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Determination of Physical and Engineering Properties of Mungbean (*Vigna radiata* L.)

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Abstract

In the design and optimization of machinery and tools used in various phases of agricultural processing, including transportation, sorting, separation, and storage, understanding the physical properties of crops like mungbeans is essential. In the Philippines, where mungbean plays an important role, this information gap assumes particular significance. To fill this void, this study investigates the physical characteristics of mungbean, focusing on two widely-grown varieties grown by farmers in Pangasinan: *Kusapo* and *Kintab*. Results show that while the bean densities of *Kintab* (764.52 kg/m^3) and *Kusapo* (777.78 kg/m^3) did not differ significantly, their pod and bean dimensions varied notably. The average terminal velocity of whole beans was 10.34 m/s, and the optimal moisture content for shelling ranged from 8–10%. These physical property data are crucial parameters in the design of cleaning, separating, and drying equipment. The study provides empirical evidence that supports localized machine design for mungbean processing and offers practical insights for farmers and processors to enhance efficiency, reduce postharvest losses, and improve product quality.

Keywords: Agricultural processing, Kintab, Kusapo, Machinery

Introduction

Mungbean (*Vigna radiata* L.), locally known as “*mungo*,” is a legume cultivated for its edible seeds and sprouts across Asia (Food and Agriculture Organization, 2016). It is the cheapest source of vegetable protein, containing 22 to 27%, as well as a good source of vitamins, calcium, and sodium. Dried mungbean seeds are high in vitamins A and B, while the sprouts are rich in vitamins B and C (PCAARRD-DOST, 2015). With this, mungbean is the most important legume in the Philippines in terms of agricultural area and value of production.

In the Philippines, the Department of Agriculture reports that mungbeans can be grown during the wet season (May-June), dry season (September-October), and late dry season (February-March). It is harvested by priming 60 to 70 days after planting.

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Harvesting can be done as soon as 75% of the pods have dried up. Harvestable pods are picked by hand, with harvesting repeated every 3 to 5 days. The number of primings (number of harvests) depends on the available soil moisture and fertility, and the crop's condition. Right after harvesting, mungbean pods are dried, usually by solar drying. When pods are sufficiently dried, they are threshed by placing them in a sack and beating them until all seeds are separated from the pods. Some farmers use mechanical rice threshers for large-scale production. Clean, undamaged beans with the desired moisture content are important factors for a good-quality product. Mungbean seeds can be stored in tight containers or nylon/jute sacks, or in a cool, dry place protected from rodents (DA, 2015).

In the first quarter of 2023, production of mungbeans dropped to 9.02 thousand metric tons from 9.17 thousand metric tons in the same quarter of 2022. On the other hand, the area devoted to mungbean production increased to 41.73 thousand hectares in 2019 from 41.58 thousand hectares in 2018.

Ilocos Region registered the largest mungbean production of 3.35 thousand metric tons or 37.1% of the total output in the first quarter of 2023. The other major producing regions were Western Visayas and Central Luzon, with 19.1 and 16.1% shares, respectively (Philippine Statistics Authority, 2023).

Inekwe *et al.* (2019) conducted a study with the objectives: (i) to determine the physical properties of mungbeans; and (ii) to determine the relationship between moisture content and the physical properties. The variety of agricultural materials' shapes, sizes, moisture contents, and levels of maturity makes it challenging to determine their physical properties. The study revealed that mungbean seeds are between 13 to 15% moisture at harvest time. It was also found that Mungbean contains 26.4 g protein, 0.72 g non-protein nitrogen, 4.5 g ash, 1.75 g fat, 6.15 g crude fiber, and 61.2 g carbohydrates in 100 g on a dry weight basis.

The morphological and physical characteristics of 10 varieties of mungbean grown in the Philippines were investigated, and the results showed that the varieties differed in terms of their pod length, pod width, pod thickness, bean length, bean width, bean thickness, and moisture content (Bautista *et al.*, 2017). Also, the effect of different varieties and harvest stages on the physical properties of mungbean showed that the variety and harvest stage had significant effects on the moisture content, density, and geometric mean of the mungbean (De Guzman *et al.*, 2018). The relationship of the physical properties, such as moisture content, density, and geometric mean, between the shelling efficiency of mungbean revealed that there was a significant correlation that may affect the performance of the mungbean sheller or related machinery (de Guzman *et al.*, 2019).

