Design of Seeder in Relation to the Physical and Frictional Properties of Black Gram Varieties

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Authors' contributions

This work was carried out in collaboration among all authors. Author KH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SSS and JJG managed the analyses of the study. Authors VAA and PKP managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Physical and frictional properties of black gram seeds play an essential role in designing a seeder in order to decide cell size, shape, thickness of metering disc and material, inclination of seed hopper. The present study aimed to determine the physical and frictional properties of black gram seeds of three varieties *viz.,* VBN 6, ADT 5 & T9. Length, breadth, thickness, roundness, thousand seed weight, geometric mean diameter, sphericity were evaluated for designing metering disc of seeder. Bulk density, true density, angle of repose, coefficient of restitution and coefficient of static friction were evaluated for designing seed hopper of seeder. Cell diameters and thickness of the seed metering discs were designed based on the maximum breadth and length of seeds. Seed flow through the various components of the seeder were affected by both roundness and sphericity. Roundness of VBN 6, ADT 5 and T9 were 0.52, 0.49 and 0.51 respectively, while sphericity in the natural rest position of these seeds were 0.85±0.05, 0.85±0.06 and 0.85±0.04 respectively. The slope of the seed hopper was fixed at 30□, which is moderately higher than the average angle of

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repose of seeds for ensuring free flow of seeds. Mild steel sheet of material grade Fe 410 and 18 gauge *i.e.,* 1.214mm thickness was selected for seed hopper in reference to the coefficient of static friction to other materials (Al, GI, SS & wood). In addition, the inner bottom surface of the seed hopper from where the seed enters into metering disc was imbedded with 3mm thick rubber sheet as its coefficient of restitution was lower than mild steel sheet of same thickness at different heights. It was observed that the average coefficient of restitution values of three varieties (VBN 6, ADT 5 & T9) were 4.2, 2.8, 2.8, 2.9, 2.9 & 2.1 times lower in rubber sheet compared to MS sheet at the heights of 50, 100, 150, 200, 250 & 300 mm respectively.

1. INTRODUCTION

Black gram is a member of the Asiatic Vigna crop group. Similar to the other pulses, black gram, being a legume, enriches soil nitrogen content and has relatively short (60 - 75 days) duration of maturity [1]. Black gram is scientifically known as *Vigna Mungo* L. and it is commonly known as Urad or Mash in India. India is its primary origin and is mainly cultivated in Asian countries including Pakistan, Myanmar and parts of southern Asia. Black gram supplies a major share of protein requirement of vegetarian population of the country. About 70% of world's black gram production comes from India [2,3].

India currently represents the largest producer of black gram accounting for more than 70% of the global production. India is followed by Myanmar and Pakistan. In India about 7.629 lakh ha area was covered under black gram during rabi (2018-19). The states of Tamil Nadu (2.70 lakh ha), Andhra Pradesh (2.61 lakh ha), and Odisha (2.01 lakh ha) are the major producers of rabi black gram in India [4]. The production of black gram in India gradually increases from 17.7 lakh tonnes in 2011-12 to 35.6 lakh tonnes in 2017-18 and decreased to 26.5 lakh tonnes in 2018-19 [5].

The seeder sows the seeds at the proper seeding rate and depth, ensuring that the seeds are covered by soil. This saves them from being eaten by birds and animals, or being dried up due to exposure to sun. With seeder machines, seeds are distributed in rows, The distance between rows is typically set by the manufacturer. This allows plants to get sufficient sunlight, nutrients, and water from the soil.

In India still sowing with seeder is not practicing even though many researchers are suggesting that sowing with machinery will provide better yields and consume less time. One of the main reasons for this condition is unavailability of black gram sowing machinery in Indian market. In view of this, the seeder which can sow black gram seeds as per requirement should be developed for precise sowing. To achieve this, suitable metering mechanism with appropriate cell geometry for metering seeds and suitable material for seed hopper with proper dimensions are essential which can be designed by studying the physical and frictional properties of seeds. Hence the study on "Design of seeder in relation to the physical and frictional properties of black gram varieties" has been contemplated.

