The Pharma Innovation Journal 2024; 13(2): 76-83

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
TPI 2024; 13(2): 76-83
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www.thepharmajournal.com
Received: 09-11-2023
Accepted: 12-12-2023

Varietal evaluation and comparison of physical and engineering properties of selected varieties of some key staple food grains

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Abstract

This study aimed to determine and compare the physical and engineering properties of some food grains widely used as staple foods in Gujarat. The crops studied included three varieties of rice (Oryza Sativa SSP Indica): Parimal, Gujarat 17, and Lachkari; three varieties of wheat (Triticum aestivum): Bhalia, Sharbati, and GW 173; and three varieties of pearl millet (Pennisetum glaucum (L.) R. Br.): S. Gold, 86M11, and 86M22. These varieties were selected based on their availability and popularity as staple food grains in Gujarat.

Various physical properties and mechanical properties were determined and compared among the three varieties of each grain for significant differences at a level of 0.05. This research paper analyzed the differences among the means of three varieties of rice, wheat, and pearl millet.

The results of one-way ANOVA indicate a statistically significant difference among the means of each variety, with probability values much lower than the significance level of 0.05. Specifically, the F-value for rice was 22.06358 with a probability (Prob>F) of 3.28616×10^{-9}, the F-value for wheat was 51.46932 with a probability value of 6.43116×10^{-13}, and the F-value for pearl millet was 63.39453 with a very low probability value of 7.27796×10^{-9}. These findings suggest that there is a significant difference in the properties of each variety studied. This database will be instrumental in the development and design of specialized machines post-harvesting processing.

Keywords: Engineering properties, pearl millet, physical properties, wheat, rice

1. Introduction

Food grains are essential source of nutrition for human beings, providing carbohydrates, proteins, vitamins, and minerals. As the global population continues to grow, the demand for food grains is increasing. However, food grains are not all created equal. Their physical, chemical, and mechanical properties can vary widely depending on the type of grain, the soil conditions in which they are grown, and the storage conditions after harvest (Müller *et al*. 2022) [1]. Understanding the engineering properties of food grains is crucial for developing efficient harvesting, processing, and storage systems, as well as for maintaining the quality and safety of the grains throughout the entire food chain (Mobolade *et al*. 2019) [2]. In this context, the study of the engineering properties of food grains is of utmost importance to ensure the availability of safe, nutritious, and high-quality food for the growing population, and to process food on a commercial production scale.

The engineering properties of food grains include size and shape, density, hardness and texture, moisture content, color, thermal properties, and rheological properties. These properties are essential for predicting storage behavior, transport properties, processing performance, microbial growth, consumer acceptance, and energy requirements for processing and cooking. Understanding these properties is critical for developing efficient and effective grain processing and storage systems, as well as for maintaining the quality and safety of the grains throughout the food chain.

Engineering of systems for food materials can be more thorough if there is an understanding of the changes that occur in food as it is processed by the system. Raw food materials are biological in nature and as such possess certain unique properties which distinguish them from other manufactured products (Mandala and Protonotariou 2021) [3]. Because food materials are mainly of biological origin they have (a) irregular shapes commonly found in naturally occurring raw materials; (b) properties with a non-normal frequency distribution; (c) heterogeneous composition; (d) composition that varies with variety, growing conditions, maturity and other factors; and they are (e) affected by chemical changes, moisture, respiration, and enzymatic activity. Dealing with materials that have these unique properties requires additional consideration, most often indirectly, in that there are additional sources or causes of variation.

Having a comprehensive understanding of the physical and chemical responses of food materials to different treatments is crucial for designing food equipment and processes that guarantee food quality and safety (Amit *et al*. 2017) [4]. Knowledge of the physical and mechanical properties of food is essential for describing and quantifying food materials, providing fundamental data for food engineering and unit operations, and predicting the behavior of new food materials (Berk 2018) [5].

During processing operations, food often undergoes changes in its physical properties (El Fawal, Tawfik, and El Shal 2009) [6]. Ignoring these changes can result in processing failures, highlighting the importance of understanding these modifications. Physical properties are a crucial component of food quality and have a direct impact on food safety. Instruments and sensors used in the food industry are based on these properties (Watson *et al*. 202) [7].