According to Halil Unal *et al.* (2008), the design machinery for processing, transportation, sorting, separation, and storage, requires consideration of mungbean geometrical and mechanical characteristics. These properties serve as essential input parameters in determining equipment dimensions, material flow behavior, and operational efficiency. Neglecting such factors in the design phase may result in suboptimal machine performance, including inefficient separation, higher product losses, increased energy consumption, and elevated operational costs. Moreover, knowledge of these characteristics enables manufacturers to tailor equipment to specific mungbean varieties, thereby enhancing productivity, reducing postharvest losses, and improving the overall cost-effectiveness of the mechanization process. Therefore, the determination and consideration of these properties play an important role in the success of designing equipment for mungbeans. Inekwe *et al.* (2019) also reported that recent scientific developments have enhanced the handling and processing of biomaterials using mechanical and thermal devices, but the underlying physical properties of these materials remain underexplored. For engineers and food scientists engaged in handling and processing, such as transportation, drying, threshing, cleaning, aeration, grading, and post-harvest equipment design, such understanding is essential.

Mechanization of mungbeans in production is challenging. Harvesting of mungbean pods is tedious due to their characteristics. The pods do not mature at the same time, thus priming is widely done during harvesting. Mungbean pods are sundried to reduce moisture content before shelling, which is still done manually by beating the pods and or trampling by the feet of humans or animals, and the seeds are cleaned by winnowing. Manual shelling of mungbeans is a time and energy-consuming process in mungbean production (Gregorio et. al., 2021).

Generally, this study was carried out to determine the physical characteristics of mungbean relevant to the optimization of machine design and compare the different physical properties of the two identified common varieties planted by mungbean farmers in Pangasinan, the *Kusapo* and the *Kintab*, also known as NSIC Mg 11 varieties.

Materials and Methods

Analysis of mungbean samples for this study was conducted in a controlled laboratory at the Philippine Center for Postharvest Development Mechanization-Agricultural Machinery Division Laboratory room. All samples were dry and ready for shelling according to the farmers' perspective of where the samples were sourced. The varieties used in the study were *Kintab*/NSIC Mg 11, released in 2001, with glossy green seeds (DA, 2015), and *Kusapo* (Torralba, 2000).

Various laboratory experiments on the physical and engineering properties of mungbean and its by-products were performed to determine the following parameters: moisture content (MC), physical dimension (length, width, and thickness), geometric mean, density, bean-to-pod ratio, and terminal velocity.

1. Moisture Content Determination

Three (3) sets of 100 g representative samples were randomly collected from bulk samples and placed in the assigned sampling containers. The samples were dried at 105 degrees Celsius in a drying oven for 24 hours before collecting and placing them into the desiccator to ensure that there is no gain and loss of moisture until the samples reached the room temperature before weighing, recording, and calculating for moisture content determination (PAES, 2000). (PNS/BAFS PAES 203:2000). Moisture content was determined using the formula below.

$$MC\ \%,\ w.b. = \frac{(Mo - M1)}{M1} x\ 100 \qquad (1)$$

where: MC %, w.b. is the moisture content (%)

Mo is the initial weight of the sample (g)

M1 is the final weight of the sample (g)

2. Physical Dimension (length, width, and thickness)

One hundred (100) beans and one hundred (100) pods were collected from the test samples as representative samples in measuring the dimension. The length, width, and thickness of the samples were measured using a digital caliper.

3. Geometric Mean

The geometric mean diameter, Dg, of the grain was calculated using the following relationship as described by Inekwe *et al.*(2019):

$$Dg = (LBT)^{1/3} \qquad (2)$$

where: L, B, and T are the Length, Width, and Thickness of the mung bean.

4. Bulk Density

In similar studies (Ahangarnezhad *et al.*, 2019; Celik *et al.*, 2007; Goyal *et al.*, 2007; Yeganeh, 2016), the determination of density was discussed, indicating that this parameter can be considered useful in designing the transfer, displacement, and sorting system and determining the size of the machine to be developed.

