Geometric Characteristics and Mass-Volume-Area Properties of Haricot Beans (Phaseolus vulgaris L.): Effect of Variety

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ABSTRACT
The geometric characteristics and mass-volume-area properties of haricot beans are essential for the design of equipment for harvesting, handling, drying, storing, dehulling, processing, and packaging. This study was carried out to determine the effect of variety on the geometric characteristics and mass-volume-area properties of four improved haricot beans varieties. The moisture content, 1000 seed mass, and true density of beans varied significantly (p < .05) in the range of 9–11.28%, 199.9–529.93 g, and 1127.52–1212.40 Kg/m³, respectively. The dimensional properties of the improved haricot bean were significant (p < .05) among the varieties, indicating that these would require some variation in the processing equipment design. Hydration capacity varied significantly from 0.14 to 0.36 g/seed among the improved haricot bean varieties. The hydration index also displayed significant differences among the varieties. Significant differences were observed in hydration coefficient and swelling capacity among the varieties and varied from 1.71% to 1.77% and 0.28 to 0.81 mL/seed, respectively.

INTRODUCTION
Common beans are the most broadly grown legume species in the world and are the third most significant bean after soybean (Glycine max (L.) Merr.) and peanut (Arachis hypogea L.). Common beans have considerable potential now and in the future to contribute to nutrition and food security. Haricot beans (Phaseolus vulgaris L.) are a type of legumes that are widely consumed due to their high nutritional value, delicious taste, and ease of preparation. In the East and Great Lakes regions of Africa, haricot beans play an important role in human nutrition. They have a high protein source and are recognized as the “poor man’s meat.” They are nearly 2–3 times higher in protein than cereals. Besides, they are also an important contributor of fiber, prebiotic, vitamin B, and other micronutrients in the human diet.

Haricot bean (Phaseolus vulgaris L.) has been an export crop for Ethiopia for more than 50 years. There are a wide range of haricot bean types grown in Ethiopia, including mottled, red, white, and black varieties. The most commercial varieties are pure red and white-colored beans, and they are becoming the most commonly grown types with increasing market demand. Nowadays a continuous increase in area and volume of production in the country has been noticed due to the growing demand for the local and export market of these crops. This demonstrates that, while Ethiopia produces a large amount of haricot beans on a global scale, postharvest handling is still inefficient and mostly done by hand. Therefore, it is necessary to have information on the geometric characteristics and mass-volume-area properties of haricot beans to handle them mechanically. As a result, there is an
urgent need to investigate the geometric characteristics and mass-volume-area properties of Ethiopia’s improved haricot beans varieties.

Information on the physical properties of common beans is important in the design of equipment used for processing, transportation, sorting, separation, and storage. Furthermore, these properties are required during the processing and handling of agricultural materials to set the operational parameters of the equipment for efficient operations.\textsuperscript{[8,9]} For instance, the size and shape of foods are important physical characteristics that are used in screening, grading, and quality control.\textsuperscript{[10]} Data on the angle of repose, volume, density, and porosity are also important for the design of processing, storage of particulate material, determining the power required for pumping, and modeling and design of various heat and mass transfer processes, such as drying, frying, baking, heating, cooling, and extrusion.\textsuperscript{[10]} The functionality of raw materials is a combination of properties that determine product quality and process effectiveness. These properties are relevant to the mechanization of processing to increase the utilization as a food resource. Hence, the knowledge of the geometric characteristics and mass-volume-area properties of haricot beans is needed. Thus, the objective of this study was to explore geometric characteristics and mass-volume-area properties of improved haricot beans and their dependence on variety, which can help out in the design of handling, processing, and packaging machinery for haricot beans production.

\section*{MATERIALS AND METHODS}

\subsection*{Sample}

Four improved varieties of haricot bean (\textit{Phaseolus vulgaris} L.), namely: SER 119, SER 125, SAB 632, and Awash 2, were obtained from the Awash Melkassa Agricultural Research Institute of Ethiopia, from February to March 2020 (Figure 1). The choice of exploring these haricot beans varieties was based on the fact that they have been shown to have a high production percentage, disease tolerance, short period to ripe and easy to adopt in Ethiopia.