The handling and processing of plant and animal materials in modern agriculture involve a range of techniques such as mechanical, thermal, electrical, optical, and sonic methods. With the growing significance of agricultural products and the complexity of modern technology used for their production, processing, and storage, it is essential to have a deeper understanding of their engineering properties (Dhanaraju *et al*. 2022) [8]. This understanding helps in designing machines, processes, and handling operations that can achieve maximum efficiency and the highest quality of the end products.

Several studies had been carried out which investigated the physical and mechanical properties of different agricultural products.

Some selected engineering mechanical properties of the certain varieties of grains (cowpea) are highly significant at a 5% level, while properties such as mass, density, and angle of repose were not significant at the same level (Chukwu and Sunmonu 2010) [9]. The moisture-dependent physical properties of red kidney beans, including grain dimensions, grain mass, surface area, projected area, sphericity, bulk density, true density, porosity, terminal velocity, static coefficient of friction against different materials, and shelling resistance all change their behavior with reference to moisture content (IŞIK and ÜNAL 2007) [10]. The physical properties of plant and animal materials are required to determine the stress distribution in materials under load for developing sizing and grading machines and for analytical prediction of its drying behavior (Mohsenin 1968) [11]. Some physical properties such as length, width, thickness, geometric mean diameter, unit mass, volume, sphericity, and density for groundnut kernel variety (NC2) as a function of moisture content were determined and used for the design of storage, handling, and processing equipment (Olajide and Igbeka 2003) [12].

No comprehensive literature was found regarding the specific physical and engineering properties of selected food grains in the state of Gujarat; hence, this study was undertaken to determine, evaluate and compare the various physical and engineering properties of rice, wheat and pearl millet with a view to generate database for effective design of grain handling machineries.

2. Materials and Methods

Samples of three varieties of rice, wheat and pearl millet were selected as shown in figure 1 from the local market based on their usage in the region and availability. Prior to analysis, all extraneous materials such as stones, dust, chaff, immature and broken seeds, as well as defective seeds were removed by means of winnowing and manual picking. Digital Vernier Caliper were used to determine the size (length, width, thickness), surface area, roundness and sphericity of each grain. Weight, volume and density were measured by means of a weighing balance. The angle of friction and angle of repose were determined by employing an angle of friction/repose apparatus. Additionally, hardness was evaluated using a Hardness Tester. Three varieties of rice, wheat and pearl millet were selected as shown in figure 1.

Fig 1: Different Varieties of Rice wheat and pearl millet: Rice- from left 1) Gujarat 17, 2) Parimal, 3) Lachkari: wheat- from left 1) Sharbati, 2) GW 173, 3) Bhalia; pearl millet- from left 1) S. Gold, 2) 86M11, 3) 86M22

2.1 Methods

2.1.1 Size

The physical properties of grains were determined for three different varieties of rice wheat, pearl millet. A total of 500 grains of each were randomly selected and their linear dimensions, including length (L), width (W), and thickness (T), were measured with a digital vernier caliper (BAKER ED 30) with an accuracy of 0.01mm.

2.1.2 Roundness

The roundness of a grain refers to its shape and specifically how close it is to being perfectly round. Grains can have varying degrees of roundness depending on factors such as their origin, the forces they have been subjected to (such as water or wind erosion), and their age. A perfectly round grain would have a circular cross- section, with no sharp edges or corners. In reality, most grains are not perfectly round and may have some irregularities or angular edges. The degree of roundness of a grain can be measured using various methods, such as image analysis or visual inspection.

The roundness of grains is an important property in fields such as sedimentology, geology, and engineering, as it can affect the behavior of grains in various contexts. For example, rounder grains may be more easily transported by water or wind, while angular grains may be more resistant to erosion. Additionally, the roundness of grains can influence their packing and porosity.

$$\text{Roundness} = \frac{\Sigma r}{NR} \quad \ldots (1)$$

Where,
r = radius of curvature of edges and corners
R = radius of the maximum inscribed circle
N = total number of corners summed

2.1.3 Sphericity

The sphericity of a grain is a measure of how closely it approximates a sphere. It is an important property in fields such as geology, agriculture, and civil engineering, as it can affect the flow and packing of granular materials.

