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Morphometric and Nutritional Characterization of Black Gram (*Phaseolus mungo*) for Post-Harvest Application

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ABSTRACT

Pulses are an essential component of the diet, and information on their physical and structural properties is needed for designing post-harvest machinery. The current study was undertaken to evaluate the morphometric, structural and nutritional composition of black gram. The black gram grain results were statistically analyzed using Stat-Ease Design Expert Software using a simple sample design. The length, width and thickness of the black gram were 5.03 ± 0.02 mm, 4.66 ± 0.02 mm and 4.25 ± 0.03 mm, respectively. The arithmetic mean diameter and geometric mean diameter of the black gram were reported to be 33.28 ± 0.46 mm and 4.64 ± 0.02 mm. The thousand seed weight and volume of the black gram were found to be 44.03 ± 0.15 g and 59.40 ± 0.20 mL. The density, bulk density and true density were reported to be 741.00 ± 4.36 (g/mL), 828.67 ± 9.02 (Kg/m^3) and 1270.67 ± 6.11 (Kg/m^3). The porosity, sphericity and aspect ratio percentage of the black gram were 34.78 ± 0.96%, 92.23 ± 0.32%, and 92.65 ± 0.34, respectively. The nutritional composition of black gram reveals that it contains 8.88 ± 0.03% moisture, 25.96 ± 0.03% protein, 1.72 ± 0.02% fat, 3.65 ± 0.03% ash, 59.78 ± 0.01% carbohydrate and 2.85 ± 0.04% crude fiber. These findings indicate that black gram possesses favorable morphometric and nutritional properties, highlighting its potential as a valuable ingredient in product formulation and its importance in addressing nutritional security. The morphometric and structural properties results would be useful for the development of post-harvest machinery, such as cleaning, grading, dehulling and storage equipment, contributing to enhanced processing efficiency and minimization of post-harvest losses.

Keywords Black gram, Morphometric properties, Structural properties, Nutritional composition.

Study Highlights

Morphometric properties of black gram

Structural properties of black gram

Nutritional properties of black gram

INTRODUCTION

India's population is rising rapidly. To meet the food

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needs of an expanding population, the agriculture sector's output must be increased. India produces 26% of the world's pulses, consumes 27%, and imports 15%. Pulses account for approximately 20% of the food grain area and provide 7–10% of the country's total production (Bairwa *et al.* 2020). "Pulses are cultivated in both the *Kharif* and *Rabi* seasons, with *Rabi* pulses contributing over 60% of the total production" (Bhat *et al.* 2022 ; Manjunatha *et al*. 2023). India's main pulse crops are chickpea, pigeon pea, green gram (mung bean), and black gram (urad bean), in that order. Green gram covers 4.4 million hectares with an annual yield of 2.56 million tonnes. Black gram is grown on around 4.1 million hectares and yields around 2.42 million tonnes (Madhusudan *et al*. 2023). Chickpeas, pigeon peas, mung beans, and urad beans are among the major pulse imports from Australia, Canada, and Myanmar. Increasing the production of pulses, especially in our nation, is necessary to lower imports. Legumes play a significant role in human nutrition, particularly for low-income populations in developing countries. Legume seeds are rich in proteins, carbohydrates, and other nutrients, making them a nutritious option for most people globally. Legumes contain phytochemicals such as polyphenols, flavonoids and phytosterols, which have been linked to health benefits (Kritchevsky and Chen 2005; Roy *et al.* 2010). Legumes account for the majority of protein in the Indian diet, with production remaining stable at 10–13 million tonnes over the past two decades (Wani *et al*. 2013). The country's population growth has led to a drop in daily protein consumption per person, indicating a serious malnutrition problem (Nawab 2004).