The physical properties and frictional properties are useful and necessary in the design and operation of various farm equipment's employed for agricultural operations [6]. The important physical and frictional properties which are directly related to the seeder development, were determined in the present study. The knowledge of physical and frictional properties is important for design, development and efficient operation of a seeder. Seed flow through a planter or seeder is dependent on physical and frictional properties of seeds. In addition, the impact of seeds on the internal components of the planter is influenced by the coefficient of restitution of seeds on various impinging surfaces. Basic information on these properties is of great importance and help for engineers and scientists towards the equipment development and its efficient operation.

Since the size and shape of many local varieties vary from each other, attempts were made to find out the optimum design parameters of a seeder by determining the relevant physical and frictional properties of three varieties of black gram seeds (ADT 5, VBN 6 & T9). These three varieties are selected in such a way that these varieties should cover all the districts of Tamil Nadu as well as which can sow in all the three seasons i.e., ADT 5, VBN 6 & T9 belongs to *kharif, Rabi and Zaid* seasons respectively [1].

1.1 Objectives of Paper

1. To determine physical properties of black gram seeds.
2. To determine frictional properties of black gram seeds.
3. To design seed metering disc and seed hopper for black gram seeder based on obtained physical and frictional properties.

1.2 Review of Literature

Wani et al., in 2013 [7] done experiment on physical and cooking characteristics of black gram cultivars grown in India and concluded that most of the physical properties did not show significant differences among the black gram cultivars.

Theertha et al., in 2014 [8] studied on effect of moisture content on physical and gravimetric properties of black gram and declared that if moisture content increases, the average length, width, thickness, geometric mean diameter, thousand seed mass, true density, coefficient of friction and angle of repose were increased where as bulk density was found to be decreased.

Manoharan in 2018 [6] has done a comprehensive study on physical properties of black gram and green gram for developing a planter and concluded that the metering cells for black gram planter based on the maximum seed dimension should be 4.25 mm.

Sharon et al., in 2015 [9] studied on moisture dependent physical properties of black gram and said that except bulk and true densities all other properties increases as moisture content increases.

Liny et al., studied on geometric and gravimetric characteristics of black gram and stated that raw material characteristics of seeds can be used for proper equipment design. Also, because of the sphericity values of black gram seeds, he said that the seeds are of hemispherical shape.

2. MATERIALS AND METHODS

In a seeder design, the seed hopper and the seed metering disc are the two main components where seeds are placed and conveyed for sowing. For the proper conveying of seeds to the furrow bottom there should not be any seed damage and missing of seeds while picking the seeds by metering disc also we should avoid stammering of seeds in the seed hopper. To achieve this an appropriate cell size of seed metering disc should be designed in such a way that the selected seeds can pick the seeds without any damage or missing and also, to avoid stammering, seed hopper side walls should be designed with appropriate inclination and with suitable sheet material. To achieve this, determination of physical and frictional properties of seeds is necessary. Here, seeds of three black gram varieties viz., VBN 6, ADT 5 & T9 were selected for determining the physical and frictional properties. The samples for testing were selected randomly from the bulk samples of each variety.

2.1 Physical Properties of Black gram Seeds

Physical properties of black gram seeds such as moisture content, length, width, thickness, geometric mean diameter, aspect ratio, sphericity, roundness, thousand seed weight, bulk density, true density are important for design of metering mechanism and seed hopper of seeder in order to decide the size, thickness, cell size of metering disc and capacity of seed hopper. Hence the physical properties of three varieties of black gram viz., VBN 6, ADT 5 & T 9 were determined by using standard procedure and techniques.

2.1.1 Moisture Content (MC)

The moisture content of black gram seeds was determined using thermogravimetric method. With the help of electronic weighing balance initial weights of samples were recorded. Three replications of each variety were dried in hot air oven at temperature of 105 ± 2 (ASAE, 1994). At 6 hrs intervals the samples had been weighed until the weights of the samples were found to be constant. The moisture content of black gram seeds was calculated by using following relationship [10].

$$MC\ (\%db) = \frac{w1 - w2}{w2} \times 100 \qquad (1)$$

Here,
W1 = Weight of the wet sample (g)
W2 = Weight of the dry sample (g)

2.1.2 Size of black gram seeds

For estimating the size, with the help of digital Vernier callipers (0.01mm precision), principle

dimensions such as length (L), width (W) and thickness (T) were recorded. The measurement was replicated for 100 samples of each variety and their means were computed [11,12,13].