There are various methods to determine the sphericity of a grain, but one commonly used approach is to measure its equivalent diameter, which is the diameter of a sphere that has the same volume as the grain. This can be determined using different techniques such as calipers or image analysis software.

Once the equivalent diameter has been determined, the sphericity can be calculated using the following formula:

$$\text{Sphericity } (\Phi) = \frac{d}{D} \quad (2)$$

Where,
d = equivalent diameter
D = circumscribing diameter

2.1.4 Angle of Repose

The angle of repose for grains refers to the maximum angle at which grains or other granular materials can remain stable on a surface without sliding or collapsing. It is an important parameter for many engineering and industrial applications involving the handling, transportation, and storage of granular materials such as grains, powders, and pellets. There are several reasons why determining the angle of repose for grains is important: Design of storage containers and silos, prediction of flow behavior, quality control, and safety. It can be determined by following equation.

$$\text{Angle of Repose } (\theta) = \tan^{-1}\frac{2h}{D} \quad (3)$$

Where, θ= angle of repose
h= height of cone
D=diameter of platform

2.1.5 Angle of Internal Friction

The angle of internal friction is an important property for granular materials such as grains, and helps to estimate the lateral pressure in storage silos. It was determined by the tilting surface method using angle of internal friction apparatus.

$$\text{Angle of internal friction } (\theta) = \tan^{-1}\frac{y}{x} \quad \ldots (4)$$

where, θ = coefficient of friction
y = vertical distance
x = horizontal distance

2.1.6 Mass, Volume and Density

Weights of the samples were obtained with weighing balance (METTLER TOLEDO Cub II) with readability 1 gram, ingress protection IP 65 and operating temperature range of -10 to +40 °C. Volume was determined by toluene displacement method. Grain sample of about 50g was dipped into the toluene. The volume displaced by the grains was noted. The true volume of grains was divided by the number of grains to find the grain volume. Density determined from the relationship between mass, density and volume using equation.

$$\text{Density } (\rho) = \frac{M}{V} \quad \ldots (5)$$

Where, ρ = density
M = mass
V = volume

2.1.7 Hardness

The study of hardness is important for grains because it can provide valuable information about the physical properties and quality of the grain. Hardness refers to the resistance of a material to deformation, indentation, or scratching. The study of hardness is needed for grains for quality control, processing efficiency, storage and transportation, and nutritional value.

Hardness tester (Fujiwara Seisakusho) was used to obtain the hardness of the grains. The upper part of instrument slot was screwed downward to press the sample. The first sound made by the sample when tightly pressed indicates its hardness.

2.1.8 Analysis

Statistical analysis of physical and engineering properties of grains is crucial for several reasons. Firstly, it allows for the objective and quantitative comparison of different grain varieties, which is essential for selecting the most appropriate variety for a given application. For example, some applications may require grains with specific properties, such as high density, hardness, or surface area, and statistical analysis can help identify which variety possesses these properties to the greatest degree. Statistical analysis can help in identifying the variability in the physical and engineering properties of different grain samples. This information is important for understanding the distribution of these properties across a population of grains, and can aid in the development of quality control measures for grain processing and handling. It can also help in identifying any correlations between different physical and engineering properties of grains. For example, there may be a relationship between grain hardness and density, or between surface area and volume. Understanding these correlations can provide valuable insights into the fundamental properties of grains and aid in the development of new grain processing and handling technologies.

ANOVA, which stands for Analysis of Variance, is a statistical method that is used to compare the means of more than two groups. There were three different varieties of each grain *viz* rice, wheat and pearl millet under studied, hence, one way ANOVA had used to determine whether there are any significant differences between the means of the three groups of each grain in terms of the measured properties.