The "urd bean," also known as black gram (*Phaseolus mungoo* L/*Vigna mungo* L.) *Hepper*), belongs to the Leguminosae family and is India's third-largest pulse crop (Wani *et al.* 2013). One of the most expensive legumes, it is native to India and has been grown there since ancient times. This leguminous crop has unavoidably established itself as the most widely consumed legume, and the FAO appropriately referred to it as the "King of legumes" (Modgil *et al.* 2019). India is the world's largest producer and consumer of black gram. It produces 1.5 to 1.9 million tonnes of urad annually from 3.5 million hectares, with an average yield of 500 kg per hectare. India produces roughly 1.3–1.5 million tonnes of black gram per year, accounting for about 10% of the country's overall pulse production (12-15 million tonnes) (Anonymous 2018). It is commonly grown in Maharashtra, Uttar Pradesh, Andhra Pradesh, Orissa, Tamil Nadu, Rajasthan, Chhattisgarh, and Madhya Pradesh (Modgil *et al.* 2019). Black gram, also known as urd bean, mash, mah, and black maple, is a short-duration pulse crop widely farmed in India. This crop can be produced as a mixed crop, cash crop, or sequential crop. It can also be grown as a solo crop under residual moisture circumstances after rice harvest, as well as before and after the harvest of other summer crops on semi-irrigated or dry land. This legume is consumed in several forms, including whole, dehusked, and split forms. Legumes are commonly utilized in popular foods such as idli, dosa, vada, papad, and wadian (Modgil *et al.* 2019 ; Singh 1999). Manay and Shadaksharaswamy (1987) state that the mucilaginous arabinoglactins found in black gram are a crucial component of dosa, badi, idli, and several other food preparations. It aids in the preparation of desserts like vada and imarti. It is also consumed as a salted and fried snack. Papads, thin wafer-like products made from black gram or a combination of black gram and other pulses, with or without spices, are produced in small scale factories or at home (Kanth *et al.* 2021).

The physical properties of black gram, including length, width, thickness, shape, density, bulk density, true density, porosity, thousand kernel weight, thousand kernel volume, sphericity, surface area, density, angle of repose, and static coefficient of friction, are crucial for designing equipment for handling, harvesting, processing, and storage (Sahay and Singh 1996 ; Madhusudan *et al.* 2024). Much research has not been conducted on the morphometric and nutritional qualities of black gram in Uttar Pradesh for the purpose of product formulation and building of post-harvest machinery. So, the current study was designed to assess these parameters.

MATERIALS AND METHODS

MATERIALS

The Black gram grains were purchased from the Subhash Ganj market of Jhansi, Uttar Pradesh, India. Digital vernier calliper of brand tHemiSto, model name TH-M61 of resolution 0.01 mm, range 0–150 mm, accuracy .01 mm was purchased from Flipkart, an E-commerce shopping platform. Measuring cylinder 100 mL and 500 mL, weighing balance were issued from the Institute of Food Technology, Bundelkhand University, Kanpur Road, Jhansi (UP) India.

Determination of morphometric and structural properties

The morphometric and structural properties of black gram (Urad) used for the study were determined in terms of length, width, thickness, arithmetic mean diameter, geometric mean diameter, thousand kernel weight, thousand kernel volume, density, bulk density, true density, porosity, sphericity, aspect ratio, shape and color.

Length, width and thickness (L, W, T)

A digital vernier calliper of the brand tHemiSto, model name TH–M61, with a resolution of 0.01mm, a range of 0–150 mm, and an accuracy of 0.01 mm, was used to measure the axial dimensions of a randomly selected black gram grain.

Arithmetic mean diameter (AMD)

The arithmetic mean diameter was determined using the method outlined by Mpotokwane *et al.* (2008). Ten typical black gram grains were measured for length (the longest dimension L), width (the second-longest dimension W), and thickness (the third-longest dimension T). The arithmetic mean diameter (AMD) was then calculated as the equivalent diameter.

$$\text{Arithmetic mean diameter} = (L \times W \times T)/3 \qquad (1)$$

Geometric mean diameter (GMD)

The Geometric mean diameter (GMD) of the black gram was measured according to (Mpotokwane *et al*. 2008) [16] and determined as the equivalent diameter.

$$\text{Geometric mean diameter} = (L\times W\times T)1/3 \qquad (2)$$

Thousand seed weight and volume

An analytical balance was used to determine the average weight of 1000 grains of black gram. A random sample of 1000 grains were chosen, and their volume was measured in a graduated cylinder.

Density

The density (g/mL) of the black gram grains was determined by dividing the thousand kernel weight by volume.

Bulk density and true density

Bulk density (kg/m^3) is defined as the ratio of sample mass to total volume (Vanrnamkhasti *et al*. 2008, Kashim and Gautam 2025). The determination was made by filling a 500 ml cylinder with black gram grains using the (Mariotti *et al.* 2006) method. The bulk density (kg/m^3) was determined by dividing the sample weight by the cylinder volume.

$$\text{Bulk Density} = \frac{\text{Sample weight}}{\text{Volume}} \qquad (3)$$

Using a top loading balance, the liquid displacement method is used to determine the true density (kg/m^3). A hundred ml measuring cylinder was filled with fifty ml of water, and five grams of grains were immersed in it. Water displacement was measured (Karababa and Coşkuner 2013 ; Kashim and Gautam, 2025).

$$Pt = \frac{\text{Sample weight}}{V2\text{-}V1} \qquad (4)$$

Where, Pt = true density, V_1 = initial volume and V_2 = final Volume.

