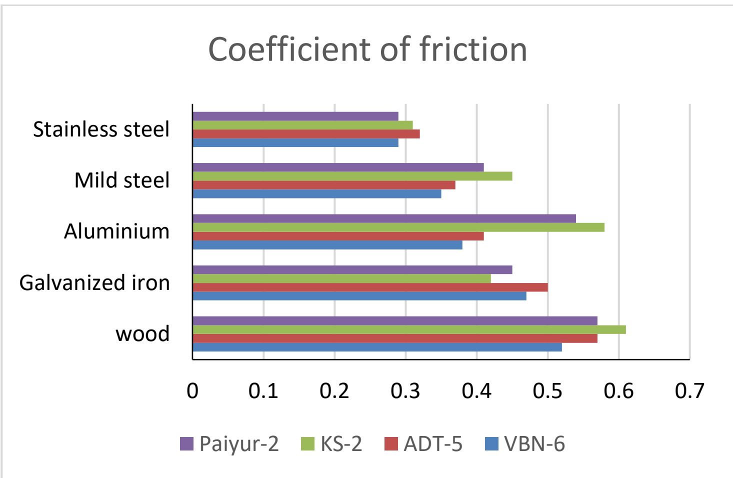

Fig. 3. Coefficient of friction across various surfaces for black gram and horse gram varieties

In the present study, the diameter of openings on the seed plate (d_o) was also based on the less than 50% size of the geometric mean diameter of the black gram and horse gram. The maximum geometric mean diameter of black gram seeds was Dg = 3.69 mm and for horse gram it is 4.00 mm.

For black gram: For black gram seeds, the diameter of the openings (do) in the seed plate should be designed to be less than or equal to 50% of the geometric mean diameter (Dg). Given that the geometric mean diameter for black gram is 3.69 mm, this calculation results in do being less than or equal to 1.845 mm. Based on the guidelines provided by Sial and Persson [32] and Afify et al. [33], for conical angles of 90°, 120°, or 150°, the relationship between Dg and do can be expressed as Dg cosβ ≤ do < Dg.

For an angle of 90° (where β = 45°), the opening diameter range is 2.61 mm ≤ do < 3.69 mm. For an angle of 120° (where β = 60°), the range is 1.845 mm ≤ do < 3.69 mm. For an angle of 150° (where β = 75°), the range is 0.96 mm ≤ do < 3.69 mm.

Therefore, in this study, the opening diameter of the seed plate (metering plate) must be considered between 0.96 to 3.69 ≈ 3.5 mm for black gram seeds.

For Horse Gram: the opening diameter (do) of the seed plate was set to be less than 50% of the geometric mean diameter (Dg = 4.00 mm), resulting in do ≤ 2 mm. Considering angles 2β = 90°, 120°, or 150°, the opening diameter ranges were established as follows: for 2β = 90°, do is between 2.83 to 4.00 mm; for 120°, from 2 to 4 mm; and for 150°, from 1.04 to 4 mm. Thus, the study recommends an optimal seed plate opening diameter range of 1.04 to 4 mm for Horse Gram seeds, in alignment with the guidelines of Sial and Persson [32] and Afify et al. [33].

Number of openings on the seed plate: The rotational speed of the ground (transporting) wheel of seeding machine and seed plate were considered equal ($n_s = n_w$), then the circumference of ground wheel (C_w) for wheel diameter D_w = 63.5 cm, it will be [34]:

$$C_w = \pi \times D_w$$

$$C_w = \pi \times 63.5 = 199.4 \text{ cm} \approx 200 \text{ cm}$$

If seed spacing within row (x_s) for black gram and horse gram seeds is 15 cm, thus from under given Equation, the number of openings or cells on the seed plate with assuming $N_r = 0.5$

$$n = \frac{C_w}{x_s \times N_r}$$

Then,

$$n = \frac{200}{15 \times 0.5}$$

N = 26.67 ≈ 26

The number of openings on the seed plate was calculated based on the rotational speed of the seeding machine ground wheel, resulting in approximately 26 openings [35].