3. Results and Discussions

The mean differences in various properties among three different varieties of three grains: rice, wheat, and pearl millet are as shown in figures 2,3 and 4. The mean values are represented by squares at the center of each data set, while the maximum and minimum values are depicted by whiskers. This figure provides valuable information about the variability in the measured properties of each grain variety, with the length of the whiskers indicating the extent of this variation. Additionally, the mean values allow for easy comparison of the three grain varieties with respect to each property.

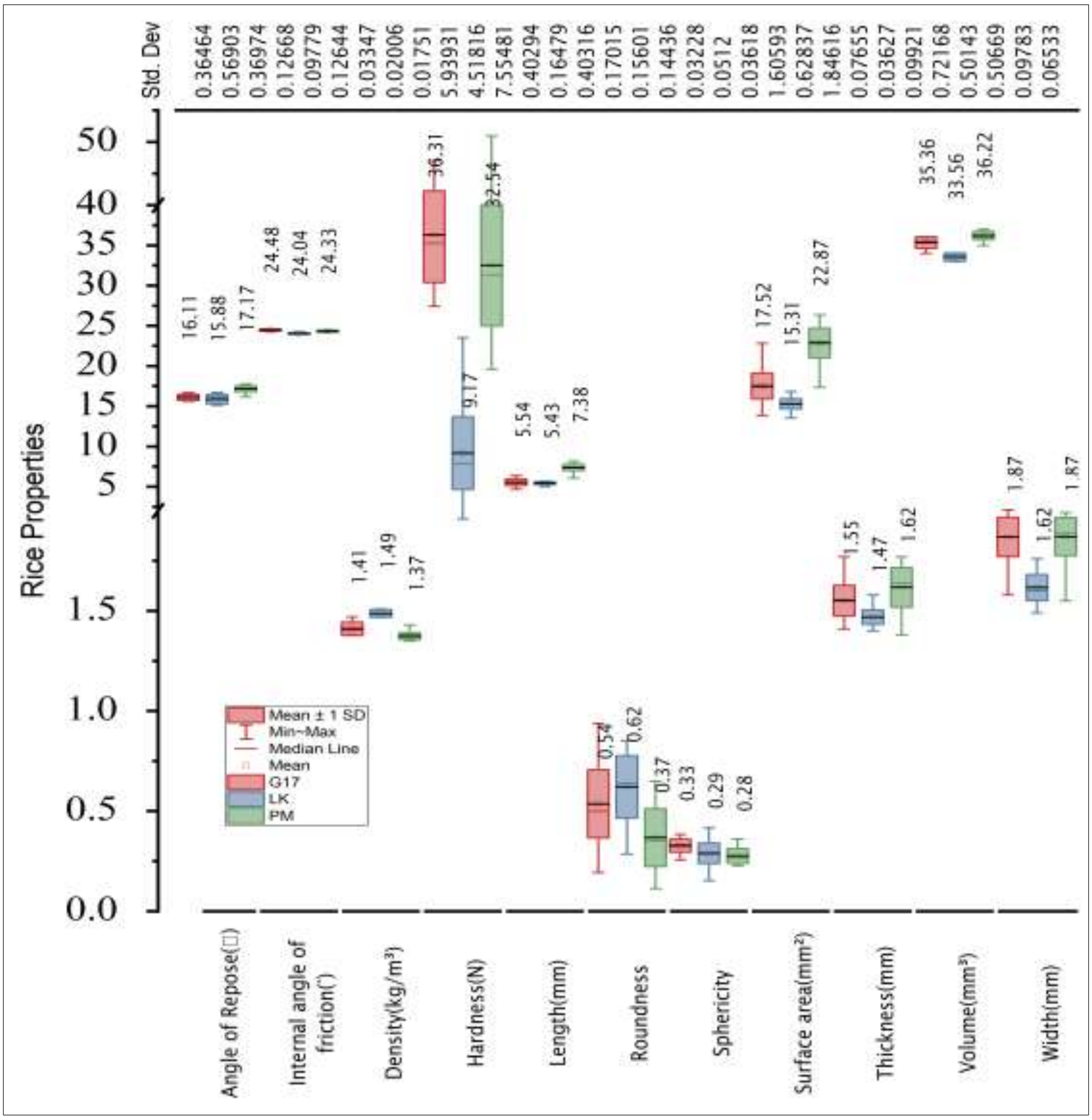

Fig 2: Distribution of different properties labeled on x-axis of rice for each three varieties GJ17, LK and PM with box chart labeled with mean, median with pink line and standard deviation on top axis. Whiskers shows the maximum and minimum range of the data.