2.1.3 Geometric mean diameter (D_g)

The length (L), width (W) and thickness (T) measured for 100 samples of black gram were used to calculate geometric mean diameter (D_g) with the following relationship [14,15,16].

$$D_g = (L \times W \times T)^{\frac{1}{3}} \qquad (2)$$

2.1.4 Aspect ratio (R)

The aspect ratio (R) is the ratio of width (W) and length (L) as following relation [17,18].

$$R = \frac{W}{L} \qquad (3)$$

2.1.5 Sphericity

The degree of sphericity (ϕ) was determined using the following equation [15,19].

$$\emptyset = \frac{(L \times W \times T)^{\frac{1}{3}}}{L} \qquad (4)$$

2.1.6 Roundness

Roundness is a measure of the sharpness of the corners of solid materials. The roundness of irregular particle was determined by most widely accepted method. Ten samples of each variety were taken and the shape of seed at its natural rest position was traced on paper. The smallest circumscribing circle was constructed on each

tracing paper and the diameter of circle was noted. The area of the smallest circumscribing circle (Ac) was calculated and the largest projected area (Ap) of each sample was measured using a planimeter. Then the roundness was determined using the following expression [20,6].

$$Roundness = \frac{A_p}{A_c} \qquad (5)$$

Here,

A_p = Largest projected area of black gram seed in natural rest position, mm^2
A_c = Area of smallest circumscribing circle, mm^2

2.1.7 Thousand seed weight

Thousand seed weight was determined for 10 random samples of 1000 seeds each (per seed variety) using an electronic balance having sensitivity of 0.01 g [21,17,22].

2.1.8 Bulk density (ρ_b)

A 10×10×10 cm box was filled with black gram seeds and weighed using an electronic weighing machine of 0.01 g accuracy. The trails were repeated 10 times using different varieties of seeds and the bulk density was calculated from the following equation [23,20].

$$\rho_b = \frac{M}{V}, g \ cm^{-3} \qquad (6)$$

Here,
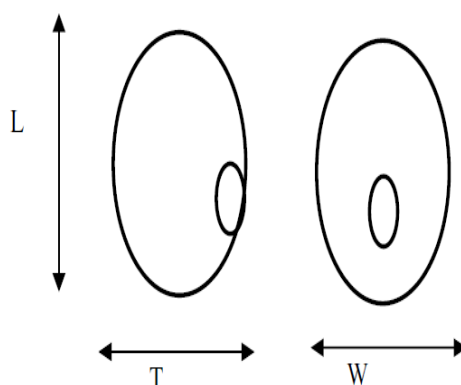
M = Mass of the seed (g)
V = Volume of sampler (cm^3)

Fig. 1. Length, width & thickness measurement of black gram seed

2.1.9 True density (ρ_t)

True density of seeds was calculated as [10].

$$\rho_t = \frac{Bulk\ density}{1 - Porosity}, Kg\ m^{-3} \qquad (7)$$

For this, porosity was determined using a standard porosity apparatus with ten replicates.

2.2 Frictional Properties of Black gram Seeds

The frictional properties such as angle of repose, coefficient of static friction and coefficient of restitution are important in designing of hoppers, chutes, conveying systems etc. of the planters or seeders. In mechanical and pneumatic conveying systems, the materials generally move or slides in direct contact with the trough, casing and other components of the machine. Thus, various parameters affect the power requirement to drive the machine. Among these parameters, the frictional losses are one of the factors which must be overcome by providing additional power to the machine. Hence, the knowledge of frictional properties of the agricultural materials is necessary; therefore, following frictional properties of the black gram were determined as explained below.

