Journal of Scientific Research and Reports

Volume 30, Issue 5, Page 931-938, 2024; Article no.JSRR.115815
ISSN: 2320-0227

Design of Vertical Rotor Metering Plate for Precision Seeding of Okra: Incorporating Physical and Engineering Properties

P. D. Verma [a,b++#*], A. Verma [c†], R. K. Naik [c†], S. V. Jogdand [c†], A. K. Dave [c‡] and A.S. Rajput [d^]

[a] IGKV, Raipur, India.
[b] Farm Machinery & Power Engineering, KVK – Bhatapara, IGKV, India.
[c] SVCAET & RS, FAE, IGKV, Raipur, India.
[d] DKSCARS, IGKV, Raipur. India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2024/v30i52010

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/115815

Original Research Article

Received: 11/02/2024
Accepted: 15/04/2024
Published: 18/04/2024

ABSTRACT

An investigation was conducted with the aim of examining the physical and engineering properties of okra seeds. The physical and frictional characteristics of okra seeds play a crucial role in the design of a seeder, influencing decisions regarding cell size, shape, metering disc thickness, and material, as well as the inclination of the seed hopper. The study aimed to determine these

[++] Ph.D Scholar (Agril. Engg. – FMPE);
[#] Subject Matter Specialist;
[†] Professor (FMPE);
[‡] Professor and Head, (FMPE);
[^] Assoc. Professor (Agronomy);
**Corresponding author: E-mail: pdvermafmp@gmail.com;*

properties of okra seeds. The primary findings indicated that the typical values for the length, width, and thickness of the seeds were 5.58 mm, 4.61 mm, and 4.18 mm, respectively. The maximum width and length of the seeds served as the basis for the design of the cell diameters and thickness of the seed metering rotor. The okra variety "VNR-Deepika" exhibited a geometric mean diameter of 4.79 mm, with sphericity and roundness values of 85.2% and 82.85%, respectively. The roundness and sphericity of the seed affected its ability to move through the seeder's components. Test weight, bulk density, true density, volume, porosity, angle of repose, and coefficient of static friction were measured as 57.06 g, 0.56 g cm^{-3}, 1.12 g cm^{-3}, 111.46 mm^{-3}, 50.22%, 25.97° and 0.42, respectively. The depth of the vertical rotor cells was established at 6.25 mm, slightly exceeding the average seed length to ensure singular seed dispensing. Simultaneously, the width of each cell was calculated to be 6.98 mm, offering adequate space for accommodating one seed per cell. Featuring 14 cells positioned around the vertical rotor's circumference, the seed metering rotor was designed to have an 85 mm diameter.

Keywords: Vertical rotor design; Okra seeds; Seed properties of okra.

1. INTRODUCTION

Planting is a pivotal process in agricultural cultivation, encompassing considerations such as selecting the right amount of seeds, ensuring optimal depth of planting, and achieving proper seed spacing to enhance crop productivity to its maximum potential. The exact insertion of a single seed at the appropriate spacing into the soil is the characteristic of precision planting. Typically, farmers and researchers employ the manual dibbling method to achieve this level of accuracy. Planters, equipped with single-seed metering mechanisms, are employed to facilitate this process. These devices prevent seed scattering and excessive seed usage by ensuring a consistent seed distribution in rows. This is achieved by avoiding the metering of multiple seeds and minimizing bouncing in the furrow.

In India, there are various types of planters with different seed metering mechanisms, such as horizontal plate, vertical plate, inclined plate, and cup type. These models cater to both animal and tractor power sources, offering diverse options for precision planting in agricultural practices. Kumar et al. [1] studied "on physical properties of okra seed and reported that the physical properties of any seed are vital information for the metering mechanism's development". Rathore and Shrivastava [2] examined and found that developing a seed's metering mechanism requires a thorough understanding of its physical characteristics.