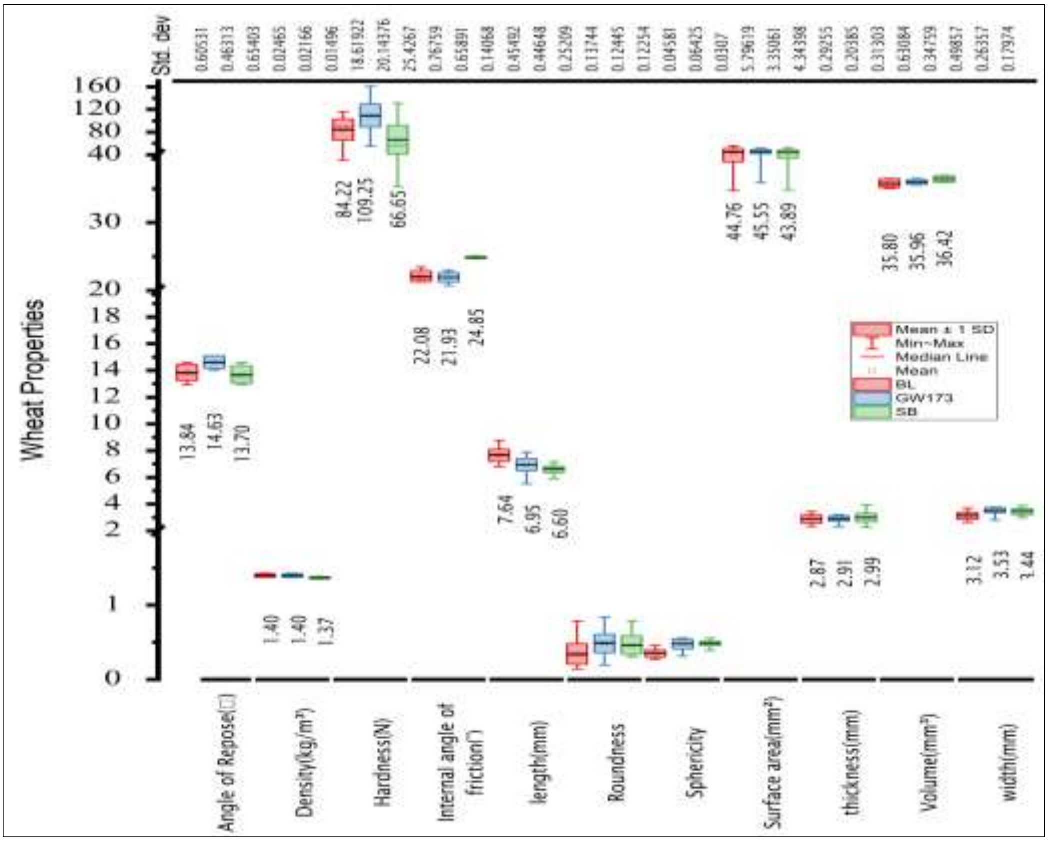

Fig 3: Distribution of different properties labeled on x-axis of wheat for each three varieties Bhalia, GW173 and Sharbati with box chart labeled with mean, median with pink line and standard deviation on top axis. Whiskers shows the maximum and minimum range of the data.