2.2.1 Angle of repose (θ)

The angle of repose of seeds was determined by the following method. The seeds were allowed to fall from a height of 300 mm on circular discs of 250, 200 and 100mm diameter until maximum height was reached and the height of seed heap was noted. The experiment was replicated ten times for each seed variety and the average values were computed. The following equation was used to calculate the angle of repose of the selected seeds [27].

$$\theta = \tan^{-1}\frac{h}{r} \qquad (8)$$

Here,
h = height of cone (mm)
r = radius of cone (mm)

2.2.2 Coefficient of static friction (μ)

Coefficient of static friction is a measure of resistance, determined for selecting hopper material for uniform and free flow of seeds. The static coefficient of friction (μ) was determined for five structural materials namely plywood, aluminium, mild steel, stainless steel and galvanized iron sheet. An amount 250 grams of sample was placed on the block (Normal force) and it was pulled across the plane at a constant speed by adding load at the end (Frictional force). The force required to create "bump" which pulls the seeds was noted. Static coefficient of friction (μ) is the ratio of frictional force to the normal force. The procedure was repeated 10 times for each variety and the mean value was calculated [14,21,6].

$$\mu = \frac{F}{N} \qquad (9)$$

Here,
F = Frictional force (force applied)
N = Normal force (weight of the grain)

2.2.3 Coefficient of restitution

Coefficient of restitution of seeds was determined by the following method. In this method, a seed is dropped from a height of 50, 100, 150, 200, 250 and 300 mm on a 3mm thick mild steel and rubber sheets. A graduated scale of 500mm was kept at the background and the maximum height of seed rebounce recorded using a high-speed digital video camera. Height of rebounce was measured in the monitor using the video editing unit. This was replicated 10 times for each seed variety and the coefficient was calculated using the following equation [25,26].

$$Coefficient\ of\ restitution = \sqrt{\frac{h}{H}} \qquad (10)$$

Here

h = height of rebound (mm)
H = height of drop (mm)

3. RESULTS AND DISCUSSION

Results show that VBN 6, ADT 5 and T9 variety seeds were 4.71±0.54, 4.62±0.48 and 4.61±0.47 mm long and 3.88±0.42, 3.85±0.33 and 3.85±0.43 mm wide respectively (Table 1) similar results were obtained with Wani *et al.,* in 3013. Accordingly, the seed metering discs were fabricated with cell diameter of 5mm where

almost similar dimension was taken by Manoharan in 2018 and a plate thickness of 6mm which can suit most varieties of black gram seed. This is expected to meter 1 to 2 seeds when the metering disc cell hole overlaps with the hopper hole. The thickness of each cell in metering wheel was designed in such a way that it can meter only single seed. Movement of non-spherical seed is usually slower under gravity. Sphericity of VBN 6, ADT 5 and T9 in natural rest position were 0.85±0.05, 0.85±0.06 and 0.85±0.04 respectively. Since the metered seeds are to be transferred to the seed placement unit quickly, the lower sphericity value of black gram seeds should be taken into consideration for designing the slope of seed transfer cup. Here the sphericity of all three varieties are almost equal. Again, seed weight effects seed flow from seed metering device to the boot of seeder and in turn, influences the design of seed hopper. Although Bulk density of all 3 variety of seeds were almost same highest value was found in ADT 5 (0.84 g/cm^3) followed by VBN 6 (0.83 g/cm^3) and T9 (0.82 g/cm^3) where similar results were found by Wani *et al.,* in 2013. The mean angle of repose of VBN 6, ADT 5 and T9 were 25.44, 24.86 and 24.19° respectively.

The energy transfer during impact between the falling seed and the seed transfer cup where seed metering disc is placed and related to the coefficient of restitution. Hence, the slope of the seed hopper was kept at 30□ to ensure free flow of seed, which is moderately higher than the average angle of repose of seeds. Furthermore, seeds that fell on the rubber sheet experienced minimum coefficient of restitution compared to that on the mild steel sheet (Table 2) where the similar trends of results was found by Jayan and Kumar in 2004. Therefore, a 3 mm thick rubber sheet was imbedded on the inner surface of the seed transfer cup to minimize seed bouncing. Also, the maximum and minimum values of coefficient of restitution was found for MS sheet and rubber sheet which are 0.553 for VBN 6 and 0.118 for T9 respectively at a height of 50mm. From all the above findings the seeder components (seed metering disc and seed hopper) were designed as shown in Figs. 2 & 3.