The physical properties of seeds, such as their size, shape, the angle of repose, test weight, and bulk density, are crucial factors according to design of seed metering units. These characteristics significantly influence the effectiveness of seed metering systems utilized in planters or seed drills. Research by Jayan and Kumar [3] investigated the physical properties of maize, red gram, and cotton seeds, highlighting the importance of sphericity and roundness in seed flow through various planter components. Variations in parameters like average unit mass, volume, true density, bulk density, and thousand-seed mass, and porosity among different seed varieties also impact the performance of seed metering mechanisms, as noted by Ramesh et al. [4]. When designing the seed hopper volume for the seed planter, bulk density plays a crucial role.

Physical and engineering properties of seeds are vital for precision planter seed metering rotor design, ensuring accurate and efficient planting. In the Department of Processing and Food Engineering Laboratory at IGKV, Raipur (C.G.) studied the physical and engineering properties of okra seeds to optimize the design of a vertical seed metering rotor.

2. MATERIALS AND METHODS

2.1 Determination of Physical and Engineering Properties of Okra Seed

The physical and engineering properties of seeds, such as size-shape, bulk density, angle of repose, and thousand-grain weight, are pivotal in ensuring the efficiency of seed metering mechanisms. These properties were extensively analyzed to inform the design of an effective seed metering system. Size specifications guided the dimensions of grooves, including length, depth, and the requisite number of seeds per groove. Shape characteristics facilitated smooth and uniform seed flow within the grooves. True density and bulk density values were instrumental in determining optimal seed hopper volume and thickness. The optimal slope for unimpeded seed flow from the hopper was determined by accounting for the angle of repose and coefficient of friction. Measurement of the coefficient of static friction aided in selecting suitable hopper materials conducive to consistent seed flow. Furthermore, thousand-grain weight played a vital role in calculating the necessary seed quantity per meter area to achieve desired seeding rates.

Physical properties of okra seed (Variety-Deepika) namely size, shape, sphericity, thousand seed weight, bulk density, angle of repose and moisture content were determined using standard procedures. For estimating the size, one hundred seeds were randomly selected and their dimensions were measured along all the three major planes. The measurement was replicated five times and their means computed. Sphericity and shape were characterized using the seed dimensions. Test weight was determined for five random samples of one thousand seed using electronic balance with 0.01 g sensitivity. Bulk density was calculated using a thousand cubic centimeter measuring cylinder by determining the weight to volume ratio of the seed. Standard methodology was also employed to ascertain the angle of repose.

Average width (W), length (L), and thickness (T) were calculated as suggested by Singhal and Samuel [5]. Twenty seeds were chosen randomly for measuring the dimensions with following relationship:

$$L = \frac{\sum_{i=1}^{n} L}{n} \quad --- (1)$$

$$W = \frac{\sum_{i=1}^{n} W}{n} \quad --- (2)$$

$$T = \frac{\sum_{i=1}^{n} T}{n} \quad --- (3)$$

In which,

L = Longest intercept (mm),
W= Width (mm),
T = Thickness (mm).

The subsequent equation was used to compute the geometric mean diameter (D_p) [6].

$$D_p = (LWT)^{1/3} \quad --- (4)$$

Sphericity (ϕ) was calculated by following given formula (Sahay and Singh, 1994).

$$\text{Sphericity} = \frac{(LWT)^{1/3}}{L} \quad --- (5)$$

The following formula was used to determine the roundness (R) of the okra seeds [7].

$$R = \frac{\left(\frac{W}{L}\right) + \left(\frac{T}{L}\right) + \left(\frac{T}{W}\right)}{3} \quad --- (6)$$

Test weight was determined [8] for five random samples of selected crop variety of okra seed on an electronic balance having least count of 0.001 g. One thousand seeds of okra were counted manually and then weighed on the electronic balance.