The sample seeds were cleaned from foreign materials, such as dust, stones, dirt, immature seed, damaged seeds, and other impurities by manual picking and for further analysis; the healthy selected seeds were kept at 5°C by placing in an airtight plastic vessel. Before starting a test, the seeds were allowed to warm up to room temperature. Throughout the test and experiments, sample selection was randomized.

\subsection*{Moisture content}

Before oven drying each of the cleaned and selected seeds samples were weighed using an electronic weight of accuracy of 0.001 g (Metler toledoML303T/00, China). By the use of small trays, all samples were put in an oven at a temperature of 103 °C as per ISO-665-2020\textsuperscript{[11]} and weighed every time after cooling the samples in a desiccator till constant mass. The moisture content was then calculated by using equation 1.

\begin{equation}
\text{Dry basis } mc_d = \left( \frac{W_w - W_d}{W_d} \right) \times 100
\end{equation}

where $W_d$ is dried beans weight, $W_w$ is wet bean weight (total mass) and $mc_d$, is moisture content (dry basis) in percentage.

\subsection*{Thousand seed weight}

The 1000 seed weight was determined using a digital electronic balance (Metler toledo ML303T/00, China) having an accuracy of 0.001 g following the procedure as described by Sharma \textit{et al}.\textsuperscript{[12]} with some modification. To assess the 1000 seed weight, 1000 randomly selected haricot bean seeds were counted and weighed. The reported value is the mean of three replications.
Bean mass

The mass of the improved haricot beans was determined by using a precision electronic balance reading to an accuracy of 0.01 g.

Bulk density, true density, and porosity

The bulk density, true density, and porosity of the haricot beans were determined using the method of Sharma et al.\cite{12} In brief, the bulk density was obtained by filling 500 mL in the volume of a circular container with the seed from a height of 150 mm to create a tapping effect in the container to mimic the settling effect during storage at a constant rate and then weighing the contents with a digital electronic balance with an accuracy of 0.001 g. No manual compactions were done for each seed variety. The bulk density, \( \rho_b \) was calculated as the ratio of the mass of the beans to the volume of the cylinder.

\[
\rho_b = \frac{M_S}{V_c}
\]  
(2)
where \( V_c \) is the volume of a cylinder \((m^3)\), and \( M_s \) is the mass of seed \((kg)\). The true density of haricot beans was determined using the toluene \((C_7H_8)\) displacement method. The true density was found as an average of the ratio of their masses to the volume of toluene displaced by the seeds. The volume of toluene displaced was found by immersing a weighted quantity of haricot seed in the toluene. True density was then calculated from the obtained values using the formula:

\[
\rho_t = \frac{M}{V_2 - V_1} 
\]

(3)

where \( M \) is the mass of seeds \((kg)\), \( V_1 \) is the initial volume \((m^3)\), and \( V_2 \) the final volume \((m^3)\).

The porosity of haricot beans was determined by using the following equation:

\[
\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 
\]

(4)

where \( \varepsilon \) is the porosity \%(\), \( \rho_b \) is the bulk density \((kg/m^3)\), and \( \rho_t \) is the true density \((kg/m^3)\).

**Angle of repose**

The angle of repose of the sample was determined by filling the seed beans in a topless and bottomless cylinder \((with a 10 \text{ cm diameter and 15 cm height})\) placed on a flat surface and allowing it to overflow and form a cone in its natural rest position. The angle of repose was calculated using the formula given by Aviara et al.\([13]\)

\[
\theta = \tan^{-1} \left( \frac{h}{r} \right) 
\]

(5)

where \( \theta = \text{Angle of repose in degrees, } h \text{ and } r = \text{-height and the radius of the cone, respectively.} \)

**Color measurement**

The color of haricot beans was measured with a precision colorimeter (3NH Technology co., LTD, China). The color readings were displayed as \(L^*\), \(a^*\) and \(b^*\) format values where \(L^*\) represents lightness/darkness dimension; positive and negative \(a^*\) values indicate redness and greenness, respectively; and \(b^*\) indicates yellowness for positive and blueness for a negative value. The color measurement was repeated seven times.