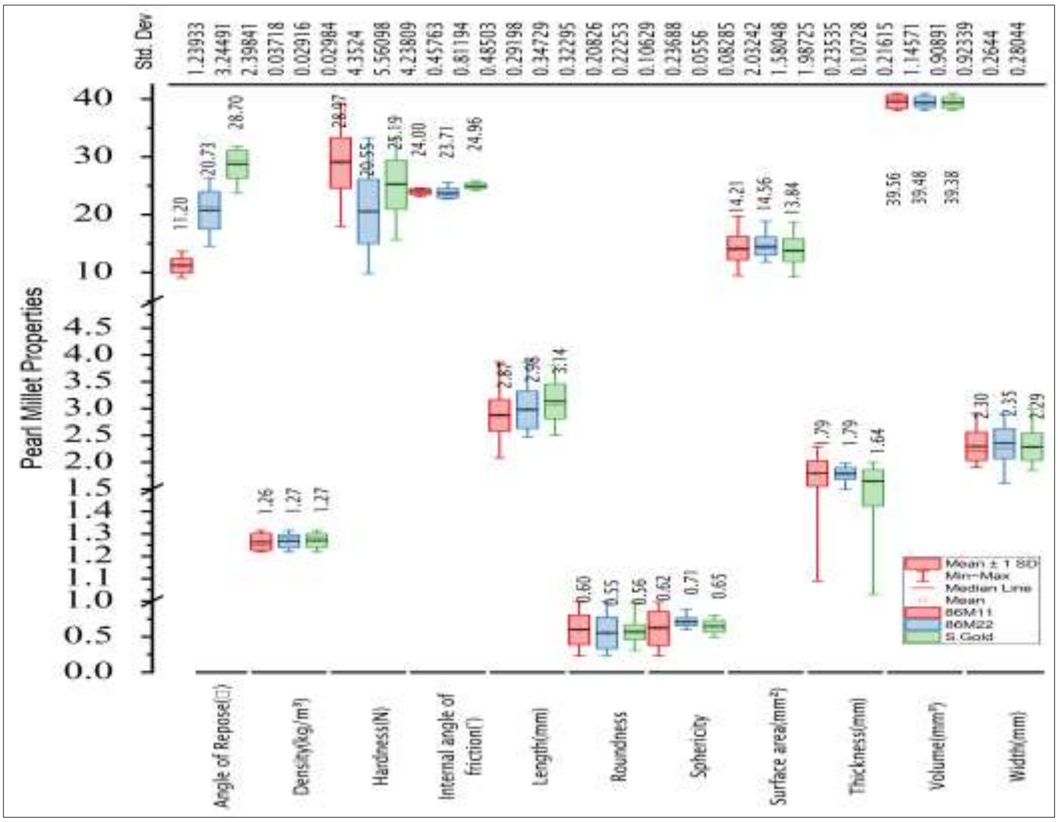

Fig 4: Distribution of different properties labeled on x-axis of pearl millet for each three varieties 86M11, 86M22 and S. Gold with box chart labeled with mean, median with pink line and standard deviation on top axis. Whiskers shows the maximum and minimum range of the data.

3.1 Comparison of Percentage Change Among Different Varieties of Rice

The results indicate that the mean length of Parimal is 25% and 26% larger than that of Gujarat 17 and Lachkari, respectively. Moreover, the mean width of Parimal is found to be similar to that of Gujarat 17, but 14% larger than Lachkari. The mean thickness of Parimal is also observed to be 4% and 9% larger than Gujarat 17 and Lachkari, respectively. The study further reveals that the mean roundness of Parimal is 46% and 69% smaller than that of Gujarat 17 and Lachkari, respectively. Additionally, the mean sphericity of Parimal is found to be 18% and 5% smaller than Gujarat 17 and Lachkari, respectively.

Mean angle of repose of Parimal is 6% and 7% bigger than Gujarat 17 and Lachkari respectively. Mean angle of internal friction of Parimal is 1% smaller than Gujarat 17 and 1% bigger than Lachkari. Mean moisture content of Parimal is 2% smaller than Gujarat 17 and 3% bigger than Lachkari respectively. Mean volume of Parimal is 2% and 7% bigger than Gujarat 17 and Lachkari respectively. Mean density of Parimal is 3% and 8% smaller than Gujarat 17 and Lachkari respectively. Mean hardness of Parimal is 12% smaller and 72% bigger than Gujarat 17 and Lachkari respectively. Mean surface area of Parimal is 23% and 33% bigger than Gujarat 17 and Lachkari respectively.

The descriptive statistics as shown in Table 1, provided useful insights into different properties of the three varieties of rice.