Plate 1. Apparatus for measuring coefficient of static friction

Table 1. Physical and frictional properties of black gram seeds

Sl. No.	Parameters	Black gram seed varieties		
		VBN 6	ADT 5	T9
1.	Size and Shape			
	Length (mm)	4.71±0.54	4.62±0.48	4.61±0.47
	Breadth (mm)	3.88±0.42	3.85±0.33	3.85±0.43
	Thickness (mm)	3.49±0.40	3.43±0.32	3.37±0.37
	Geometric mean diameter (mm)	3.99±0.39	3.94±0.28	3.91±0.38
2.	Moisture content (% db)	10.49	11.17	10.74
3.	Roundness	0.52	0.49	0.51
4.	Aspect ratio	0.82	0.84	0.84
5.	Sphericity	0.85±0.05	0.85±0.06	0.85±0.04
6.	Bulk density (g/cm^3)	0.83	0.84	0.82
7.	True density (kg/m^3)	1475	1450	1515
8.	Angle of repose (°)	25.44	24.86	24.19
9.	Coefficient of static friction for different materials			
	Aluminium	0.46	0.54	0.36
	Galvanized iron	0.46	0.53	0.44
	Mild steel	0.38	0.42	0.41
	Stainless steel	0.28	0.34	0.31
	Wood	0.87	0.49	0.60
10.	Thousand seed weight (g)	45.70±0.92	44.28±2.19	40.50±0.16

(95% confidence limit = mean ± 1.645 SD)
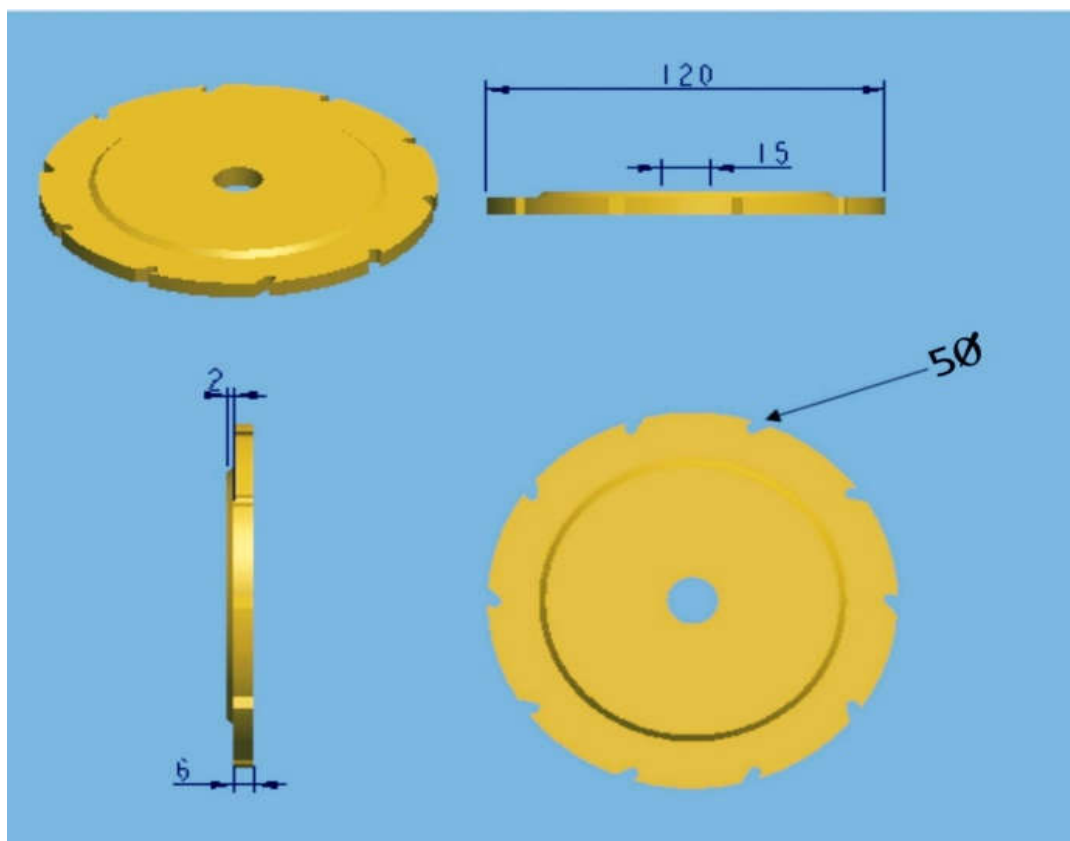
All dimensions are in mm