**Dimensional Properties**

The three principal axial dimensions \((length (L), width (W), and thickness (T))\) of the haricot bean were measured using the method of Sahin and Sumnu.\([10]\) The dimensions of 100 randomly selected haricot beans from each variety were measured using a digital vernier caliper \((TA, M5 0–300 \text{ mm, China})\) of 0.01 mm precision. The arithmetic mean diameter \((D_a)\), geometric mean diameter \((D_g)\), square mean diameter \((D_4)\), and equivalent mean diameter \((D_e)\) of the haricot bean were determined by using the following equations \((6, 7, 8, \text{ and } 9)\).\([14]\)

\[
D_a = \frac{(L + W + T)}{3} 
\]

(6)

\[
D_g = (LWT)^{1/3} 
\]

(7)

\[
D_4 = (LW + WT + TL)^{1/2} 
\]

(8)
The volume (V) and surface area (S) of the haricot bean were determined using equations adopted by Baryeh and Mangope.  

\[ V = \frac{\pi B^2 L^2}{6(2L - B)} \]  

\[ S = \frac{\pi B^2 L^2}{2L - B} \]

where \( B = (WT)^{0.5} \); \( L \) is the length of the seeds; \( W \) is the width of the seeds; \( T \) is the thickness of the seeds in mm.

**Sphericity, aspect ratio, flakiness ratio, and percent roundness**

The sphericity and the aspect ratio of the haricot beans were calculated using the following equation 12 and 13 as per the method of Wani et al.  

\[ \Phi = \frac{Dg}{L} \times 100 \]

\[ R_a = \frac{W}{L} \]

The flakiness ratio \( (R_f) \) of the haricot bean seed was determined using the following equation.  

\[ R_f = \frac{T}{W} \]

where \( \Phi \) is sphericity, \( R_a \) is the aspect ratio, \( R_f \) is the flakiness ratio, and \( L, W, Dg \) are the length, width, and geometric mean diameter of haricot beans seeds, respectively. The percent roundness \( R_p \) was calculated as follows. The projected area of the seed was measured by an image analysis method. The area of the minimum circumscribing circle was determined by taking the largest axial dimension of the seed at a natural rest position (length of the seed) as the diameter of the circle. The process was repeated for 20 seeds selected randomly. The average was taken as the representative value of roundness.  

\[ R_p = \frac{A_p}{A_c} \times 100 \]

where: \( A_p \) is the projected area of seed in mm\(^2\), and \( A_c \) is the minimum circumscribing circle in mm\(^2\).

**Functional properties**

**Hydration and swelling capacity**: The hydration and swelling capacity of the haricot bean were determined using the method of Shimelis and Rakshit; Kaur and Singh.

**Hydration and swelling index**: Hydration and swelling index were evaluated using the method of Shimelis and Rakshit.

**Hydration and swelling coefficients**: The percentage increase in the mass of haricot bean seeds soaked in distilled water for 24 hours was used to measure the hydration coefficient. The swelling coefficient was calculated as a percentage of the volume of bean seeds after soaking divided by the volume before soaking.
Table 1. Effect of variety on some selected properties of improved haricot bean varieties.

| Parameters     | SAB 632 | SER 119 | Awash 2 | SER 125 |
|----------------|---------|---------|---------|---------|
| Moisture content (%) | 9.8 ± 0.5<sup>a</sup> | 9.00 ± 0.07<sup>a</sup> | 9.3 ± 0.5<sup>b</sup> | 11.3 ± 0.3<sup>a</sup> |
| Mass of beans (g) | 0.51 ± 1.8<sup>b</sup> | 0.26 ± 0.65<sup>b</sup> | 0.2 ± 0.8<sup>b</sup> | 0.26 ± 0.07<sup>b</sup> |
| Thousand seed weight (g) | 530 ± 14<sup>b</sup> | 255 ± 2<sup>b</sup> | 200 ± 5<sup>c</sup> | 260 ± 3<sup>b</sup> |
| Bulk density (kg/m<sup>3</sup>) | 881 ± 3<sup>b</sup> | 891 ± 14<sup>b</sup> | 958 ± 8<sup>b</sup> | 872 ± 13<sup>b</sup> |
| True density (kg/m<sup>3</sup>) | 1185 ± 6<sup>b</sup> | 1167.6 ± 0.7<sup>c</sup> | 1212 ± 3<sup>c</sup> | 1128 ± 12<sup>b</sup> |
| Porosity (%) | 25.6 ± 0.5<sup>a</sup> | 23.7 ± 1.1<sup>d</sup> | 21 ± 0.8<sup>a</sup> | 23 ± 2<sup>a</sup> |
| Angle of repose (°) | 13.1 ± 0.8<sup>a</sup> | 13.5 ± 0.3<sup>d</sup> | 13.14 ± 0.09<sup>a</sup> | 12.9 ± 0.5<sup>a</sup> |

Values are means ± SD and values in the same row with different superscript letters were significantly different from each other (p < 0.05).

