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Exploring certain physical and engineering attributes of okra seeds

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Abstract
Understanding the physical and engineering attributes of a seed holds vital information essential for crafting its metering mechanism, processing, and storage system. A study was planned with objectives are study physical and engineering properties of okra seed. Based on the results salient finding are summarized as mean values the mean dimensions of the seed were determined to be 5.58 mm in length, 4.61 mm in width, and 4.18 mm in thickness. Geometric mean diameter for VNR-Deepika variety was found to be 4.79 mm. Sphericity and roundness found to be 85.2% and 82.85% respectively. The weight of 1000 okra seeds, along with their bulk density, true density, mean volume and average porosity were determined to be 57.06 g, 0.56 g cm^{-3}, 1.12 g cm^{-3}, 111.46 mm^3 and 50.22% respectively. The laboratory observations revealed an average angle of repose under study of 25.97°. The coefficient of static friction was found to be 0.42.

Keywords: Okra seeds, seed properties of okra, engineering properties, shape, size, roundness, sphericity, geometry mean diameter and angle of repose

Introduction

India holds the second position in global vegetable production, following closely behind China. It had 204.84 million metric tonnes vegetable production in the year 2021-22 contributing 11.35 million hectares (National Horticulture Database 3rd Advance Estimates, 2023) [9]. India leads the world in okra production. Despite this, at the current level of vegetable production, planting operations remain among the least mechanized farm operations, with only 29% mechanization. (Mehta *et al.*, 2014) [8]. The estimated per capita consumption of vegetables in India stands at 230 g day^{-1}, falling short of the recommended dietary allowance of 300 g/day. Hence, there exists a current deficit of approximately 30 million tonnes of vegetables within the country. (Vanitha *et al.*, 2013) [15]. Including vegetables in the daily diet is crucial for maintaining good health. To adequately feed the current population of India, there is a pressing need to double the total vegetable production. Additionally, there is a requirement for increased production to cater to the processing industry, exports, and the seed industry. In their study, Sahoo and Shrivastav (2002) [10] investigated the physical attributes of okra seeds in correlation with moisture content, determining that the moisture content notably influenced the seed's engineering attributes. Hazbavi (2013) [4] explored the physico-mechanical properties of Iranian okra (*Abelmoschus esculentus* L.) seed, focusing particularly on how these properties vary with moisture content. Additionally, Gautam *et al.* (2015) [3] explored the engineering properties of pelleted carrot and radish seeds, Kumar *et al.* (2018) [6] studied on physical attributes of okra seed and reported that the understanding the physical attributes of a seed is essential information for designing its metering mechanism, processing methods, and storage systems.

The primary dataset required for developing the metering mechanism of okra, a mechanism designed to dispense seeds or fertilizers at specific rates, consists of its physical properties. Additionally, this data is essential for designing the handling, processing, and storage structures for okra. With knowledge of the seed's size, shape, and density, oscillating chaffers facilitate the easier separation of unwanted materials from seeds. The design of mass flow structures is impacted by the angle of repose. Bulk density and porosity, significant in drying and aeration systems for seeds, play a crucial role in controlling the airflow hindrance.

The objective of this study was to evaluate the physical and engineering attributes of okra seeds, encompassing size, shape, bulk density, true density, angle of repose, porosity, and the test weight of seeds.
Despite these studies, there is a scarcity of published work on the comparative analysis of the engineering and physical attributes of okra seeds and their correlation with moisture content. Hence, the primary objective of the current study was to scrutinize the engineering attributes of okra seeds.

Materials and Methods
The Laboratory of Agricultural Processing and Food Engineering at the Department of Processing and Food Engineering, FAE, IGKV, Raipur (C.G.), conducted a comprehensive study on the physical and engineering attributes of okra seeds. This study encompassed the examination of size, shape, mean diameter, test weight, bulk density, angle of repose, and coefficient of friction, which are discussed herein.

Selection of the variety
The variety VNR – Deepika, F1 Hybrid were selected for the study, whose fruit color is green, fruit size-length: 13 to 15 cm and fruit size-width: 1.6 to 2 cm approx. commercially prevalent variety by the farmers in Chhattisgarh.

Average length (L), width (W) and thickness (T)
The dimensions of the seed were characterized by its length (L), width (W), and thickness (T). Utilizing a vernier caliper with a least count of 0.001 mm, both axial and lateral dimensions of the seeds were measured. The average length (L), width (W), and thickness (T) were then calculated following the methodology proposed by Singhal and Samuel (2003) [11]. Twenty seeds were selected randomly for measuring the dimensions with following relationship:

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

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

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

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

Geometric mean diameter (D_p)
The geometric mean diameter (D_p) was determined using the following formula, as outlined by Mohsenin (1986) [7].