Pitch circle diameter: It can be given in terms of a circumference of pitch circle seed plate, as follows:

$$D_p = \frac{C_p}{\pi} = \frac{N \times (D_0 + C_0)}{\pi}$$

Where;
C_o = distance between two holes
C_e = distance between hole and outer diameter

$$D_p = \frac{26 \times (12 + 4)}{3.14}$$

D_p = 132 mm

Pitch circle diameter calculated using the number of openings and the diameter of openings, was found to be 132 mm [36].

Outside diameter of the seed plate: For determining the outside diameter of the seed plate, D_s

$$D_s = D_p + D_o + 2C_e$$

Then: D_s = 132 + 12 + (2 × 20) = 184 mm

The outside diameter was determined to be 184 mm, factoring in the pitch diameter and the distance between holes and the outer diameter [37].

Material selection: Stainless steel has been chosen for the seed plate of the pneumatic metering mechanism because it has a low coefficient of friction, meaning seeds can move easily on its surface preventing them from clumping or getting stuck. Additionally, stainless steel is strong and durable, so it won't easily break or wear out, making it a reliable choice for handling both black gram and horse gram seeds under vacuum pressure and continuous rotation.

Seed properties and plate fabrication: The study findings on black gram (VBN-6, ADT-5) and horse gram (KS-2, Paiyur-2) aid to design metering plates to suit each seed type. For smaller seeds like VBN-6 and ADT-5, plates with 2.1 mm holes were found optimal, while larger 3.5 mm holes were preferred for bigger seeds like KS-2 and Paiyur-2. These plates, made of durable stainless steel and featuring twenty-six holes each, were engineered to match the seeds specific characteristics. Stainless steel was chosen for its durability and low friction. SolidWorks illustrations depict these design adaptations for efficient seed handling shown in Fig. 5.

Hopper design and capacity: The design of the seed hopper for the pneumatic planter involved several considerations based on the seed rate, working width of the planter, and the desired capacity of the seed. With a maximum seed rate of 40 kg ha-1 and a planter speed of 2 km h-1, the actual field capacity was calculated to be 0.224 ha h-1, leading to a required seed weight of 26.88 kg over a 3-hour period. Let assume the pneumatic planter has four separate hoppers were designed to accommodate this capacity, each capable of holding 7 kg of black gram seeds.

The design of the seed hoppers involved calculating their volumes based on the sections they comprise as shown in Fig. 4. Section 1, with dimensions of 30 cm in length, 15 cm in width, and 14 cm in height, has a volume of 6300 cm³. Section 2, measuring 15 cm in length, 10 cm in width, and 14 cm in height, has a volume of 2100 cm³. Section 3, with a triangular base measuring 10 cm by 10 cm and a height of 14 cm, has a volume of 700 cm³. The total volume computed from sections (i), (ii), and (iii) amounts to 9100 cm³.

Thickness of the hopper sheet: The hopper sheet thickness was determined to withstand lateral pressure from loaded pulse seeds, using Rankine's formula for maximum lateral bending moment.

$$M_b = \frac{\rho\, h^2\, b^2\, \cos\theta}{8}$$

Where, M_b = Maximum lateral bending moment, N-m; ρ = bulk density of the seeds, kg/m³; h = total height of the hopper, m; b = total breadth of hopper, m; ϴ = angle of repose of black gram (25°)

With a maximum angle of repose of black gram at 25°, the calculated maximum lateral bending moment on the hopper walls is 5.16 Nm.

