E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2025; SP-8(2): 184-188
Received: 30-11-2024
Accepted: 12-01-2025

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Engineering properties of three maize varieties for optimizing small-scale planter design in Jammu and Kashmir, India

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DOI: https://doi.org/10.33545/2618060X.2025.v8.i2Sc.2576

Abstract
A study was conducted to investigate the physical and engineering properties of three maize varieties namely PHM-34, JHM-Double and JCM-3 for the proper design of seed metering systems in small-scale maize planters in Jammu and Kashmir. The primary parameters evaluated were moisture content, tri-axial dimensions (Size, Shape and Sphericity), frictional attributes and gravimetric properties. The average moisture content was found to be 7.36% (PHM-34: 7.27 ± 0.21%, JHM-Double: 6.50 ± 0.03%, JCM-3: 8.31 ± 0.09%) influencing seed cohesion. The tri-axial dimensions illustrated favourable characteristics for metering mechanisms particularly in PHM-34, with an average length of 11.44 ± 1.48 mm, width of 9.65 ± 0.83 mm and thickness of 4.40 ± 0.74 mm. The frictional properties revealed that PHM-34 has the lowest coefficient of friction on aluminium surfaces (0.49 ± 0.01) signifying reduced resistance during seed movement within the planter. The gravimetric analysis indicated that PHM-34 possessed the highest bulk density at 0.80 g/cm³ and true density at 1.43 g/cm³, enhancing storage and handling efficiency compared to JHM-double (bulk density: 0.71 g/cm³, true density: 1.34 g/cm³) and JCM-3 (bulk density: 0.67 g/cm³, true density: 1.26 g/cm³). The JHM-double and JCM-3 showed higher porosity (JHM-double: 46.75%, JCM-3: 47.09%), while the seed characteristics of PHM-34 suggest better performance in planting operations. These findings emphasize the importance of selecting appropriate maize varieties based on their physical and engineering properties to enhance planting efficiency contributing to improved agricultural productivity in the region.

Keywords: Maize seeds, physical properties, angle of repose, planting operations

1. Introduction

Maize (*Zea mays* L.) is one of the most widely planted cereal crops in the world, serving as a vital source of grain, animal feed, and industrial raw material, essential for national food security and the corn processing industry (Vyn *et al.*, 2005) [17]. According to the Agricultural Statistics at a Glance 2023 published by the Ministry of Agriculture and Farmers Welfare, maize cultivation in India bridges approximately 9.89 million hectares, yielding around 31.65 million tonnes with an average yield of 3199 kg per hectare (Government of India, 2023) [7]. This production emphasizes the significance of maize in India's agricultural landscape mainly in addressing food security and supporting the livelihoods of small-scale farmers. In 2021 global maize production reached approximately 1,162 million tonnes from an area of 201 million hectares with the United States, China, and Brazil as leading contributors, the U.S. alone producing about 400 million tonnes highlighting maize's significance as a staple crop worldwide (FAO., 2020) [6].

The Indian agricultural sector has historically faced significant challenges particularly during the twentieth century when natural resource degradation and climate change posed severe threats to food production. To secure food for the country's rapidly growing population and combat malnutrition agricultural output and productivity must rise by 85% and 100% respectively by 2025 (Lockie *et al.*, 2020) [12]. These challenges bring to light the need for agricultural innovations especially in regions like Jammu and Kashmir where maize productivity is hindered by climate variability, inadequate irrigation and the lack of suitable planter for crops like maize. The manual methods of seed sowing like broadcasting, dibbling, seeds sown behind plough etc are infested with drudgery and high cost of operation. The method also results in labour-intensive practices, low input use efficiency, wastage of seeds, responsible for inducing a financial burden on the farmers (Malla *et al*., 2022) [13]. In India, maize production is substantial but the average yield remains lower than the global average. This is particularly factual for regions like Jammu and Kashmir where maize is primarily cultivated during the Kharif season. The area under maize cultivation in the Union Territory (UT) Jammu and Kashmir is approximately 0.29 million hectares producing around 0.51 million tonnes with an average yield of 1.76 tonnes per hectare. The farmers in this region face challenges such as variable climate and inadequate irrigation infrastructure both of which contribute to reduced productivity (Digest of statistics, 2021) [5].