"The true density and volume of the seed plays an important role in cell design of vertical rotor seed metering mechanism. The volume and true density of seed are determined by toluene (C_7H_8) displacement method. The true density and volume are evaluated for a sample of 100 seed. The weight of sample was recorded. The sample was then immersed in a graduated glass jar containing known volume of toluene" [5]. "The displaced volume of toluene is recorded for each sample, thus volume of sample of seed was calculated. True density is the ratio of weight of sample to toluene displaced volume. Observations were taken for ten samples and the mean was calculated separately for true density and volume of seed" [8].

The following formula [9,6] was used to determine the bulk density.

$$b_d = \frac{Wt}{L \times \left(\pi d^2/_4\right)} \quad --- (7)$$

In which,
b_d = Bulk density (g cm^{-3}),
W_t = Weight of the sample (g),
L = Length of the cylinder (cm),
d = Diameter of the cylinder (cm).
The porosity of seed is estimating using following expression [10]:

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{True density}}\right) \times 100 \quad --- (8)$$

Angle of repose was also crucial in correctly calculating stability in box. Tilting box method was used for fine-grained, non-cohesive materials, with individual particle size. To guarantee that seeds flow freely, the slope of the seed hopper was maintained slightly higher than the average angle of repose of seeds. Angle of repose for okra seed were determined using the following expression [3].

$$\text{Tan}\phi = \frac{2(H_a - H_b)}{D} \qquad ---(9)$$

Where,
ϕ = Angle of repose (°),
H_a = Height of the cone (mm),
H_b = Height of the platform (mm) and
D = Diameter of platform (mm).

"Coefficient of static friction (μ_s) of okra seed was estimated with respect to each of the following three structural materials such as fiber glass plate surface, galvanized iron sheet and mild steel sheet. The okra seed were placed on the test surface at the top edge. The inclined surface was tilted until the samples begin to move leaving inclined surface. Angle of inclination to the horizontal was measured directly on the instrument scale and it was taken as angle of internal friction. The tangent of the above angle was taken as co-efficient of friction between the test surface and okra seed sample. This procedure was repeated five times for each structural material with okra seed. The coefficient of friction was determined as the tangent of the angle using the equation given below" [6]

$$\mu_s = \tan\theta \qquad ---(10)$$

In which,
μ_s = Coefficient of static friction,
θ = Material surface inclination angle (°).

2.2 Okra seed Metering Mechanism Design Using a Vertical Rotor

A vertical rotor type seed metering device was designed for sowing okra. The major considerations were taken into account when designing the precision planter's okra seed metering mechanism are as follows;

1. The metering rotor should meter one seed per cell accurately.
2. Seed to seed spacing of 200 mm should be achieved.
3. The maximum permissible peripheral velocity of the plate should be 16.5 m min^{-1} [11].
4. "The maximum permissible speed of seed metering feed shaft should be 60 revolution per minute (rpm)", [11].
5. "Precision seed metering device was designed for 'VNR-Deepika' variety of okra. The measurement of physical properties showed the mean length of the seed as 5.58±0.20 mm, however, the variation in the maximum dimension of length was noted in the range of 5.51 mm to 5.87 mm. The size and shape of the cells of the metering plate were designed considering the design parameters used" [12]. Fig. 1 shows the shape of the cell on the seed metering plate which was designed considering the following four variables.