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

Sphericity (ϕ)
Sphericity, as defined by Sahay and Singh (1994) [12], represents the ratio between the diameter of a sphere possessing the same volume as the particle and the diameter of the smallest circumscribing sphere, or typically the largest diameter of the particle. This parameter indicates the shape characteristics of okra seeds in comparison to a sphere of equivalent volume. It was calculated by following given formula.

$$\text{Sphericity} = \frac{\sqrt[3]{\text{Volume of the particle}}}{\text{Volume of circumscribed sphere}} = \frac{(LWT)^{1/3}}{l} \quad ----(5)$$

Roundness (R)
The roundness (R) of the okra seeds was determined using the following equation, as proposed by Sahay and Singh (1994) [12].

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

Test weight
Test weight for VNR-Deepika variety of okra seeds was determined according to the method outlined by Singh and Goswami (1996) [13]. Five random samples were taken for each variety and weighed using an electronic balance with a least count of 0.001 g additionally, the weight of one thousand okra seeds was manually counted and recorded using the electronic balance.

Volume and true density
The volume and true density of seeds are crucial factors in designing the cell of a seed metering mechanism. These properties are determined using the toluene (C_7H_8) displacement method. In this method, a sample of 100 seeds is weighed, and its volume is evaluated by immersing it in a graduated glass jar filled with a known volume of toluene, as described by Tavakkoli *et al.* (2009) [14]. The displaced volume of toluene is recorded for each sample, enabling the calculation of the seed sample's volume. True density is then determined by dividing the weight of the sample by the volume of toluene displaced. Ten samples are observed, and the mean volume and true density of the seeds are calculated separately, following the procedure outlined by Singh and Goswami (1996) [13].

Porosity
The porosity of the seed is determined using the following formula, as presented by Chakraverty (1981) [1].

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{True density}}\right) \times 100 \quad ----(7)$$

The percentage porosity of the seed was calculated utilizing the bulk density and true density values obtained from previous experiments.

Angle of repose
The angle of repose refers to the angle formed between the base and the slope of the cone generated by the vertical descent of granular material onto a horizontal surface. It is influenced by factors such as the size, shape, moisture content, and orientation of seeds, and it is instrumental in designing appropriate hoppers and ensuring stability in boxes. For fine-grained, non-cohesive materials with individual particle sizes, the tilting box method is employed. This method involves placing the material within a box with a transparent side to observe the granular test material. The box starts level and parallel to its base, and then it is gradually tilted until the material begins to slide in bulk. The angle of tilt is measured using a scale positioned at the

corner. To guarantee the free flow of seeds, the slope of the seed hopper is kept slightly steeper than the average angle of repose of the seeds. Three readings are taken with a protractor, and the average is reported, as described by Jayan and Kumar (2004) [5].

$$\text{Tan}\phi = \frac{2(H_a - H_b)}{D} \text{ ---------------- } (8)$$

In which,
ϕ = Angle of repose
H_a = Height of cone,
H_b = Height of platform and
D = Diameter of the platform.

Bulk density

Bulk density represents the ratio of the weight of a sample to its total volume and is typically expressed in units such as kg m^{-3} or g cm^{-3}. To measure the bulk density of a seed sample, a weight per hectoliter tester (cylinder) calibrated in kg m^{-3} is utilized, as outlined by Deshpande *et al.* (1993) [2] and Mohsenin (1986) [7]. The cylinder, with dimensions of 70 mm inner diameter and 150 mm height and graduation marks on its surface, is filled with the okra seed sample to determine its volume. The filled sample is then weighed using an electronic weighing balance, and the bulk density of the material within the cylinder is computed. Ten replications are conducted for the okra seeds, and the bulk density is calculated using the following equation.

$$b_d = \frac{Wt}{L \times \left(\pi d^2/4\right)} \text{ ---------------- } (9)$$

In which,
b_d = Bulk density (g cm^{-3}),
W_t = Weight of sample (g),
L = Length of cylinder (cm),
d = Diameter of cylinder (cm).

Coefficient of static friction

The coefficient of static friction (μ_s) holds significant importance in various industries, particularly concerning bulk storage and equipment handling. To determine the coefficient of static friction (μ_s) of okra seed, tests were conducted using three different structural materials: fiber glass plate surface, galvanized iron sheet and mild steel sheet. Okra seeds were positioned at the top edge of the test surface, and the inclined surface was gradually tilted until the samples started to move, indicating the angle of internal friction. The angle of inclination was directly measured on the instrument scale. The tangent of this angle represented the coefficient of friction between the test surface and the okra sample. This process was repeated five times for each structural material with the okra sample. The coefficient of friction was then calculated as the tangent of the angle using the equation provided below, as outlined by Mohsenin (1986) [7].

$$\mu_s = \tan\theta \text{ ------------------ } (10)$$

In which,
μ_s = Co-efficient of static friction,
θ = Angle of inclination of material surface (°).

Results and Discussion

Average length (L), width (W) and thickness (T)

Size of the okra seed was measured which included length (major dimension), width (intermediate dimension) and thickness (minor dimension) of seed in mm. The range, mean, standard deviation and coefficient of variation in dimensions (length, breadth and thickness) for all the samples were given in Table 1. The dimensions of the okra seed were measured using a micrometer. The length of seed varied from 5.15-5.87 mm, width 4.24-4.87 mm, and the thickness 4.02-4.41 mm. The mean values for the average length, width, and thickness of the seed were determined to be 5.58 mm, 4.61 mm, and 4.18 mm, respectively. The standard deviation and coefficient of variation of the seed sample were also computed to assess the variability and uniformity of parameters such as length, width, and thickness within the seed sample. Standard deviation was found to be 0.20 with the 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.