Maize is known as one of the most versatile cereal crops, burgeoning across diverse agro-climatic conditions. In the UT Jammu and Kashmir, labour-intensive pre and post-harvest operations are predominantly manual highlighting the need for mechanization. In hilly areas, farmers traditionally sow maize seeds by hand, which can be improved with mechanical drilling methods or planters that enhance seed placement depth, precision and uniformity finally leading to higher yields compared to manual methods (Singh, 2014) [16]. Uniform seed spacing is essential for maximizing yield while non-uniformity can reduce productivity. The labour demands for sowing, weeding and harvesting curb maize cultivation and the irregular shape of seeds mess up their placement with existing planters. Although the pneumatic planters have been developed but due to their high cost and lack of adequate repair facilities hinder adoption leading farmers to use labour-intensive dibbling techniques. Thus, to improve maize planting efficiency, it is essential to develop economically viable precise planting equipment designed for the region's need. The common broadcasting method raises labour costs and negatively impacts crop establishment. Manual sowing leads to poor seed placement and spacing inefficiencies imposing physical strain on farmers While some areas use mechanical dibbling as this method is cumbersome and needs a shift towards power-operated planters. However, most tractor-operated models are designed for flat terrain limiting their effectiveness in Jammu and Kashmir's varied landscape (Khan *et al*, 2015) [10]. Therefore, the study of the engineering properties of maize seeds-including size, shape, test weight, angle of repose, bulk density and coefficient of static friction is vital for developing efficient planting machinery that enhances productivity and supports small-scale farmers in the region.

2. Materials and Methods

The experiment was conducted at the Faculty of Agricultural Engineering, SKUAST-Jammu, J&K. Three samples were procured from the Division of Plant Breeding and Genetics at SKUAST-Jammu. The physical and engineering properties of three maize varieties-PHM-34, JHM-double and JCM-3 were examined as illustrated in Figure 1. These varieties were selected due to their local availability and suitability for the soil and climatic conditions of Jammu and Kashmir.

Fig 1: Maize Varieties (PHM-34, JHM-Double, JCM-3)

2.1 Moisture Content

The moisture content of three samples of seeds was determined using the oven drying method. Three Samples from each variety were weighed and kept in oven for 50 minutes at the temperature of 105^{0}C (ASAE Standard, 1999). The weight of the dried samples (W_d) was compared with the initial conditions (W_w) to determine the moisture content of seeds. This method provides accurate moisture content determination essential for optimizing seed processing (Mohiuddin *et al*, 2022) [15].

$$Moisture\ content(w.b), \% = \frac{W_w - W_d}{W_w} \times 100$$

where Ww = Weight of the sample before drying (g).
W_d = Weight of oven-dried sample (g)

2.2 Size, Shape and Sphericity

The physical properties of maize seeds including size, shape and sphericity are important for the design of effective seed metering systems in maize planters. The total of 100 seeds were randomly selected were measured using a digital vernier calliper with a least count of 0.01 mm to determine the tri-axial dimensions; length, width and thickness of the grain (Figure 2). These dimensions help to determine the dimensions of the groves in the seed metering plate which influences the seed flow dynamics. The shape of maize seeds was characterized by the eccentricity index, which influences the design of the seed metering mechanism to ensure smooth and uniform seed placement. However, the values obtained were used to calculate the eccentricity index, sphericity from equations 2 and 3 (Atere *et al*, 2016) [2].

$$Eccentricity\ Index = \frac{length}{width}$$

$$Sphericity\ = \frac{Geometric\ mean}{length} = \frac{(LWT)^{\frac{1}{3}}}{L}$$

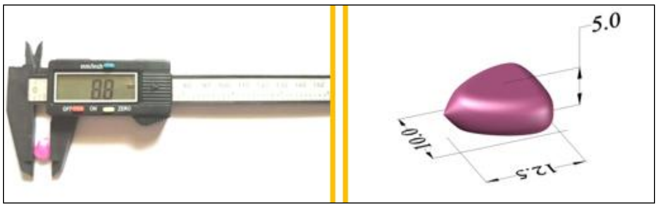

Fig 2: Tri-Axial Dimensions of Maize Seed

2.3 Coefficient of friction and Angle of Repose

The coefficient of friction for maize varieties against surfaces aluminium, cast iron and plastic was measured using a specific setup. Testing of friction of seeds on different surfaces is done for the material selection and design of hopper to ensure that the seeds flow smoothly and does not stuck during the operation. A box containing a 300 grams sample of the seeds was pulled across these surfaces using a wire and pulley system Figure 3 (Izli *et al*., 2016) [8]. The frictional force required to move the box was recorded and the static coefficient of friction (μe) was calculated as the ratio of this frictional force to the normal force.