Table 1: Mean properties of three varieties of rice

	Mean	Standard Deviation	SE of Mean
Length(mm)	6.118	1.09529	0.63236
Width(mm)	1.78553	0.14648	0.08457
Thickness(mm)	1.54593	0.07444	0.04298
Roundness	0.50858	0.12921	0.0746
Sphericity	0.29757	0.02654	0.01532
Angle of Repose (◦)	16.38786	0.68701	0.39664
Angle of Internal friction (°)	24.28038	0.22041	0.12725
Volume(mm^3)	35.04667	1.3574	0.78369
Density(kg/m^3)	1.42413	0.0579	0.03343
Hardness(N)	26.00533	14.69885	8.48638
Surface area(mm^2)	18.56507	3.88384	2.24234

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	10	4708.58567	470.85857	22.06358	3.28616E-9
Error	22	469.50166	21.34098		
Total	32	5178.08733			

The mean length of rice grains was found to be 6.118 mm with a standard deviation of 1.09529 mm, indicating that the length of the grains varies significantly. The mean width and thickness of the grains were 1.78553 mm and 1.54593 mm, respectively, with smaller standard deviations, suggesting less variability. The roundness and sphericity were found to be 0.50858 and 0.29757, respectively, with relatively high standard deviations, indicating greater variability in these properties.

The angle of repose was found to be 16.38786°, which suggests that the rice grains have good flowability. The angle of internal friction was found to be 24.28038°, indicating a moderate to high resistance to flow. The mean volume and density of the rice grains were found to be 35.04667 mm^3 and 1.42413 kg/m^3, respectively, with moderate standard deviations. The hardness of the rice grains was found to be 26.00533 N, indicating moderate firmness. The surface area of the grains was found to be 18.56507 mm^2, with a relatively high standard deviation, suggesting greater variability.

3.2 Comparison of Percentage Change Among Different Varieties of Wheat

The physical properties of GW173 were investigated and compared with those of two other varieties, Sharbati and Bhalia. The mean length of GW173 was found to be 5% greater than Sharbati and 10% smaller than Bhalia. The mean width of GW173 was 3% and 12% larger than Sharbati and Bhalia respectively. Additionally, the mean thickness of GW173 was 3% smaller than Sharbati and 1% larger than Bhalia. The mean roundness and sphericity of GW173 were observed to be 4% and 29% greater than Sharbati and Bhalia respectively. On the other hand, the mean angle of repose of GW173 was found to be 5% larger than both Sharbati and Bhalia. However, the mean angle of internal friction of GW173 was 13% and 10% lower than Sharbati and Bhalia respectively. The mean volume of GW173 is 1% smaller than Sharbati, while it is the same as Bhalia. Similarly, the mean density of GW173 is 2% larger than Sharbati, but the same as Bhalia. Furthermore, the mean hardness of GW173 is found to be 39% and 23% greater than Sharbati and Bhalia, respectively. Finally, the mean surface area of GW173 is 4% and 2% larger than Sharbati and Bhalia, respectively.

The mean length of the wheat grains was found to be 7.0634 mm with a standard deviation of 0.53135 mm, indicating relatively low variability in grain length. The mean width and thickness of the grains were 3.3656 mm and 2.92367 mm, respectively, with smaller standard deviations, suggesting less variability. The roundness and sphericity were found to be 0.42863 and 0.43581, respectively, with moderate standard deviations as shown in Table 2.

The angle of repose was found to be 14.05567°, indicating good flowability of the wheat grains. The angle of internal friction was found to be 22.95372°, indicating moderate resistance to flow. The mean volume and density of the wheat grains were found to be 36.06 mm^3 and 1.38686 kg/m^3, respectively, with relatively low variability. The hardness of the wheat grains was found to be 86.7066 N, indicating a high level of firmness. The surface area of the grains was found to be 44.73431 mm^2, with a low standard deviation, suggesting relatively low variability.