Porosity

Sangamithra *et al.* (2016) define porosity (%) as the fraction of bulk grain space that is not occupied by the grain. Porosity (%) was calculated from the true density and bulk density using the Vanrnamkhasti *et al.* (2008) method.

$$\varepsilon = \frac{Pt - Pb}{Pt} \times 100 \qquad (5)$$

Where: ε = porosity, Pt = true density and Pb = bulk density

Sphericity

Sphericity (%) was determined using the method of Hamdani *et al.* (2014) and is defined as the ratio of the surface area of a sphere with the same volume as the grain to the grain's surface area.

$$\Phi = \frac{(LWT)1/3}{L} \times 100 \qquad (6)$$

Where: Φ = Sphericity

Aspect ratio

Using the Vanrnamkhasti *et al.* (2008) method, the aspect ratio (%) was determined as follows:

$$\text{Aspect ratio} = \frac{\text{Width}}{\text{Length}} \times 100 \qquad (7)$$

Color and shape

The color and shape of black gram were determined visually.

Proximate composition

The proximate composition (moisture AOAC Method 925.10, 1990, protein AOAC Method 920.87, 1990, fat AOAC Method 920.85, 1990, and ash AOAC Method 923.03 1995) of black gram was determined as per the specifications given above. The crude fiber content was determined by (AOAC method 962.09, 1990). The carbohydrate content of black gram grains was determined by the difference method (AOAC 1995). Calories per gram of macronutrient are measured as average energy. The atwater general factor system has energy levels of 4 kcal per gram (kcal/g) of protein (17 kJ/g), 4 kcal/g of carbs, and 9 kcal/g (37 kJ/g of fat). It was determined by multiplying the average macronutrient levels by one gram of Kcal values.

Statistical analysis

All Morphometric and nutritional properties of black gram were analyzed using Stat-Ease Design Expert Software (Version 23.1.9.0, Stat-Ease Inc., Minneapolis, MN, USA). A simple sample design was employed for the statistical analysis, and the results were expressed as mean ± Standard deviation. Statistical significance was determined at $p < 0.05$.

RESULTS AND DISCUSSION

Morphometric and structural properties

Morphometric and structural attributes, including length, width, thickness, arithmetic mean diameter, geometric mean diameter, bulk density, true density, porosity, sphericity, aspect ratio, thousand kernel weights, and others, are essential for processing and value enhancement (Kashim and Gautam 2025). Designing equipment for handling, transportation, storage, and processing necessitates a comprehensive understanding of the dimensions and structural characteristics of grains and seeds. In separation processes employing oscillating chafers and gravity tables, dimensions, morphology, and density are critical. Bulk density and porosity are critical attributes in the design of aeration and drying systems, as they affect airflow resistance within a stored mass (Mane *et al.* 2022). Grain sizes play an important role in cleaning, particularly in threshing operations. Screens are essential in these procedures as they facilitate the passage of specific grain sizes and exclude other undesired substances (Brennan *et al.* 1981).

Morphometric properties

The morphometric properties determined in the present study are as follows: Length, width, thickness, arithmetic mean diameter and geometric mean diameter.

Length, width and thickness (L, W, T)

Seed size plays a crucial role in screening for foreign elements and in calculating heat and mass transfer.

Table 1. Morphometric properties of black gram.

Morphometric Properties	Black Gram
Length (mm)	5.03 ± 0.02
Width (mm)	4.66 ± 0.02
Thickness (mm)	4.25 ± 0.03
Arithmetic Mean Diameter (mm)	33.28 ± 0.46
Geometric Mean Diameter (mm)	4.64 ± 0.02

Values expressed are mean ± Standard deviation.