$$\mu e = \frac{F}{W}$$

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

The angle of repose was measured with the help of angle of repose apparatus comprising of circular platform immersed in a box. The platform is surrounded by a metal funnel leading to a discharge hole. The seeds were allowed to escape from the box leaving a free-standing cone of height (h) and radius (r) on the platform (Akaaimo *et al*., 2016) [1].

$$Angle\ of\ Repose, \theta = tan^{-1}\frac{h}{r}$$

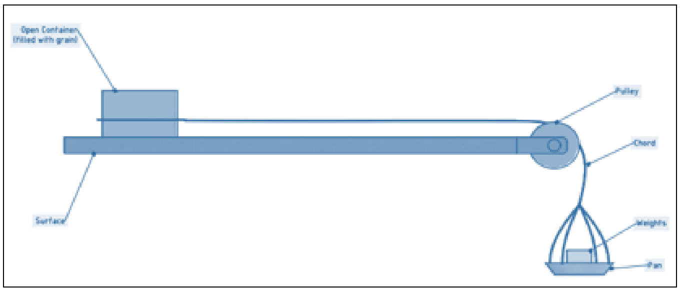

Fig 3: Experimental Setup for Coefficient of Friction

2.4 Test weight, Bulk Density, True density and Porosity

The capacity of the feeding hopper is governed by the test weight of the seeds. It also determines the quantity of maize seeds that can be fed in one fill. The randomly taken 1000 seeds from each variety were weighed on the electronic balance with least count of 0.001g.

The bulk density of seeds measures the mass occupied by seeds per unit volume in the container. An empty measuring cylinder of known volume was filled separately with seeds. The mass of filled amount was recorded using an electronic balance with accuracy of 0.001g, equation 6. The measurements were replicated thrice to check the deviation in the process (Dange *et al*., 2021) [4].

$$Bulk\ density, g\ cm^{-3} = \frac{Mass}{Volume}$$

The true density of seeds was determined by weighing a sample of each variety on an electronic balance. The actual volume of seeds without voids was determined by toluene displacement method. The weighed sample of seeds was immersed in a container filled with toluene of known volume. The displacement of toluene due to seeds was collected and measured, equation 7. Porosity was also calculated from the relationship between true and bulk densities from the equation 8, (Kumar *et al*., 2017) [11].

$$\rho t = \frac{(Ws)}{Vs}$$

Where, ρt represents the true density of seeds in grams per cm cube (g cm^{-3}), Ws refers to the weight of seeds in grams per cm cube (g/cm), and Vs denotes the true volume of seeds in cubic centimetre (cm^3).

$$Porosity = \frac{(TD - BD)}{TD} \times 100$$

Where, TD= True Density (g cm^{-3})
BD= Bulk Density (g cm^{-3})

3. Results

The physical and gravimetric parameters of maize seeds are essential for determining the capacity of the hopper, the metering system of the planter and the flowability of maize seeds from the hopper to the seed tube. These findings provide valuable insights for developing mechanized sowing systems with a particular focus on moisture content, test weight, bulk density, true density, porosity, coefficient of friction, and angle of repose.

3.1 Moisture content (percent): The moisture content significantly influences the cohesion of maize seeds. The mean moisture content on wet basis of PHM-34, JMH-Double and JMC-3 was found to be 7.27 ± 0.21, 6.50 ± 0.03 and 8.31 ± 0.09. The overall mean value of moisture content of three maize varieties was found to be 7.36% along with the standard deviation of 0.11, Table 1. This variation in moisture content among the maize varieties aligns with findings from (Brar *et al*., 2017) [3] who reported similar moisture content levels across different maize varieties indicating that moisture content can influence the cohesion and handling properties of the seeds during planting operations.