Statistical analysis

The results obtained were presented as the mean and standard deviation (SD). The data were subjected to one-way analysis of variance (ANOVA) using Statistical Package for Social Science (SPSS version 20). Significant differences between the means were determined with the Tukey test at p < .05.

RESULTS AND DISCUSSION

Table 1 shows the effect of variety on the physical properties of improved haricot bean varieties. According to the result, the value of moisture content ranged from 9% to 11.28% on a dry basis. The highest was recorded for SER 125 variety and the lowest was for SER 119 variety. There were no significant differences between SAB 632, SER 119, and Awash 2 varieties, but these three were significantly (p < .05) different from SER 125 variety. The present results show that the moisture content range was within those reported in Shimelis and Rakshit<sup>[2]</sup> for haricot bean which was between 9.08 and 11.00 g/100 g (d.b) and Tuned-Akintunde et al.<sup>[20]</sup> for soybean which was between 6.25% and 11.60% d.b. The moisture content of the seed can indicate its storage stability as well as the ease of the dehulling process.<sup>[12]</sup> For food researchers and processors, the amounts of water present in agricultural products are extremely important as they assist in determining certain phases of adaption and resistance to processing, such as drying, bagging, storing, cooking, and even consumption.

The seeds mass of improved haricot beans varied from 0.20 to 0.51 g. The highest seed mass was observed in SAB 632 variety. The haricot bean seed is heavier than soybean which is between 0.11 and 0.18 g reported by Tunde-Akintude et al.<sup>[20]</sup> but the mass of the SAB 632 variety was in tune with the observations of Palilo et al.<sup>[21]</sup> for common beans Wanja variety grown in Tanzania, which is 0.50 g. According to the classification of bean size adopted by De Barros and Prudencio, <sup>[22]</sup> the haricot beans studied were considered small, except the beans from the SAB 632 variety, which were classified as big.

Regarding the 1000 seed weight, results showed significant (p < .05) differences between the haricot bean varieties. However, SER 119 and SER 125 varieties were not significantly different in their thousands of seed weight from each other. The highest (529.93) 1000 seed weight was observed in SAB 632 and the lowest (199.90) in the Awash 2 variety. The data of 100 seeds weight are a significant factor in the design of equipment for cleaning, separation, conveying, and elevating unit operations.<sup>[13]</sup> It can also be used to estimate the overall bulk mass of haricot bean seeds during bulk handling.

There were significant (p < .05) differences in the true density values of haricot bean seed varieties. The true density of the haricot bean seed varieties had ranged from 1127.52 to 1212.40 kg/m<sup>3</sup>. Data on the true haricot bean seed density is used to design haricot bean seed separation or cleaning processes. There is a significant (p < .05) difference in the bulk density between the haricot beans varieties. SAB 632, SER 119, and SER 125 varieties had no significant differences in their bulk density. Awash 2 variety had the highest bulk density (958.2 kg/m<sup>3</sup>). The
bulk density observed was higher than those reported by Altuntas and Demirtola for legume seeds, such as kidney bean (Phaseolus vulgaris), pea (Pisum sativum), and black-eyed pea (Vigna sinensis) that were between 426.26 and 503.72 kg/m³ measured at different moisture content. Information on bulk density is an important parameter in determining packaging and storage requirements for agricultural materials. It is also practically used to calculate heat transfer problems with thermal properties, to identify Reynold’s number of materials and to predict the pressures of the stock structures and chemical composition.

