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Evaluation of Physical Properties of Maize and Pigeonpea Seeds for Seed Metering Mechanism

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Authors' contributions

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

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ABSTRACT

Physical properties of seeds such as size, shape, bulk density, angle of repose and thousand seed mass are important design parameters for seed metering mechanism. Some of the physical properties of maize and pigeonpea seeds were determined as they are crucial factor for effective planting. The average values of length, width, thickness, geometric mean diameter, sphericity, bulk density, angle of repose and thousand seed mass of maize were found as 9.79 ± 0.33 mm, 8.03 ± 0.39 mm, 4.16 ± 0.32 mm, 6.89 ± 0.26 mm, 0.70 ± 0.03, 0.76 ± 0.01 g/cm^3, 26.54° ± 0.60 and 223.91 ± 1.50 g respectively at moisture content of 10.90 ± 0.03% on dry basis while similar values for pigeonpea were 6.94 ± 0.31 mm, 5.61 ± 0.30 mm, 4.99 ± 0.27 mm, 5.79 ± 0.19 mm, 0.82 ± 0.03, 0.82 ± 0.01 g/cm^3, 28.36° ± 0.44 and 136.64 ± 1.56 g respectively at moisture content of 11.24 ±

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0.04% on dry basis. The determined properties were found relevant to the design of the components of planter. The size of cell and delivery tube were relevant to linear dimensions while bulk density and angle of repose were relevant to hopper design.

Keywords: Physical properties; seed metering mechanism, planter; angle of repose.

1. INTRODUCTION

Maize (*Zea mays L*) is a highly versatile and adaptable crop that can thrive in a wide range of agricultural and climatic conditions. Throughout the world, maize is commonly known as the "Queen of cereals" because of its superior genetic yield potential when compared to other cereal crops [1]. Maize holds the top position in global production, covering 192.50 million hectares and yielding 1,112.40 million metric tonnes. The USA is the largest producer, contributing 32.61%, followed by China (22.91%), Brazil (9.42%), the European Union (8.41%), Argentina (5.41%), and India (4.1%). In India, maize is the third most cultivated crop after rice and wheat, occupying 9.38 million hectares and yielding 28.752 million metric tons [2].

Pigeonpea, scientifically known as *Cajanus cajan L.*, is a type of legume crop that belongs to the Phaseoleae group. It holds significant importance as a grain legume. Across the globe, pigeonpea is cultivated over an area of 5.7 million hectares with production of approximately 4.91 million metric tons and average yield of 861.3 kg/ha during 2017–2020. India stands out as the leader both in terms of cultivation area and production, contributing around 82% of the world's pigeonpea cultivation area and 78% of the total production [3].

Sowing stands as one of the most crucial agricultural activities essential for successful crop production, performed following seed bed preparation. This operation involves determining key parameters such as seed spacing, row spacing, sowing depth, and seed rate, which are contingent on soil type, crop type and prevailing climatic conditions [4]. In India, despite advancements in agriculture, traditional seeding and planting techniques such as broadcasting and reliance on animal- and human-powered seed drills are still prevalent. However, these methods demand significant time, labour, and physical effort. As a result, there is an increasing emphasis on mechanization to streamline these tasks and enhance efficiency.

When considering the mechanization level, which indicates the proportion of total mechanized field operations, it is noteworthy that different crops demonstrate varying levels of adoption. For instance, wheat exhibits the highest mechanization level, reflecting the significant use of modern machinery and equipment in its cultivation. Conversely, sugarcane lags in mechanization, relying more on traditional and manual approaches [5]. This discrepancy underscores the need for further mechanization in certain crops to optimize productivity and alleviate the burden on farmers.