The stress due to bending on the hopper walls can be calculated using the following relation:

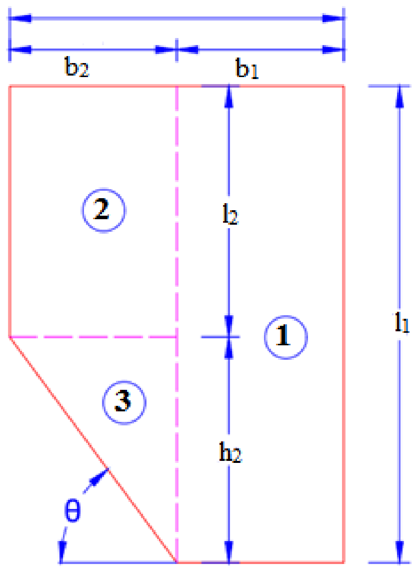

Fig. 4. Cross sectional view of seed hopper

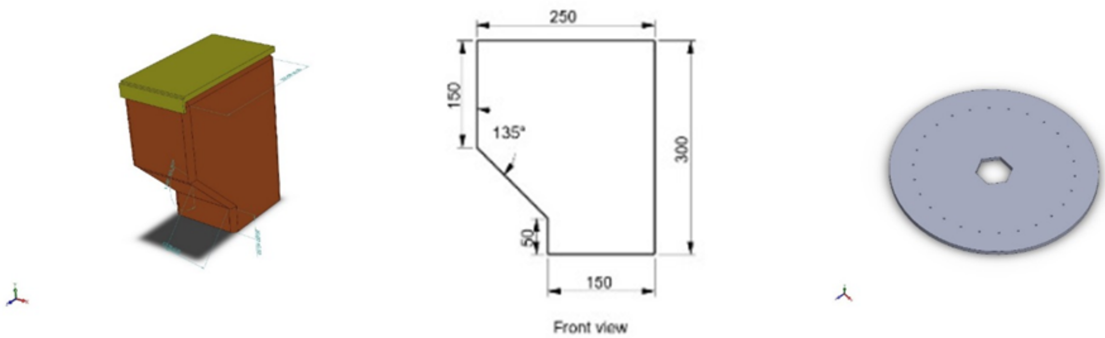

Fig. 5. Design of hopper and seed plate for pneumatic meter mechanism

Fig. 6. Fabricated seed hopper and metering plates for pneumatic meter mechanism

$$\sigma_{b\,max} = \frac{M_b Y}{I}$$

Where, σ_{bmax} = maximum bending stress, N/m^2 (250 N/m^2 for mild steel); M_b = Maximum lateral bending moment on the walls of hopper, N-m; Y = distance of sheet from the neutral axis, m; I = moment of inertia of the sheet, m^4

The calculated allowable stress is 125×10^6 N/mm². Substituting this into the equation, the thickness of the mild steel sheet needed to withstand the lateral pressure due to loading of black gram is found to be 1.0 mm. However, for safety and considering material availability, a mild steel sheet with a thickness of 2 mm was used for the hopper fabrication.

Each mild steel seed hopper, designed with a capacity of 7 kg, has a volume of 0.0091 m³. The hoppers are constructed at a 45° angle to optimize seed flow, and a total of 4 seed hoppers are required for the planter design. This design ensures consistent seed flow and aligns with Harshavardhan et al. [26] findings. Overall, the engineering properties of the seeds were crucial in designing and fabricating the pneumatic meter mechanism especially seed plate and hopper. The final developed hopper and seed plate are shown in Fig. 6.

4. CONCLUSION

This study investigated the physical and engineering properties of two black gram varieties (VBN-6, ADT-5) and two horse gram varieties (KS-2, Paiyur-2). Significant differences were observed in axial dimensions, with horse gram generally exhibiting larger seeds than black gram. The data reveals that seed properties directly influence the design of the pneumatic planter metering mechanism parts, particularly the seed plate and seed hopper. In seed plate design, optimal seed plate hole diameters were determined (approximately 2.1 mm for black gram and 3.5 mm for horse gram) to ensure precise seed singulation. Plate material (stainless steel) was selected for low friction properties and durability. In hopper design, the geometric calculations, seed bulk density and angle of repose established the hopper capacity (7 kg) and shape, including a 45° angle for reliable seed flow with 2 mm mild steel for hopper wall construction, ensuring sufficient strength. These findings offer valuable insights for the design of seed plate and hopper tailored to the specific properties of black gram and horse gram seeds. The optimized designs outlined in this study can improve seed metering accuracy, which is important for these staple crops. In future, field trials are required to evaluate the real-world performance of the designed planter components.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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