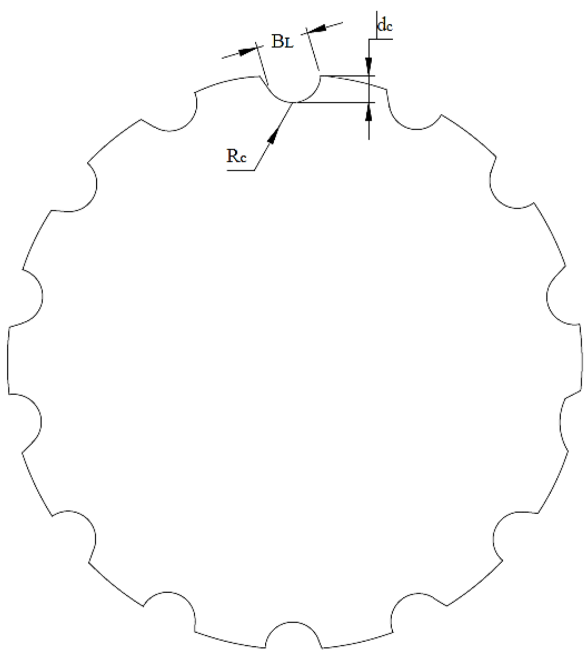

Fig. 1. Vertical rotor cell design parameters

d_c is the depth of the cell. It was slightly higher than the average length of the seed to feed only one seed at a time. Considering the average length of the okra (5.58mm), cell depths of 1.12, times the average length of the seeds were designed for the seed metering device. The depth of the cell was set at 1.12 times the average length of the seeds to ensure that there is ample space for the seed to move through the cell without any risk of getting stuck or jammed. This design consideration helps in achieving precise seed metering and prevents any potential issues during the planting process. The depth of the cells was therefore obtained as 6.25 mm.

"β_L is the left (seed delivery) side angle of the cell. Since this angle affects time delay between consecutive dropping, consequently, a compromise needs to be made. It was noted that a cell depth of 6.25 mm with 50^o will allow two seeds to be filled in the cell and therefore angle was maintained at zero throughout the cells and were used in the design of the seed metering plates" [13].

β_R is the right side angle of the cell. The right side cell angle should be less as compared with the left side cell angle. This angle was maintained at zero throughout the cells.

R_C is the radius of curvature of the cell bottom. The value of this radius of curvature was taken as half the depth of the cells.

Considering the above design parameters, seed metering rotor were designed. Profile of seed metering plates appear in Fig. 1. Width of a cell should be such that a single seed could be accommodated. Considering the largest length (5.58 mm) of okra, width of the cell in the seed metering device was designed to be 1.25 times of the length. The width of the cell in the seed metering device was designed to be 1.25 times the length of the seed to accommodate the seed's size comfortably [14]. This ensures that the seed can move smoothly through the cell without being too constrained, preventing potential blockages or damage to the seed during the metering process. Width of the cell was therefore obtained as 6.98 mm.

To ensure that, accommodate a positive knockout mechanism is accommodated 5.31 mm thick and 24.16 mm in diameter brush was provided in between seed metering vertical rotor with cells.

If number of cells is more than necessary in a rotor, it is difficult to keep the time interval between two consecutive seeds. Therefore, a proper numbers of cell were determined considering the agronomic requirement. The diameter of seed metering vertical rotor was estimated using the following equation [10]:

$$d_p = \frac{V_r}{\pi N_r} \quad --- (11)$$

Where;
d_P = The seed metering rotor's diameter (mm),
V_r =Maximum permissible, the rotor's periphery velocity for seed metering (m min^{-1}),
N_r = Expected rpm of the rotor (Nos.).

The numbers of cell on the seed metering rotor are the function of the speed of operation and the spacing between seeds and therefore it was calculated by applying the formula (Sharma and Jain, 2013).

$$N_c = \frac{\pi P_w}{G_r S_s} \quad --- (12)$$

Where,

N_c = Number of cells on the periphery of seed metering vertical rotor,
P_w = Diameter of okra precision planter wheel (mm),
Gr = Gear ratio and
S_S = Expected seed to seed spacing (mm).

3. RESULTS AND DISCUSSION

The design of the vertical rotor seed metering mechanism involved an assessment of the physical and engineering characteristics of selected variety of okra seed, these characteristics encompassed size, shape, geometric mean diameter, sphericity, roundness, test weight, bulk density, true density, volume, porosity, coefficient of static friction and angle of repose. These properties constitute pivotal factors guiding design of efficient seed metering mechanisms essential for agricultural seeders. Dimensions of okra seeds, encompassing their length, width, and thickness, were measured, length of seed varied from 5.15 - 5.87 mm, width 4.24 - 4.87 mm, and the thickness 4.02 - 4.41 mm having mean values average length, average width and average thickness of the seed was 5.58 mm, 4.61 mm and 4.18 mm, respectively. The standard deviation and coefficient of variation of okra seed sample were also calculated to check the variation and uniformity of seed parameters such as length, width and thickness within the seed sample. Standard deviation was determined to be 0.20 with coefficient of variation of 3.59% for the length dimension similarly for width and thickness dimension found 0.19, 4.06% and 0.10, 2.40% respectively.