Distinguishing between various planting techniques is achievable by observing the horizontal seed placement patterns. The first method, broadcasting, involves scattering seeds randomly across the soil surface. In contrast, drilling entails placing seeds randomly within furrows and then covering them with soil, resulting in seed emergence in neat rows. Precision planting, on the other hand, ensures uniform spacing of seeds within the rows, offering a more structured approach to planting. Additionally, another option is to transplant seedlings directly into the field, constituting a fourth planting technique. The availability and advancement of machinery and mechanisms have made each of these planting techniques possible [6].

In the process of planting, a planter plays a crucial role by creating furrows at the desired depth, precisely measuring the seed, and then depositing the seed in an appropriate pattern within the furrow. Once the seed is placed, the planter covers it and ensures the soil is compacted around it to promote proper germination.

In the market, numerous types of seed metering devices are available to accomplish this task. Some seed metering devices are designed with cells on a moving component. These cells can carry either a single seed or multiple seeds, depending on the specific planting requirements. On the other hand, there are force feed type devices equipped with a moving component that efficiently removes the seeds from the hopper. In certain stationary opening metering devices, an agitator is often incorporated above the opening. This agitator serves to ensure a smooth and consistent flow of seeds, enhancing the accuracy and precision of the planting process [7].

Physical properties of seeds such as length, breadth, surface area, roundness, equivalent diameter, sphericity, seed weight, true density and angle of repose are important design parameters for a planter. The design of the seed metering disc's thickness and cell diameters is based on the maximum dimensions of the seeds. Roundness and sphericity affect seed flow through the various components of the planter. To ensure free flow of seeds, the slope of the seed hopper is taken higher than the average angle of repose of seeds [8]. Physical properties and shape attributes have a significant effect on seeding quality and at the end it affects seed emergence and whole further growth of seeds [9].

The average diameter of seed delivery tube should not be less than the average geometric diameter of seeds. The gap of delivery tube to soil should be small to avoid the scattering of seed due to wind. The surface area of cell could be taken as the average surface area of seeds [10].

The physical and engineering characteristics of seeds play a crucial role in the performance of seed metering mechanisms. Parameters related to cell design, such as cell depth and thickness, were influenced by the dimensions and size of the seeds. The sphericity of the seed impacted the smooth flow of seeds from the cell. When designing the seed hopper, bulk density assumed significance. Additionally, the angle of repose of the seeds determined the slope of the seed hopper. To achieve the desired seed rate, the thousand-grain mass was utilized to calculate the number of seeds required per meter area.

Keeping all the points in the mind, a study was planned to evaluate the physical properties of maize and pigeonpea seeds for the design and selection of the components of seed metering mechanism of the planter.

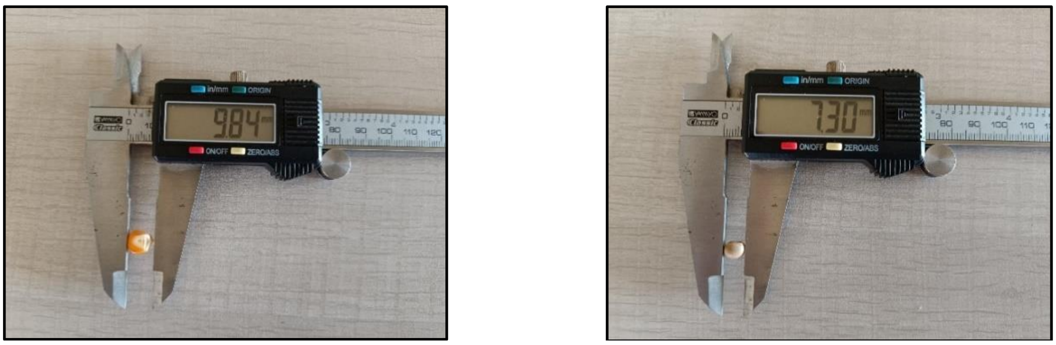
2. MATERIALS AND METHODS

The selection and design of seed metering unit components involved the measurement of various physical properties of maize of variety GAYMH-3 and pigeonpea of variety GT 106. To aid in the selection of seed metering mechanism components, measurements were taken for linear dimensions, bulk density, angle of repose and thousand-seeds mass. All the measurement work of physical properties were carried out in the laboratory of the Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Godhra.