Table 1: Physical attributes - length, width and thickness of okra seed

Observation	Length (mm)	Width (mm)	Thickness (mm)
Mean	5.58	4.61	4.18
Range	5.15-5.87	4.24-4.87	4.02-4.41
SD	0.20	0.19	0.10
CV %	3.59	4.06	2.40

Geometric mean diameter and shape of the seeds

The geometric mean diameter was derived from the measured dimensions of length, width, and thickness. For the VNR-Deepika variety, the geometric mean diameter was determined to be 4.79 mm. Standard deviation was found to be 0.20 with the coefficient of variation of 2.44% shown in Table 2.

The seed shape was quantified in terms of sphericity and roundness. The sphericity was calculated using eqn. 5. The range of sphericity varied from 82.16-91.25% and it mean value came out to be 85.26% having Standard deviation was found to be 2.26 with the 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 the coefficient of variation of 3.11%.

Table 2: Engineering properties of okra seed - geometric mean diameter, sphericity and roundness

Observation	GMD (mm)	Sphericity (%)	Roundness (%)
Mean	4.75	85.26	82.85
Range	4.50-4.93	82.16-91.25	79.69-90.29
SD	0.12	2.26	2.58
CV %	2.44	2.65	3.11

Test weight, bulk density, true density, volume and porosity of okra seed

The weight of 1000 okra seeds (test weight) ranged from 54.38 g to 58.02 g, with an average value of 57.06 g. The coefficient of variation for the weight of 1000 okra seeds was 1.47%, as indicated in Table 3.

The bulk density of okra seeds ranged from 0.52 g cm^{-3} to 0.58 g cm^{-3}, with an average value of 0.56 g cm^-3. The coefficient of variation for bulk density was calculated to be 3.22%.

Regarding true density, it varied between 1.05 g cm^{-3} and 1.21 g cm^{-3}, with an average value of 1.12 g cm^{-3}. The coefficient of variation for true density was 2.97%.

The mean volume of okra seeds was determined to be 111.46 mm^3, with variations ranging from 106.05 mm^{-3} to 114.86 mm^{-3}. The coefficient of variation for volume was found to be 2.50%.

Porosity, which indicates the proportion of inter-seed space relative to the total bulk volume of the seed, averaged at 50.22%. It ranged from 45.71% to 54.39%, with a coefficient of variation of 4.61%. All the data are depicted in Table 3.

Table 3: Test weight, bulk density, true density, volume of seed and porosity of okra seed

Observation	Test weight (g)	Bulk density (g cm^{-3})	True density (g cm^{-3})	Volume of seed (mm^3)	Porosity (%)
Mean	57.06	0.56	1.12	111.46	50.22
Range	54.38-58.02	0.52-0.58	1.05-1.21	106.05-114.86	45.71-54.39
SD	0.84	0.02	0.03	2.79	2.31
CV (%)	1.47	3.22	2.97	2.50	4.61

Angle of repose and coefficient of static friction

The angle of repose is a crucial parameter in the design of hoppers for facilitating the smooth release of seeds into the metering mechanism of the planter. In the laboratory observation, the average angle of repose under study was recorded as 25.97°.Observation to find out angle of repose varies from25.34° to 26.32° having standard deviation was found to be 0.28 with the coefficient of variation of 1.10%.

The coefficient of static friction for okra seeds was assessed on a fiberglass plate surface, yielding a value of 0.42. The observations to determine the coefficient of static friction ranged from 0.34 to 0.49, with a standard deviation of 0.04 and a coefficient of variation of 9.59%. It was noted that at higher moisture content, the seeds became rougher, leading to decreased flow ability (sliding). Consequently, at higher moisture content, the coefficient of static friction increased compared to lower moisture content. All the data are depicted in Table 4.

Table 4: Engineering attributes of okra - The angle of repose and coefficient of friction

Observation	Angle of repose (°)	Coefficient of static friction
Mean	25.97	0.42
Range	25.34-26.32	0.34-0.49
SD	0.28	0.04
CV (%)	1.10	9.59

Conclusion

The range of okra seed dimensions for length, width, and thickness were determined to be 5.15-5.87 mm, 4.24-4.87 mm, and 4.02-4.41 mm respectively. The mean values for length, width, and thickness were calculated as 5.58 mm, 4.61 mm, and 4.18 mm, respectively. The measured values for the geometric mean diameter, sphericity, roundness, test weight, bulk density, true density, volume, porosity, angle of repose, and coefficient of static friction were recorded as 4.79 mm, 85.2%, 82.85%, 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. Comprehending the physical and engineering characteristics of a seed provides crucial insights necessary for designing its metering mechanism, processing techniques, and storage infrastructure.

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