Table 2: Mean properties of three varieties of wheat

	Mean		Standard Deviation		SE of Mean
length(mm)	7.0634		0.53135		0.30678
width(mm)	3.3656		0.2173		0.12546
thickness(mm)	2.92367		0.05882		0.03396
Roundness	0.42863		0.07675		0.04431
Sphericity	0.43581		0.07532		0.04348
Angle of Repose (◦)	14.05567		0.49964		0.28847
Angle of Internal friction (°)	22.95372		1.645		0.94974
Volume(mm³)	36.06		0.32187		0.18583
Density(kg/m³)	1.38686		0.01686		0.00973
Hardness(N)	86.7066		21.40746		12.3596
Surface area(mm²)	44.73431		0.82723		0.4776
	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	10	21634.32909	2163.43291	51.46932	6.43116E-13
Error	22	924.73583	42.03345		
Total	32	22559.06492			

Based on the result table, we can conclude that there is a statistically significant difference among the means of at least one of the groups in the study (with a probability value of 6.43116E-13), as the F-value is high and the probability value is much lower than the significance level of 0.05. Hence, there is a difference among the three varieties of wheat.

These findings provide valuable information to researchers and farmers interested in selecting the appropriate variety of wheat for specific applications.

3.3 Comparison of Percentage Change Among Different Varieties of Pearl Millet

The mean length of the pearl millet grains was determined to be 2.9948 mm, and the standard deviation was calculated to be 0.13312 mm, according to Table 3. The mean width and thickness were 2.35247 mm and 1.73827 mm, respectively, with relatively low standard deviations, indicating less variability in these properties. The roundness and sphericity were found to be 0.57145 and 0.65765, respectively, with small standard deviations, indicating less variability in these properties as well.

The angle of repose for pearl millet grains was found to be 20.04286°, indicating that the grains have moderate flowability. The angle of internal friction was found to be 24.22484°, suggesting moderate resistance to flow. The mean volume and density of the pearl millet grains were found to be 39.47333 mm³ and 1.26707 kg/m³, respectively, with low standard deviations, indicating that these properties were consistent across the three varieties of grain.

Table 3: Mean properties of three varieties of pearl millet

	Mean		Standard Deviation		SE of Mean
Length(mm)	2.9948		0.13312		0.07685
Width(mm)	2.35247		0.10133		0.0585
Thickness(mm)	1.73827		0.08493		0.04903
Roundness	0.57145		0.02283		0.01318
Sphericity	0.65765		0.04577		0.02642
Angle of Repose (◦)	20.04286		8.5196		4.91879
Angle of Internal friction (°)	24.22484		0.65581		0.37863
Volume(mm³)	39.47333		0.09018		0.05207
Density(kg/m³)	1.26707		0.00333		0.00192
Hardness(N)	25.08326		4.48089		2.58704
Surface area(mm²)	14.44139		0.7459		0.43065
DF	Sum of Squares		Mean Square	F Value	Prob>F
Model	10	5399.73974	539.97397	63.39453	7.27796E-14
Error	22	187.38884	8.51767		
Total	32	5587.12858			

The hardness of the pearl millet grains was found to be 25.08326 N, which indicates that the grains were moderately firm. The surface area of the grains was found to be 14.44139 mm², with a relatively high standard deviation, suggesting greater variability in this property.

The F value of 63.39453 and the very low probability value (7.27796E-14) indicate that the differences in means are statistically significant at the 0.05 level. Therefore, it can be concluded that there is a significant difference between the means of at least one of the pearl millet varieties for the properties studied.

4. Conclusion

There are significant differences between some of the engineering properties of the different varieties of Rice and Wheat. Engineering properties which were determined for three different varieties of Rice and Wheat are useful in designing equipment for postharvest handling and processing operations. Such as size, shape, surface area, volume, density, roundness and sphericity are important in designing particular equipment or determining the behavior of the product for its handling; hardness, angle of internal friction and angle of repose are important in designing of storage bins, hoppers, chutes, pneumatic conveying system, screw conveyors, threshers; moisture content is important to control the moisture of grains in storage and processing.

5. Acknowledgement

The authors are grateful to Anand Agricultural University for providing facilities to conduct the experiment. The authors would like to thank the editor and anonymous reviewers for their comments that help improve the quality of this work.

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