The physical properties of grain were found to vary with the moisture content. So, moisture content should be reported with the physical properties. The moisture content of the grains was determined by oven drying at 105 °C for 24 h [11].

2.1 Measurement of Linear Dimensions

The three principal dimensions which were perpendicular to each other namely length, width and thickness of hundred randomly selected seeds were measured using a digital Vernier calliper as shown in Fig.1 which had a least count of 0.01 mm.



(a) **(b)**

Fig. 1. Use of digital vernier callipers for measurement of linear dimensions of (a) maize and (b) pigeonpea seed

Based on the measured values of the three principal dimensions, the geometric mean diameter (D_g) was calculated in mm using the equation [12]:

$$D_g = (LWT)^{1/3} \tag{1}$$

Where, L was Length in mm, W was width in mm, and T was thickness in mm.

2.2 Shape

Shape of the seeds affect the free flow of seed from the cell of seed metering plate. Shape of the seed is described by sphericity (φ) of the seeds. Sphericity is the degree to which an object resembles a sphere. The maximum value of sphericity is one which corresponds to perfectly spherical object. The sphericity of the seed was calculated as [12]:

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{2}$$

Where, L was Length in mm, W was width in mm, and T was thickness in mm.

2.3 Bulk Density

The design of the seed hopper relied on the bulk density of the seeds. Bulk density was calculated by completely filling a cylinder of known diameter and height, and then weighing the contents using an electronic weighing balance [13]. The dimensions of the cylinder were carefully chosen to eliminate any wall effects in the measurement [14]. Bulk density was computed by dividing the mass of the kernels by the volume of the container. The procedure was replicated ten times for maize and pigeonpea seeds and the average values were computed.

2.4 Angle of Repose

The angle of repose refers to the steepest angle or slope at which a loose material, such as grains, granules, or particles, can rest without sliding or flowing downhill due to gravity. It represents the equilibrium point where the gravitational force pulling the material downward is balanced by the friction and cohesion between the particles. When the angle of the surface exceeds the angle of repose, the material will begin to slide or flow [15].

A proper understanding of the angle of repose is vital to prevent issues like blockages, uneven distribution, or jamming within the hopper. Designing the hopper with an appropriate angle of repose allows for a steady and consistent seed flow, reducing the likelihood of clogs and ensuring that seeds can be dispensed smoothly.

The angle of repose was calculated by using the apparatus shown in Fig. 2. The apparatus was filled up to top and then the plate which was at lower portion was pulled and seeds were allowed to form a heap. The height and diameter of remaining seeds were taken and the angle of repose was calculated using equation [16]:

$$Angle\ of\ repose = tan^{-1}\left(\frac{2h}{D}\right) \tag{3}$$

Where, h was the height of the heap in cm and D was the base width of heap in cm.