Table 1: Moisture Content of Maize Varieties

Maize Variety	Moisture Content Range (%)	Mean Moisture Content (%)	Standard Deviation (%)
PHM-34	7.03-7.43	7.27	0.21
JCM-3	6.48-6.53	6.5	0.03
JHM-Double	8.23-8.40	8.31	0.09
Overall	-	7.36	0.11

3.2 Tri-axial Dimensions (Size, Shape and Sphericity)

The tri-axial dimensions (length, width, and thickness) of selected maize seeds PHM-34, JMH-Double, JCM-3 were measured using a digital Vernier Caliper. The average length, width, thickness, and shape of PHM-34 were found to be 11.44 ± 1.48 mm, 9.65 ± 0.83 mm, 4.40 ± 0.74 mm, and 1.20 ± 0.12, respectively. The sphericity of PHM-34 was calculated to be 0.80 ± 0.60, indicating that the seeds are relatively spherical. This indicates that an inclined metering mechanism could effectively facilitate the collection of seeds from the seed hopper. For the JMH-Double variety, the average length, width, thickness and shape were determined to be 10.81 ± 0.97 mm, 9.18 ± 1.41 mm, 5.07 ± 0.78 mm, and 1.26 ± 0.28, respectively (Table 2). The seeds of the JMC-3 variety presented lesser sphericity compared to PHM-34 with a sphericity value of 0.65 ± 0.05 signifying that they are less spherical in shape. Similar trend for geometric properties such as tri-axial dimensions, shape and sphericity were reported for rapeseed (Izli *et al*., 2009) [8].

Table 2: Tri-axial Dimensions of Maize Varieties

S. no	Variety	Length (mm)	Width (mm)	Thickness (mm)	Shape	Sphericity
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
1	PHM-34	11.44 ± 1.48	9.65 ± 0.83	4.40 ± 0.74	1.20 ± 0.12	0.80 ± 0.60
2	JMH-Double	10.81 ± 0.97	9.18 ± 1.41	5.07 ± 0.78	1.26 ± 0.28	0.71 ± 0.09
3	JMC-3	10.94 ± 0.99	8.04 ± 0.79	4.18 ± 0.85	1.37 ± 0.13	0.65 ± 0.05

3.3 Frictional Properties (coefficient of friction and Angle of Repose)

The angle of repose is an essential parameter that indicates the flow characteristics of seeds within a seed hopper. For the investigated maize varieties PHM-34, JHM-Double, JCM-3, the angles of repose were found to be 30.23°, 31.97° and 33.4° respectively. These values are notably close to the standard 45-degree angle which is known to facilitate the free flow of materials from inclined surfaces thereby enhancing operational efficiency during the seeding process These results align with the findings of Kaleemullah *et al*., 2002 [9] and are crucial for choosing materials for planter hoppers and seed plates, thereby ensuring optimal interaction between the seeds and the planter components. The coefficient of friction, an important performance parameter that influences seed movement in the hopper was measured for the maize varieties PHM-34, JHM-Double and JCM-3 across different surface materials. The average values for these varieties were as PHM-34: aluminum (0.49 ± 0.01), cast iron (0.55 ± 0.01), plastic (0.60 ± 0.01) JHM-Double: aluminum (0.55 ± 0.01), cast iron (0.61 ± 0.01), plastic (0.56 ± 0.01) and JCM-3: aluminum (0.61 ± 0.01), cast iron (0.62 ± 0.01), plastic (0.61 ± 0.01). The average coefficients of friction across the materials were calculated to be 0.55 for aluminium, 0.59 for cast iron and 0.59 for plastic. The coefficient of friction was highest against plastic surface and lowest against aluminium surface (Figure 4) which can be attributed to its smooth surface properties that reduce seed adhesion compared to the other materials tested. The similar increasing trend for static coefficients of friction.