The methods described by Halil Unal *et al.* (2008), Mohsenin (2020), and Soyoye (2020) were used to determine the density of the bean. The bulk density was determined using the standard test weighting procedure. A container of known weight was filled with a known weight of samples (0.12 kg), and then the dimensions of the cylinder were measured, the volume was then calculated and recorded. Bulk density was determined as the ratio of the mass of beans only to the volume occupied by the beans. Five (5) replicates per sample were conducted and calculated to get the average.

$$Pb = \frac{m}{v}Pb = \frac{m}{v} \qquad (3)$$

where: P_b = bulk density of the bean, kg/m^3
m = weight of the bean, kg
v = volume of the container, m^3

5. Measurement of the bean-to-pod ratio

To measure the bean-pod ratio, three (3) representative samples of 100 g from the test materials were taken. Each sample was manually shelled and separated into the bean and the shell, which were then weighed separately using a weighing scale. The data were recorded, and the bean-to-pod ratio was calculated (PNS/BAFS PAES 269:2019).

$$R = \frac{Wsb}{Wp} \qquad (4)$$

where: R = bean-to-pod ratio
Wsb = weight of shelled mungbean (g)
Wp = weight of pod (g)

6. Terminal Velocity

To measure the terminal velocity, three (3) replicates with 100 g each of impurities, cracked beans, shells, and whole beans were prepared. The terminal velocity was measured using a vertical air column contained in the electrical motor, centrifugal fan, and wind tunnel. The sample was placed in the wind tunnel, and the airspeed was gradually increased until the seed began to float. The airspeed was measured using an anemometer.

Statistical Analysis

The physical properties of two (2) mungbean varieties (*Kintab and Kusapo*) were evaluated to determine variations in bean and pod dimensions, as well as bulk density. Data were analyzed using a t-test to assess whether significant differences existed between the two varieties for each measured parameter. The analysis was conducted at a 5% level of significance to ensure statistical reliability.

Results and Discussion

Physical and Engineering Properties of Mungbean

The following were the results of the experiments conducted to establish the identified physical and engineering properties of mungbean:

1. Moisture Content

Moisture content is one of the most important factors in determining grain/bean quality during harvesting, storage, trading, processing, and transportation. High moisture can cause problems for farmers, such as mold growth, higher insect infestation, poor seed germination, and lower market prices. It can also affect the design of effective agricultural machinery (Hossain *et al.*, 2016).

Table 1 shows the moisture content of the mungbean samples used during the laboratory analysis. The average moisture content of the two (2) samples, (*Kintab* represented as MC1 and *Kusapo* represented as MC2) with five (5) replicates, was determined using the standard procedure, the oven method.

Table 1. Moisture Content, (%)

Replicate	MC 1	MC 2
1	10	8
2	10	8
3	9	10
4	10	10
5	11	8
Average	**10± 0.71**	**8.8± 1.10**

The moisture content of the mungbean

samples ranged from 8.0% to 11.0%, with mean values of 10.00 ± 0.71% for MC 1 and 8.80 ± 1.10% for MC 2. An independent samples *t*-test showed no significant difference between the moisture contents of the two samples ($p > 0.05$), indicating comparable drying conditions before testing. The relatively low variability suggests uniformity of samples, which is essential for the reliable determination of physical and engineering properties relevant to machine design and postharvest operations.

Results showed that the moisture content of mungbean samples ready for shelling ranged from 8% to 10%, consistent with farmers' traditional drying practices. This range is considered optimal for efficient shelling and minimal seed damage, as supported by Gregorio *et al.* (2021). Comparable findings were also reported by Cruz *et al.* (2013) and Arcilla *et al.* (2016), who observed pod moisture contents between 7.5% and 12.5% before shelling.

2. Physical Dimension

Physical dimension (length, width, and thickness), and geometric mean of a bean/grain can be useful parameters in designing an effective agricultural machinery for crops like mungbean, such as threshing, sorting, and packaging machines (Ahangarnezhad *et al.*, 2019). Post-harvest machinery and equipment can aid farmers in minimizing losses.

Based on the second part of the experiments, the following properties were established:

a. Dimensions of Beans

Table 2 shows the average dimension and the geometric mean of 2 varieties of mungbean using a digital caliper. The physical dimension (length, width, and thickness), and the geometric mean of the two varieties revealed that beans of the *Kusapo* variety were longer with an average dimension of 5.65 mm in length, 4.17 mm in width, 4.27 mm in thickness, and 4.65 in geometric mean, compared to the *Kintab* variety, which has an average dimension of 5.32 mm in length, 4.29 mm in width, 4.45 mm in thickness, and 4.66 geometric mean.