Size measurements typically include length, width, thickness, and equivalent diameter (Wani *et al.* 2013). The length, width, and thickness of black gram are shown in Table 1. The mean length (mm), width (mm), and thickness (mm) of black gram were found to be 5.03 ± 0.02 mm, 4.66 ± 0.02 mm and 4.25 ± 0.03 mm, respectively. Agarwal and Singh (2004) analyzed black gram and reported its length as 5.20 mm. According to Nimkar *et al.* (2004), the results of the length, width and thickness of the black gram reported measured 5.36 mm in length, 4.28 mm in breadth, and 3.68 mm in thickness at 13.95% moisture. Similar results with slight modifications were observed by (Wani *et al.* 2013 ; Modgil *et al.* 2019) for black gram varieties. Thus, the results (L, W, T) obtained in this study are similar to the findings of (Wani *et al.* 2013; Modgil *et al.* 2019; Nimkar *et al.* 2004).

Arithmetic mean diameter (AMD)

The arithmetic mean diameter (AMD) of black gram was calculated by the formula (L×W×T)/3. The mean AMD of black gram was found to be 33.28 ± 0.46 mm.

Geometric mean diameter (GMD)

The geometric mean diameter (GMD) can be used to estimate the cylinder concave clearance of a threshing unit. It has a key role in determining the drag coefficient and terminal velocity (Mohsenin 1986). The mean GMD of black gram ranged between 4.64 ± 0.02 mm. Madhusudan *et al.* (2024) analyzed the black gram and reported the mean GMD 4.02 mm, which is similar to the results obtained in the present study. Table 1. represents the morphometric properties of black gram, such as length, width, thickness, AMD and GMD.

Structural properties of black gram

The structural properties of black gram evaluated in this study include thousand seed weight (g), thousand seed volume (mL), density (g/mL), bulk density (Kg/m^3), true density (Kg/m^3), porosity (%), sphericity (%) and aspect ratio (%).

Thousand seed weight and volume

The mean thousand seed weight of black gram was reported to be 44.03 ± 0.15 g. According to Modgil *et al.* (2019), black gram seeds weigh in the range 40.56 to 43.14 g, although Madhusudan *et al.* (2024) recorded seed weights of 41.82 g, and Malhotra *et al.* (1998) reported a weight of 43 g for 1000 kernel seeds. Hence, it can be concluded that the results obtained in the present study are in accordance with the results obtained by (Modgil *et al.* 2019 ; Madhusudan *et al.* 2024 ; Malhotra *et al.* 1998 ; Wani *et al.* 2013) with slight differences in seed weight ranging from 1–2 g. The difference in weight may be due to differences in variety, region and cultivar of black gram. The thousand seed volume of black gram was found to be 59.40 ± 0.20. The results of thousand seed volume are similar to the results obtained by (Wani *et al*. 2013), with slight changes in the decimal values.

Density

Density is the weight-to-volume ratio of the seed or mass per unit volume. Density is significant because it indicates how densely a substance's atoms are packed (Madhusudan *et al.* 2024). Understanding the density of agricultural products is crucial for effectively separating them from unwanted components and designing the appropriate fan. It is also used to assess the purity of agricultural products (Rao *et al.* 2020). The density (g/mL) of black gram was reported to be 741.00 ± 4.36.

Bulk density and true density

The density of food ingredients is useful in calculating mass to volume. Density measurements can be used to examine the quality of dietary materials. Food density data is needed for pneumatic and hydraulic transportation of seeds (Wani *et al.* 2013) The bulk density and true density of black gram, analyzed in the present study were reported to be 828.67 ± 9.02 and 1270.67 ± 6.11 (Kg/m^3). Nimkar *et al.* (2004) found that the true and bulk density of black gram seeds ranged from 1.13–1.33 and 0.65 to 0.82 g/mL, respectively. Madhusudan *et al.* (2024) reported the bulk density of black gram in the range 0.86–0.87 g/mL, while Modgil *et al.* (2019) found the bulk density in the range 0.81–0.85 g/mL. The minor differences in the results obtained in the present study with the previous studies might be due to different varieties and cultivars of black gram.

Porosity

Porosity is a key physical characteristic for material packing, modelling and designing heat and mass transfer operations such as chilling, frying and drying (Wani *et al.* 2013). The mean porosity % of black gram was reported to be 34.78 ± 0.96 %. According to reports, the porosity of black and green grams ranges between 38.04 and 42.02% and 40.77 and 45.16%, respectively (Nimkar *et al.* 2004 ; Nimkar and Chattopadhyay 2001). The porosity % obtained in the present study is significantly lower than in previous research studies due to differences in sample size. According to earlier research, black gram has slightly higher porosity values, which could be because of the size and different cultivar variety of the seeds.