The VNR-Deepika variety of okra was found to have a geometric mean diameter of 4.79 mm. The coefficient of variation was determined to be 2.44%, while the standard deviation was found to be 0.20.

The sphericity ranged from 82.16 to 91.25% and it mean value came out to be 85.26% having Standard deviation was found to be 2.26 with coefficient of variation of 2.65%. The higher value of sphericity showed that seeds were nearly spherical in shape.

The roundness was the measure of sharpness of the corner of okra seed and it was varied from79.69-90.29% and mean value found to be 82.85% having Standard deviation was found to be 2.58 with coefficient of variation of 3.11%.

The weight of 1000 seeds of okra varied from 54.38 g to 58.02 g with average value of 57.06 g. Bulk density of okra seed varied between 0.52 g cm^{-3} and 0.58 gcm^{-3}. The average value of bulk density of seed was 0.56 g cm^{-3}. Coefficient of variation of bulk density was 3.22%.

True density of okra seed varied between 1.05 g cm^{-3} and 1.21 g cm^{-3}. The average value of true density of okra seed was 1.12 g cm^{-3}. Coefficient of variation of true density was 2.97%. The mean volume of okra was 111.46 mm^3 and it varied in range from 106.05 mm^3 to 114.86 mm^3.

Porosity indicates the percentage of inter-seed space to volume of the seed bulk. The mean value of porosity of okra seed was 50.22%. It ranged between 45.71% and 54.39% with coefficient of variation as 4.61%.

One of the most important design parameters for the hopper is the angle of repose, which is used to drop seeds into the planter's metering mechanism. The average value of angle of repose under study as observed in the laboratory were 25.97°. Observation to find out angle of repose varies from 25.34° to 26.32°.

The coefficient of static friction for okra seed was tested on the fiber glass plate surface. The coefficient of static friction was found to be 0.42. Observation to find out coefficient of the static friction varies from 0.34 to 0.49. These findings are of paramount importance for designing tailor-made seed metering vertical rotor and related components, ensuring efficient seed handling, dispensing, and sowing, while minimizing damage and losses in agricultural practices. The study also found that the frictional coefficient between okra seeds and galvanized iron sheet as well as mild steel sheet is higher than that between okra seeds and fiber glass plate surface. This suggests that fiber glass plate surface is a more suitable material for vertical rotor in okra seed seeders, as it reduces the risk of seed jamming. The physical properties of seeds, such as their size, shape, weight, and surface properties, can affect their behavior in vertical rotor planter. For example, larger and heavier seeds may be more likely to jam or damage other seeds during the metering process. Seeds with a higher sphericity may also be more likely to roll and jam. Engineering properties of okra seeds, such as their coefficient of friction with different materials, can also affect their behavior in vertical rotor planter.

The study findings highlight the importance of considering the engineering and physical properties of seeds when designing vertical rotor okra seed metering mechanism for precision planter. This information utilized to optimize the design of vertical rotor okra seed metering mechanism for minimizing seed damage, losses, and jamming while ensuring optimal sowing performance.

3.1 Vertical Rotor Okra Seed Metering Mechanism design

Peripheral velocity of rotor for minimum seed breakage and expected rpm of the rotor assumed 14.67 m min^{-1} (14679 mm min^{-1}) and 55 rpm respectively, which is less than maximum permissible peripheral velocity 16.5 m min^{-1} and The seed metering feed shaft's maximum allowable speed should be 60 revolutions per minute. [10].

$$d_p = \frac{14679}{3.14 \times 55} = 84.99 \text{ mm}$$

Accordingly, the vertical rotor for metering okra seeds, as shown in Fig. 2, was designed with a diameter of 85 mm.