Table 2. Average dimensions of Mungbean seed (mm)

Variety	Length	Width	Thickness	Geometric Mean
Kusapo	5.65±0.41	4.17±0.22	4.27±0.25	4.65±0.24
Kintab	5.32±0.54	4.29±0.28	4.45±0.37	4.66±0.34

The result of the analysis using the T-test revealed that the two varieties are significantly different from each other in terms of their length, p (-4.76) =0.0000, width, p (3.16) =0.0019, and thickness, p (3.99) =0.0001, with standard deviation indicated in each dimension.

Significant variations in dimensional attributes imply that the two varieties may respond differently to mechanical operations such as shelling, sorting, and separation. For instance, differences in bean length, width, and thickness influence the required adjustments in machine settings, such as sieve aperture, airflow velocity, and clearance spacing. Failure to account for these varietal differences could result in inefficient processing, increased mechanical losses, or product damage.

b. Dimension of Pod

Table 3 shows the average dimensions of Mungbean pods, where the *Kusapo* had a length of 90.35 mm, which was longer than the 76.42 mm length of the *Kintab*.

Table 3. Average dimensions of Mungbean Pod (mm)

Variety	Length	Width	Thickness	Geometric Mean
Kusapo	90.35±10.96	5.67±0.56	5.83±0.58	14.44±1.21
Kintab	76.42±12.79	4.50±0.60	5.21±0.85	12.15±1.39

Furthermore, a statistical comparison using the T-test of the two varieties shows that *Kusapo* and *Kintab* are significantly different from each other in length, p (-8.70) =0.0000, width, p (-14.19) =0.0000, and thickness, p (-5.97) =0.0000, with standard deviation indicated in each dimension.

Significant variations in pod dimensions may affect how different mungbean varieties respond to mechanical shelling operations. These differences directly influence the necessary machine adjustments, particularly in selecting and configuring shelling mechanisms such as the peg-tooth drum. Parameters including peg-tooth length, spacing, and the clearance between the shelling drum and concave must be optimized according to pod size. Failure to account for these varietal differences may lead to inefficient shelling performance, increased mechanical losses, and higher rates of seed damage.

3. Bulk Density

Table 4 shows the bulk density of the mungbean samples during the laboratory analysis. Bean density of the *Kintab* and *Kusapo* varieties was calculated at an average of 764.52 and 777.78 kg/m^3, respectively, resulting in no significant difference.

Table 4. Average bulk density of Mungbean (kg/m^3)

Replicate	Kintab	Kusapo
1	774.19	774.19
2	774.19	816.33
3	774.19	774.19
4	750.00	774.19
5	750.00	750.00
Average	**764.52 ± 13.25**	**777.78± 23.96**

The bulk density of the mungbean varieties ranged from 750.00 to 816.33 kg/m^3, with mean values of 764.52 ± 13.25 kg/m^3 for Kintab and 777.78 ± 23.97 kg/m^3 for Kusapo. An independent sample *t*-test indicated no statistically significant difference between the bulk densities of the two varieties ($p > 0.05$). This similarity suggests that both varieties may be handled similarly in terms of storage, packaging, and transportation requirements. The relatively low variability further indicates uniform grain packing behavior, which is advantageous for the design and calibration of postharvest equipment such as bins, conveyors, and storage structures.

4. Terminal Velocity

Terminal velocity is a critical parameter in the design and optimization of cleaning and separation machinery, such as blowers, as it directly influences the efficiency of sorting and removal of foreign materials. Accurate determination of terminal velocity enables proper calibration of airflow and power requirements, minimizing grain losses while ensuring effective cleaning and maintaining mungbean quality.

Mungbean shells and impurities are the components that are alienated during the shelling process. It could be separated from the beans significantly using the values of the terminal velocity. Table 5 shows that the average terminal velocity of the whole bean is 10.34 m/s, while the mungbean shell, crack beans, and impurities have an average terminal velocity of 7.24 m/s, 4.30 m/s, and 1.72 m/s, respectively.