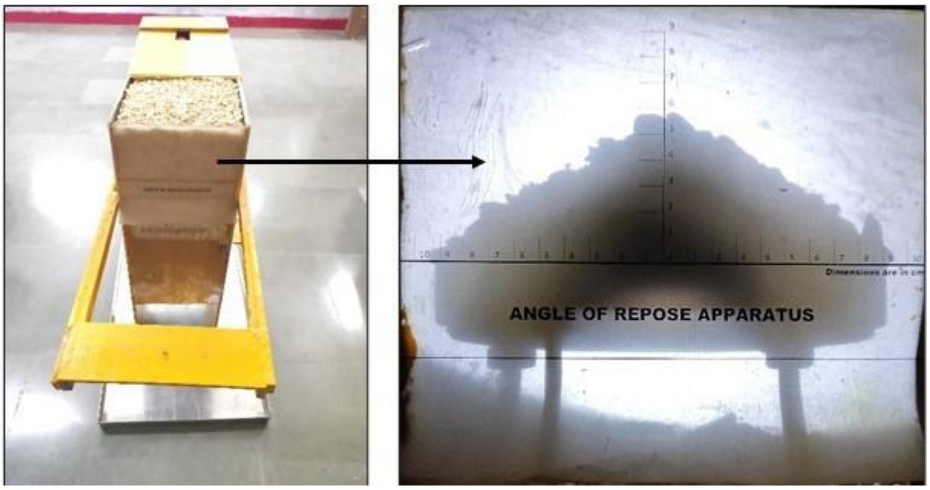


Fig. 2. Measurement of angle of repose

2.5 Thousand Seed Mass

The thousand-seed mass is a pivotal factor in determining the seed rate for a planter or any sowing machine. To assess the thousand-seed mass, ten sets of one hundred randomly selected kernels were weighed from the bulk sample, and the resulting measurement was then multiplied by ten to determine the mass of a thousand seeds [17]. The procedure was replicated ten times for maize and pigeonpea seeds and then average values were computed.

3. RESULTS AND DISCUSSION

The size, shape, bulk density and angle of repose were measured for maize and pigeonpea. The determined average values are given in Table 1. The moisture content on dry basis for maize and pigeonpea were found 10.90 ± 0.03% and 11.24 ± 0.04% respectively.

Table 1. Average values of the physical properties of maize and pigeonpea

Properties	Maize	Pigeonpea
Moisture content (%, d.b.)	10.90 ± 0.03	11.24 ± 0.04
Length (mm)	9.79 ± 0.33	6.94 ± 0.31
Width (mm)	8.03 ± 0.39	5.61 ± 0.30
Thickness (mm)	4.16 ± 0.32	4.99 ± 0.27
GMD (mm)	6.89 ± 0.26	5.79 ± 0.19
Sphericity	0.70 ± 0.03	0.82 ± 0.03
Thousand seed mass (g)	223.91 ± 1.50	136.64 ± 1.56
Bulk density (g/cm^3)	0.76 ± 0.01	0.82 ± 0.01
Angle of repose (°)	26.54 ± 0.60	28.36 ± 0.44

3.1 Size

The dimensions of these seeds, encompassing length, width, and thickness were measured through the analysis of a sample consisting of 100 seeds for each crop. Subsequently, the geometric mean diameter was also computed. For maize, the measurements spanned from 8.91 to 10.54 mm in length, 7.24 to 9.27 mm in width, 3.44 to 5.35 mm in thickness and 6.05 to 8.00 mm in geometric mean diameter. Fig. 3 to Fig. 5 illustrate the frequency distribution of length, width and thickness of maize seeds.

Meanwhile for pigeonpea, the dimensions ranged from 6.23 to 7.79 mm in length, 4.81 to 6.26 mm in width, 4.42 to 5.51 mm in thickness and 4.91 to 6.37 mm in geometric mean diameter. Fig. 6 to Fig. 8 display the frequency distribution of length, width and thickness for pigeonpea seeds.

The mean values for these dimensions were as follows: for maize, the mean values were 9.79 ± 0.33 mm for length, 8.03 ± 0.39 mm for width, 4.16 ± 0.32 mm for thickness and 6.89 ± 0.26 mm for geometric mean diameter. Similarly, for pigeonpea, the corresponding mean values were 6.94 ± 0.31 mm for length, 5.61 ± 0.30 mm for width, 4.99 ± 0.27 mm for thickness and 5.79 ± 0.19 mm for geometric mean diameter.

3.2 Shape

Sphericity was determined as a measure to characterize the shape of the seeds, as it plays a significant role in the flow of seeds from the seed metering device to the sowing attachment. The sphericity of 100 seed samples from each crop was calculated. The sphericity values for maize ranged from 0.65 to 0.77. On the other hand, the sphericity of pigeonpea ranged from 0.74 to 0.89. The average sphericity values for maize and pigeonpea were found to be 0.70 ± 0.03 and 0.82 ± 0.03 respectively. The average value of sphericity for pigeonpea were reported between 0.83 to 0.88 at different moisture contents by researchers [18,19]. Similarly, the average value of sphericity for maize were reported between 0.69 to 0.78 at different moisture contents by researchers [10,20].