The values of porosity and angle of repose were statistically the same for all the varieties. The values are lower than that reported for Indian kidney bean cultivars, 33.6% to 37.5% and 15.20 to 18.67°, 35 to 40° for common beans grown in Tanzania. Seeds with low porosity take a long time to dry, while seeds with higher porosity have greater aeration and water vapor diffusion during the drying process. The angle of repose of the haricot bean measured in the present study is higher than 6.09 to 8.40° for soybean. The porosity refers to the percentage of space in bulk seeds that is not filled by seeds. It is useful for calculating the rate of aeration, cooling, drying, and heating, as well as designing heat exchangers and other similar bean handling equipment. The angle of repose is important when designing hopper openings, storage bin sidewall slopes, and chutes for bulk seed transport, and is especially useful when measuring the number of granular materials that can be stored in implied or flat storages.

**Color measurement**

Table 2 shows the effect of variety on the color of improved haricot bean varieties. The L* value which shows the lightness of the samples are significantly (p < .05) different due to variety. The highest 80.91 L* value was recorded for the Awash 2 variety. The L values of different dry bean varieties, which ranged from 28.823 to 73.937 was reported by Shimelis and Rakshit. The skin color and brightness are some of the most significant quality parameters of the common bean.

The a* and b* values, which indicate the red or green and the yellow or blue color, respectively, of the improved haricot beans, showed significant (p < .05) difference due to variety. However, SAB 632, SER 119, and SER 125 varieties were not significantly different in their a* and b* values from each other. These findings are similar to the range reported (1.693 to 14.390 and 5.710 to 25.393 for a* and b* values, respectively,) by Shimelis and Rakshit for improved dry bean (Phaseolus vulgaris L.) varieties grown in Ethiopia. Color values of L*, a* and b* in the range of 33.31–38.90, 3.43–8.58, and f 1.88–7.32, respectively, have been reported for Indian kidney bean cultivars. Red color beans are favored by Ethiopians as the beans provide an attractive red color when cooked with other cereals and legumes.

**Dimensional properties**

Table 3 shows the effect of variety on the dimensional properties of improved haricot bean varieties. The dimensional properties of the improved haricot bean were significant (p < .05) among the varieties, indicating that these would require some variation in the processing equipment design. The average length of the improved haricot beans ranged from 11.12 to 13.09 mm, while the corresponding width ranged from 6.23 to 8.41 mm. Comparisons in terms of length and width indicate that SAB 632 variety is longer and wider than SER 119, SER 125 and Awash 2 varieties and

| Table 2. Color measurement of improved haricot beans as affected by a variety. |
|---------------------------------|-------|-------|------|------|
| Parameters                      | SAB 632 | SER 119 | Awash 2 | SER 125 |
| L*                              | 63 ± 2   | 26 ± 2  | 81 ± 2  | 26 ± 3   |
| a*                              | 13 ± 1   | 15 ± 6  | 2.4 ± 0.4 | 14 ± 1   |
| b*                              | 20.2 ± 1 | 22 ± 4  | 14 ± 1  | 23 ± 4   |

Values are means ± SD and values in the same row with different superscript letters were significantly different from each other (p < 0.05).
Table 3. Size dimensional properties of improved haricot beans as affected by the variety.

| Parameter                        | SAB 632       | SER 119       | Awash 2        | SER 125        |
|----------------------------------|---------------|---------------|----------------|----------------|
| Length (mm)                      | 13.09 ± 0.74  | 11.12 ± 0.79  | 8.76 ± 0.37    | 11.76 ± 0.60   |
| Width (mm)                       | 8.41 ± 0.45   | 6.23 ± 0.46   | 6.37 ± 0.29    | 6.31 ± 0.30    |
| Thickness (mm)                   | 7.01 ± 0.50   | 4.91 ± 0.32   | 5.16 ± 0.32    | 4.79 ± 0.31    |
| Arithmetic mean diameter (mm)    | 9.50 ± 0.47   | 7.42 ± 0.43   | 6.76 ± 0.25    | 7.62 ± 0.32    |
| Geometric mean diameter (mm)     | 9.16 ± 0.46   | 6.97 ± 0.39   | 6.60 ± 0.25    | 7.08 ± 0.30    |
| Equivalent mean diameter (mm)    | 11.60 ± 0.58  | 8.94 ± 0.51   | 8.31 ± 0.30    | 9.13 ± 0.38    |
| Square mean diameter (mm)        | 16.14 ± 0.80  | 12.42 ± 0.70  | 11.57 ± 0.42   | 12.68 ± 0.53   |
| Sphericity (%)                   | 70.1 ± 2.4    | 62.8 ± 2.5    | 75.4 ± 2.3     | 60.2 ± 1.9     |
| Roundness (%)                    | 67.4 ± 3.8    | 67.3 ± 6.9    | 75.2 ± 3.8     | 69.7 ± 6.9     |
| Aspect ratio (%)                 | 0.64 ± 0.03   | 0.56 ± 0.04   | 0.73 ± 0.03    | 0.54 ± 0.03    |
| Flakiness ratio                  | 0.83 ± 0.05   | 0.79 ± 0.07   | 0.81 ± 0.05    | 0.76 ± 0.05    |
| Projected area (mm²)             | 98 ± 7       | 73 ± 7       | 47 ± 3        | 77 ± 6        |
| Surface area (mm²)               | 1726 ± 270   | 806 ± 137    | 885 ± 96      | 732 ± 96      |
| Volume (mm³)                     | 288 ± 44     | 119 ± 20     | 112 ± 13      | 122 ± 16      |