Sphericity

Shape plays a crucial role in heat and mass transfer calculations, solid screening for foreign elements, and food quality evaluations. A food material's shape is typically described by its sphericity and aspect ratio. The sphericity % of black gram analyzed in the study was found to be 92.23 ± 0.32%. According to Wani *et al.* (2013), sphericity % was observed between 77.6 3% and 82.5%. Sphericity varies between 81.1–83.6% for black gram (Nimkar *et al.* 2004), 73.8–76.2% for moth gram (Nimkar *et al.* 2005), and 81.5–84.0% for green gram (Nimkar and Chattopadhyay 2001), depending on moisture levels. The result of this study varies significantly from the results of previous studies ; this might be because of different varieties, regions, and cultivars.

Aspect ratio

The aspect ratio of black gram was found to be 92.65 ± 0.34%. A higher aspect ratio was found than the results of (Wani *et al.* 2013), which were in the range 0.74–0.80, respectively.

Color and shape

Visual observation was used to determine the color and form of seeds. The black gram was dark black in color. According to Agarwal and Singh (2004), black gram is dull black in color, but Modgil *et al.* (2019) state it is black in color. Variations in black gram color may be attributed to both varietal differences and agroclimatic circumstances during cultivation. The black gram seeds were found to be oblong in shape, which was similar to the visual results reported by Modgil *et al.* (2019). Table 2. Highlights the structural properties of black gram determined in the present study.

Nutritional characterisation of black gram

The moisture content of black gram was found to be 8.88 ± 0.03 %. The protein content of the black gram was reported to be 25.96 ± 0.03 %. Protein content has been reported to vary from 24.5% to 28.4% (Wani *et al.* 2013). The fat and carbohydrate content of the black gram were in the range of 1.72 ± 0.02 % and 59.78 ± 0.01 %, respectively. Similar results for the carbohydrate content of black gram were obtained by Modgil *et al.* (2019). Higher carbohydrate content ranging from 60.4% to 63.3% was observed by

Table 2. Structural properties of black gram.

Structural Properties	Black Gram
Thousand Kernel Weight (g)	44.03 ± 0.15
Thousand Kernel Volume (mL)	59.40 ± 0.20
Density (g/mL)	741.00 ± 4.36
Bulk Density (Kg/m^3)	828.67 ± 9.02
True Density (Kg/m^3)	1270.67 ± 6.11
Porosity (%)	34.78 ± 0.96
Sphericity (%)	92.23 ± 0.32
Aspect Ratio (%)	92.65 ± 0.34
Color	Dark black
Shape	Oblong

Values expressed are mean ± Standard deviation.

Table 3. Nutritional analysis of black gram.

Nutritional Analysis	Black Gram
Moisture (%)	8.88 ± 0.03
Protein (%)	25.96 ± 0.03
Fat (%)	1.72 ± 0.02
Ash (%)	3.65 ± 0.03
Carbohydrate (%)	59.78 ± 0.01
Crude Fiber (%)	2.85 ± 0.04
Energy (Kcal)	358.48 ± 0.08

Values expressed are mean ± Standard deviation.

Wani *et al.* (2013). The mean ash content was found to be 3.65 ± 0.03 %, respectively. According to Wani *et al.* (2013), black gram has ash content ranging from 2.8% to 3.7%, while Modgil *et al.* (2019) reported the ash content of different varieties of black gram to be in the range 3.17% to 3.47%. The mean crude fiber content and energy value reported in the black gram were found to be 2.85 ± 0.04 % and 358.48 ± 0.08 (Kcal). Girish *et al.* (2012), reported comparable results for the composition of black gram seeds. According to Bravo *et al.* (1999), black gram has 67.0% carbohydrates, 23.6% protein, 0.45% fat, and 3.51% ash content. Table 3. Represents the nutritional composition of black gram.

CONCLUSION

This study explores the morphometric, structural, and chemical properties of black gram, highlighting its potential as a nutrient-dense grain. The current study's findings imply that black gram is a rich source of nutrients and can be employed as an alternative in the formulation of protein-dense food products. This study provides useful insights for agricultural engineers, food scientists, and processors. Understanding the physical properties of grains, such as their geometric mean diameter and sphericity, can help improve equipment design for planting, harvesting, storage, processing, and packing. According to the findings of the current study, when compared to earlier research on the physical and structural properties of black gram, similar equipment can be designed for post-harvest machinery. Knowing the structural and chemical properties improves the quality of black gram-based food products. Using these data, manufacturers may optimise processing procedures and ensure improved efficiency and quality of black gram-based foods.

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