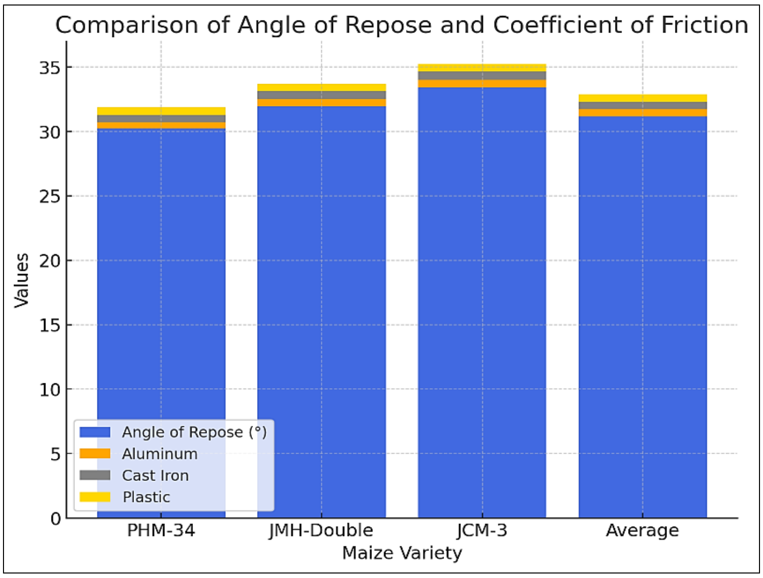

Fig 4: Coefficient of Friction and Angle of Repose for Maize Seeds

3.4 Gravimetric Properties

The gravimetric properties of three maize varieties PHM-34, JHM-Double and JCM-3 were assessed Table 3. The average test weight for the PHM-34 variety was found to be 328.33 g, while JHM showed a higher average test weight of 368.33 g, signifying greater seed density while as the JCM-3 were found the lowest average test weight at 267.33 g. The bulk density values recorded were 0.80 g/cm³ for PHM-34, 0.71 g/cm³ for JHM-double and 0.67 g/cm³ for JCM-3 indicating that PHM-34 exhibits increased seed compactness which can be valuable for storage and handling. In terms of true density, PHM-34 illustrated the highest value at 1.43 g/cm³ followed by JHM-double at 1.34 g/cm³ and JCM-3 at 1.26 g/cm³, emphasizing the significance of this property in assessing seed quality and performance during planting. Also, the porosity values were 44.02% for PHM-34, 46.75% for JHM-double and 47.09% for JCM-3 with higher porosity potentially impacting the flow ability of seeds in hoppers and planters. These findings are comparable to those of Mohamed *et al*., 2021 [14] highlighting significant differences in the gravimetric properties among maize varieties, which can influence their handling and planting characteristics.

Table 3: Gravimetric Properties of Maize Varieties

Parameters	PHM-34				JHM-Double				JCM-3			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Test Weight (g)	322	335	328.33	4.72	362	375	368.33	5.06	262	272	267.33	3.65
Bulk Density (g/cm³)	0.79	0.81	0.8	0.01	0.70	0.72	0.72	0.01	0.64	0.67	0.67	0.02
True Density (g/cm³)	1.33	1.54	1.44	0.11	1.32	1.36	1.34	0.02	1.21	1.32	1.26.	0.06
Porosity (%)	40.60	47.40	44.02	3.4	46.31	47.20	46.75	0.45	44.8	49.62	47.09	2.42

4. Conclusion

The study on the tri-axial dimensions, frictional and gravimetric properties of maize varieties PHM-34, JHM-Double and JCM-3 provides valuable insights for proper design of maize planter. The variety PHM-34 exhibited higher sphericity aligning with the requirements of inclined metering mechanisms, while as JCM-3 variety showed lower sphericity suggests the need for specialized mechanisms to ensure smooth seed flow. The coefficients of friction and angle of repose across surfaces inform material choices for seed hoppers with plastic showing the highest friction ideal for preventing seed slippage. The gravimetric properties reveal PHM-34 variety with greater density and compactness which are advantageous for storage and ease of handling. The JHM-Double and JCM-3 with higher porosity and different flow characteristics needs modified hopper. These findings support the development of efficient, variety-specific planter mechanisms that enhance seed handling, reduce losses and improve planting precision particularly promoting for small-scale farmers.

5. Acknowledgment
The authors would like to acknowledge the help provided by the scientific and technical staff of Faculty of Agricultural Engineering SKUAST-J.

6. Authors' contribution
M. Mohi ud din: Conceptualization, Field experimentation, Data collection, Writing – original draft; J. P Singh: Supervision, Writing – initial draft; S. Sharma: Statistical Analysis and Draft Writing; S. Khar: Execution, Formal analysis, Data interpretation, Writing - review & editing; Sherab Dolma: Execution

7. Conflicts of Interest
The authors declare that there is no conflict of interest in any form that could have influenced the research work reported in this paper.

8. Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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