The higher sphericity of pigeonpea could be attributed to pigeonpea seeds having less difference in length, width, and thickness compared to maize seeds, which have a greater length.

3.3 Bulk Density

Bulk density plays a crucial role in designing the hopper capacity of the planter. The average values of bulk densities for maize and pigeonpea were recorded as 0.76 ± 0.01 and 0.82 ± 0.01 g/cm^3 respectively. Bulk density values exhibited slight variations, with maize ranging from 0.74 to 0.78 g/cm^3 and pigeonpea varying from 0.79 to 0.84 g/cm^3.

3.4 Thousand Seed Mass

The mass of a thousand seeds was determined by weighing 100 seeds and then multiplying the result by 10. For maize, the thousand-seed mass ranged from 221.90 to 226.20 g indicating a relatively narrow range of variation. In the case of pigeonpea, the thousand-seed mass exhibited variations from 133.70 to 138.70 g. The mean values for the thousand-seed mass of maize and pigeonpea were found to be 223.91 ± 1.50 g and 136.64 ± 1.56 g respectively.

3.5 Angle of Repose

The angle of repose is a critical parameter used to determine the slope of the seed hopper to ensure the free flow of seeds. For maize, the angle of repose ranged from 25.46 to 27.66°, while for pigeonpea, it varied from 27.53 to 28.95°. The mean values of the angle of repose for maize and pigeonpea were reported as 26.54° ± 0.60 and 28.36° ± 0.44, respectively.

The average angle of repose values for three varieties of maize namely PMH-1, PIONEER-3396 and PMH-10 were determined as 28.59°, 27.10° and 28.66°, respectively [21]. Similarly, for Pigeonpea, the angle repose values of 21.57 to 26.57° [19] and 17 to 31° [22] were reported.