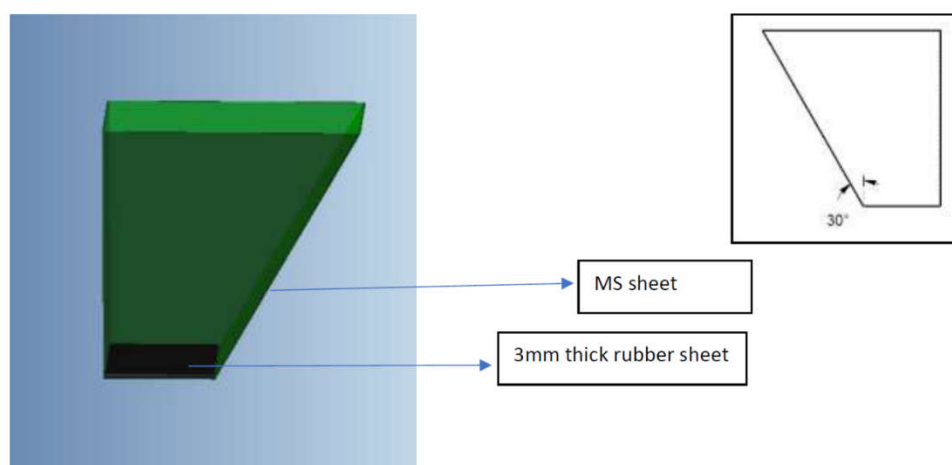**Fig. 2. Seed metering disc for black gram seed**

Fig. 3. Seed hopper for black gram seed

Table 2. Coefficient of restitution of black gram seeds at different dropping heights

Seeds	Impact surface (3mm thickness)	Coefficient of restitution at different dropping heights					
		50mm	100mm	150mm	200mm	250mm	300mm
VBN 6	MS Sheet	0.553	0.452	0.410	0.406	0.407	0.374
	Rubber Sheet	0.141	0.173	0.148	0.141	0.143	0.183
ADT 5	MS Sheet	0.546	0.446	0.413	0.407	0.405	0.378
	Rubber Sheet	0.134	0.145	0.137	0.143	0.140	0.182
T 9	MS Sheet	0.544	0.443	0.403	0.412	0.395	0.370
	Rubber Sheet	0.118	0.161	0.153	0.140	0.136	0.180

The preferred material selected for the fabrication of seed hopper is Mild steel sheet based on the coefficient of static friction. The inclination of the hopper side wall is considered as 30□ which is moderately higher value than the results of angle of repose. Even though mild steel optimum for the fabrication of metering disc, seasoned wood is also preferrable for its low cost, easy availability and less impact on seeds while rotating leading to minimal damage of seeds. At the bottom of the hopper box a 3mm rubber sheet was attached to reduce the rebounding of seeds as per the results of coefficient of restitution.

4. CONCLUSION

All the results of three varieties of black gram (VBN 6, ADT 5 & T 9) were nearly similar so a common metering disc and a common seed hopper for seeder are suitable for all the varieties of black gram. From all the above physical and frictional properties, the design of the metering disc and the seed hopper was finalized. The thickness of the metering disc was taken as 6mm and the thickness of the seed cell was taken as per roundness of the seed viz., 6mm, diameter of the seed cell was considered as 5mm for easy

metering of seeds and also to meter only a single seed in each cell as shown in Fig. 2.

Mild steel sheet of material grade Fe 410 and 18 gauge *i.e.,* 1.214mm thickness was selected for seed hopper in reference to the coefficient of static friction to other materials (Al, GI, SS & wood). At the bottom of the hopper box a 3mm rubber sheet was attached to reduce the rebounding of seeds as per the results of coefficient of restitution as shown in Fig. 3.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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