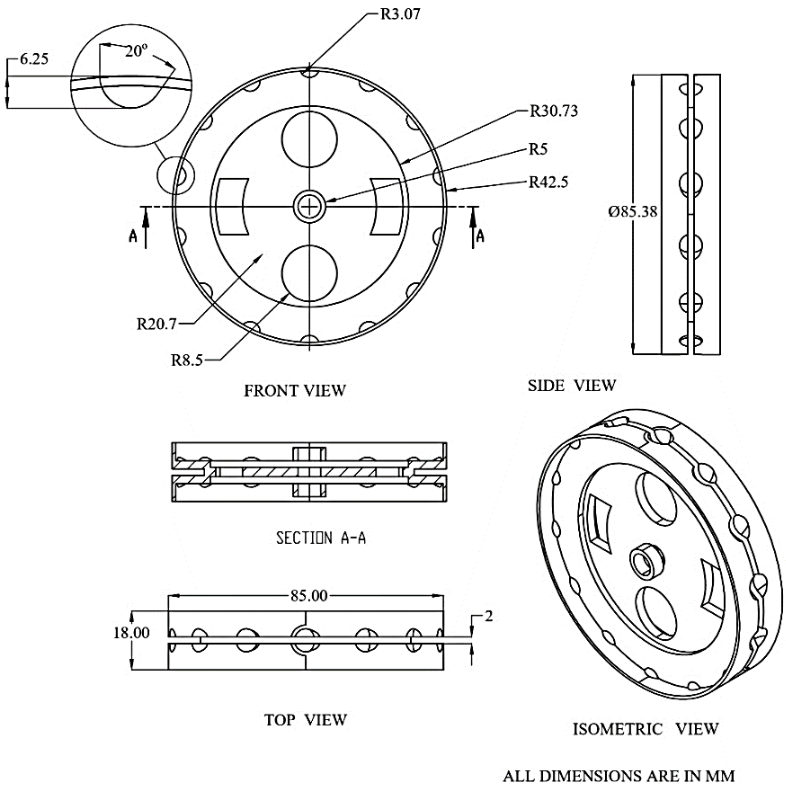

Fig. 2. Design detail of okra seed metering vertical rotor

Number of cells on okra seed metering vertical rotor was found to be:

$$N_c = \frac{3.14 \times 238}{0.267 \times 200} = 13.99$$

Thus, the seed metering rotor was designed with 14 cells around the periphery of the vertical rotor for okra seed metering. The quantity of cells on the okra seed metering vertical rotor depends on the operational speed and the spacing between seeds, as illustrated in Fig. 2.

4. CONCLUSION

The okra seeds exhibited a range of dimensions, with lengths ranging from 5.15 to 5.87 mm, widths from 4.24 to 4.87 mm, and thicknesses from 4.02 to 4.41 mm. The mean values for length, width, and thickness were recorded as 5.58 mm, 4.61 mm, and 4.18 mm, respectively. Additionally, the geometric mean diameter was computed as 4.79 mm, while the sphericity and roundness were revealed to be 85.2% and 82.85%, respectively. The test weight was measured at 57.06 g, with bulk density and true density recorded as 0.56 g cm^{-3} and 1.12 g cm^{-3}, respectively. Volume of the seeds was determined to be 111.46 g cm^{-3}, resulted to a porosity of 50.22%. The angle of repose was measured at 25.97°, and the coefficient of static friction was found to be 0.42. The seed metering rotor was specifically engineered to have a diameter of 85 mm, additionally, it was designed to accommodate 14 individual cells positioned around its periphery. The depth of the vertical rotor cells was determined to be 6.25 mm, it was slightly higher than the average length of the seed to feed only one seed at a time. Meanwhile, the cell width for a single seed was computed at 6.98 mm to provide sufficient space for accommodating one seed per cell.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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