Table 5. Terminal Velocity of shelled mungbean and its by-products (m/s)

Variety	Impurities	Crack bean	Shell	Whole Beans
Kusapo	2.16	4.39	6.47	11.26
Kintab	1.28	4.20	8.01	10.41
Average	**1.72**	**4.30**	**7.24**	**10.34**

These results closely align with those reported by Cruz *et al.* (2013), who observed terminal velocity values between 10.8 m/s and 11.2 m/s, and are further supported by De Guzman (2015), who documented varietal differences in terminal velocity among *Kintab, Kusapo, and NSIC Mg 11*. The consistency among these studies reinforces the reliability of terminal velocity as a key parameter in designing and optimizing airflow-based separation and cleaning mechanisms for mungbean processing equipment.

5. Bean-to-pod Ratio

This ratio is obtained using 100 g of

harvested mungbeans. The potential shelling recovery is referenced to this value. Data gathered reveal that the average bean recovery for the *Kusapo* variety was 70%, whereas 66% for *Kintab,* as shown in Table 6. The bean-to-pod ratio is a critical parameter in the design and evaluation of shelling machinery. It indicates the proportion of usable beans relative to the total pod mass, and therefore directly affects the expected output efficiency during shelling operations. A higher bean-to-pod ratio generally reflects better shelling potential and reduces the amount of residual pod material that must be separated.

This ratio is also essential in computing shelling recovery, which measures the percentage of beans successfully extracted from the pods during the shelling process. Based on the results of this study, the average shelling recovery for mungbeans ranges from 66% to 70%, indicating the typical proportion of beans that can be efficiently recovered under optimal conditions.

Overall, understanding the bean-to-pod ratio allows engineers to properly size and calibrate shelling mechanisms—such as peg-tooth length, concave clearance, and separation airflow—to achieve maximum recovery and minimize losses.

Determination of bean-pod ratio can be useful in designing a threshing/shelling machine, in calculating the machine recovery of specific crops like mungbean.

Table 6. Average Bean–pod ratio

Variety	Bean	Pod	Bean-pod ratio
Kusapo	70.20	29.80	2.36
Kintab	65.95	26.95	2.45

Conclusion

Understanding the geometric and mechanical properties of mungbeans is essential for the effective design and optimization of machinery used in processing, sorting, separation, and storage. These physical characteristics directly guide engineering decisions and ensure efficient, safe, and loss-minimizing postharvest operations.

This study compared the physical properties of two commonly cultivated mungbean varieties—*Kusapo* and *Kintab* (NSIC Mg 11). While bean density showed no significant difference between varieties, several key dimensions, including bean length, width, thickness, and pod characteristics, varied significantly. The average terminal velocity of whole beans (10.34 m/s) was also distinctly higher than that of shells, cracked beans, and impurities, demonstrating its usefulness in separation processes. Shelling recovery averaged 70% for Kusapo and 66% for Kintab.

This study examined and compared the physical characteristics of two mungbean varieties (*Kusapo and Kintab (NSIC Mg 11)*) to support the optimization of machine design for postharvest operations. Results showed that while bean density exhibited no significant difference, other parameters, such as bean length, width, and pod dimensions, varied significantly. These differences directly influence the performance and calibration of shelling, sorting, and separation equipment, requiring adjustments in sieve openings, airflow velocity, and shelling clearance. Meanwhile, the similarity in bulk density suggests both varieties can be handled similarly during storage and transport, reducing the need for separate machine settings.

Overall, the findings highlight the critical role of physical characterization in designing efficient and cost-effective mechanization technologies, ultimately contributing to reduced postharvest losses and improved productivity in mungbean production systems. This was supported by the study of de Guzman et al. (2019), which found that the relationship between the physical properties of mungbeans and shelling efficiency showed a significant correlation that may affect the performance of related machinery.

Future research may focus on applying the physical properties of the mungbean obtained in the actual design and optimization of postharvest machinery such as shellers, cleaners, and sorters. Validation through prototype development and performance testing is recommended. Further studies may also explore including additional mungbean varieties from different regions to establish a more comprehensive database for equipment calibration. Integrating computational modeling and simulation tools can enhance the accuracy of machinery, crop interaction analysis, and support the development of cost-effective and sustainable mechanization technologies for mungbean production systems.

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