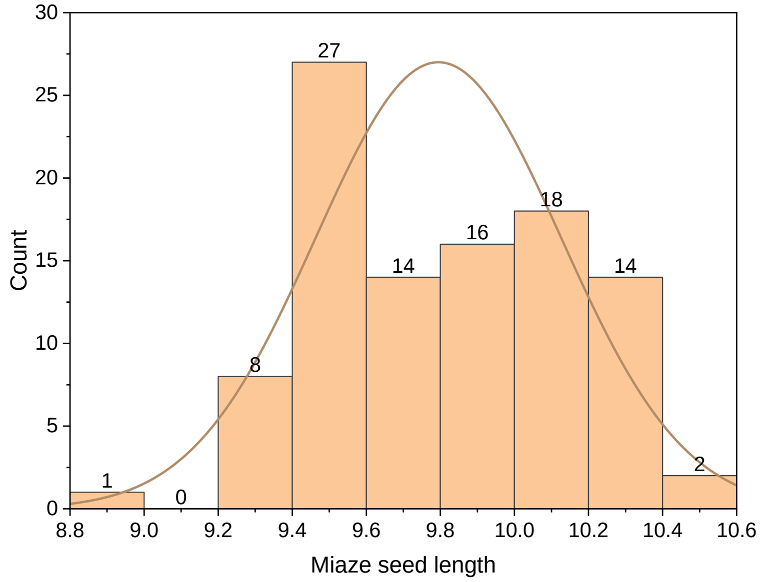


Fig. 3. Frequency distribution of length of maize seeds

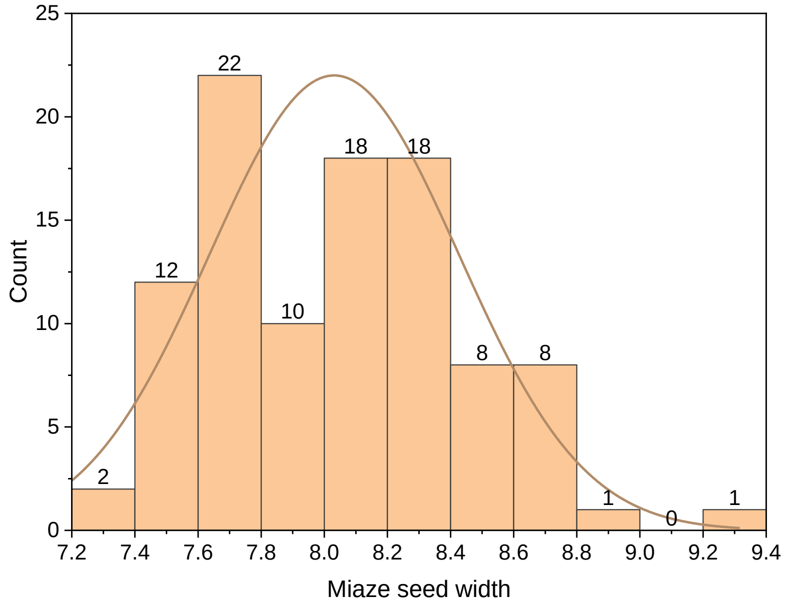


Fig. 4. Frequency distribution of width of maize seeds

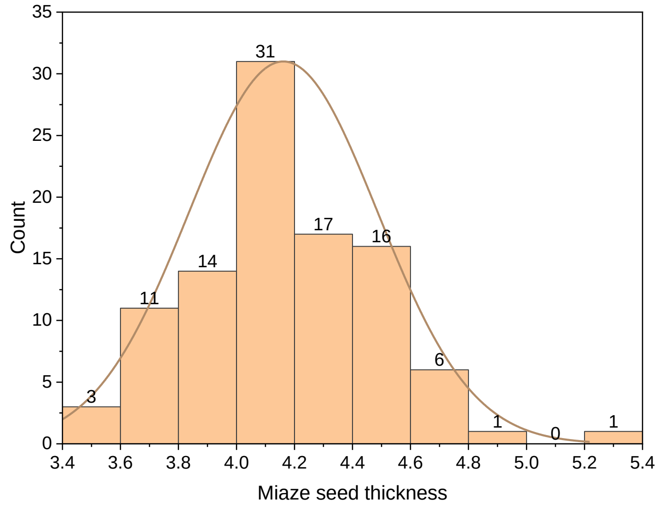


Fig. 5. Frequency distribution of thickness of maize seeds

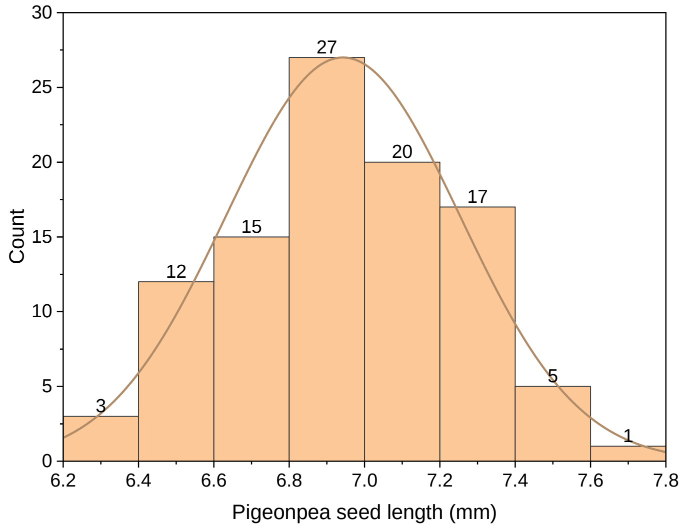


Fig. 6. Frequency distribution of length of pigeonpea seeds

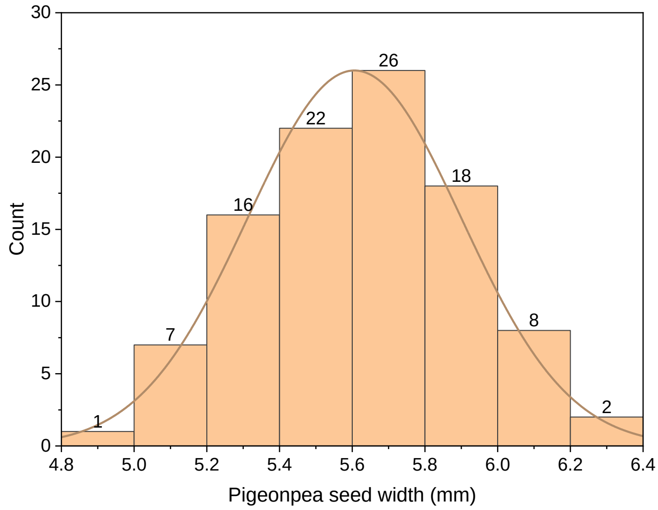


Fig. 7. Frequency distribution of width of pigeonpea seeds

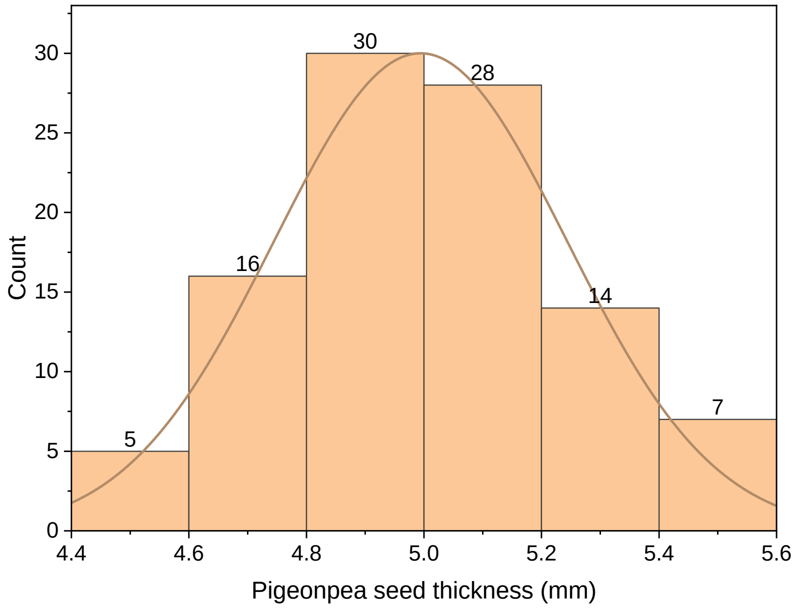


Fig. 8. Frequency distribution of thickness of pigeonpea seeds

4. CONCLUSION

Based on the above result, following conclusions can be drawn:

a) The cell diameter for the maize and pigeonpea should be greater than the maximum principal dimension i.e., 10.54 and 7.79 mm respectively.
b) The diameter of the delivery tube should be greater than the geometric mean diameter of the seeds. The average minimum diameter of delivery tube for maize and pigeonpea should be greater than 6.89 and 5.79 mm.
c) The seeds of pigeonpea with average sphericity of 0.82 tends to scatter more as compared to maize seeds with sphericity of 0.70
d) The average values of bulk density i.e., 0.76 g/cm^3 for maize and 0.82 g/cm^3 for pigeonpea should be used for the capacity design of hopper.
e) The average thousand seed mass for maize and pigeonpea were determined as 223.91 and 136.64 g respectively which further could be used for the determination of average seed rate.
f) The slope of hopper should be greater than the angle of repose of seeds. The average angle of repose of maize and pigeonpea was found as 26.54 and 28.36°. So, slope of hopper should be taken greater than 28.36°.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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