Values are means ± SD and values in the same row with different superscript letters were significantly different from each other (p < 0.05).

is within the range of 13.71–18.32 mm (length) and 7.61 to 8.97 mm (width) reported by Palilo et al.\textsuperscript{21} for common beans cultivated in Tanzania. The thickness of the improved haricot bean is found to be between 4.79 and 7.01 mm, and the highest was recorded for SAB 632 variety, while the lowest was for SER 125 variety. Wani et al.\textsuperscript{16} reported length, width, and thickness in the range of 11.45–16.45 mm, 6.65–7.80 mm, and 4.70–6.13 mm, respectively, for Indian kidney bean cultivars.

The arithmetic and geometric mean diameters of improved haricot beans were ranged from 6.76 to 9.50 mm and 6.60 to 9.16 mm, respectively, being this value lower than the length and width, and higher than thickness. The equivalent and square mean diameters of the four improved haricot beans were 8.31 to 11.60 mm and 11.57 to 16.14 mm, respectively. SAB 632 reported the highest and Awash 2 the lowest arithmetic, geometric, equivalent, and square mean diameters. The equivalent diameter of Indian kidney bean cultivars has been reported to vary from 7.31 to 9.24 mm.\textsuperscript{16} The geometric mean diameter is useful for the appraisal of the projected area of a particle moving in the turbulent or near-turbulent area of an air stream, which is a useful parameter in the design of separation systems for the seeds from extraneous materials.\textsuperscript{25}

The improved haricot beans have a sphericity and roundness range of 60.2–75.4% and 67.33–75.18%, respectively. The results showed that the aspect ratio, flakiness ratio, projected and surface area, and volume of the improved haricot beans ranged between 0.54 and 0.73\textsuperscript{a}, 0.76 and 0.83, 47.08 and 97.54 mm\textsuperscript{a}, 731.95 and 1726.29 mm\textsuperscript{a}, and 112.99 and 287.72 mm\textsuperscript{a}, respectively. Sphericity, aspect ratio, seed volume, and surface area of Indian kidney bean cultivars have been reported to vary from 52.13% to 63.08\textsuperscript{a}, 0.40 to 0.61, 113.83 to 223.96 mm\textsuperscript{a}, and 137.84 to 224.18 mm, respectively.\textsuperscript{16} The nearer the sphericity to 1.0, the higher the affinity to roll about any of the three-axis, and the closer the ratio of thickness to width to 1.0, the higher the tendency to rotate about the major axis.\textsuperscript{26} This propensity to either roll or slide is very essential in the design of hoppers and de-hulling equipment for the seed since flattest seeds slide more easily than spherical seeds that roll on structural surfaces.\textsuperscript{27}

Table 4. The effect of variety on the functional properties of improved haricot bean varieties.

| Parameters                  | SAB 632       | SER 119       | Awash 2       | SER 125       |
|-----------------------------|---------------|---------------|---------------|---------------|
| Hydration capacity (g/seed) | 0.36 ± 0.17   | 0.19 ± 0.01   | 0.14 ± 0.00   | 0.19 ± 0.01   |
| Hydration index             | 0.72 ± 0.01   | 0.75 ± 0.02   | 0.71 ± 0.02   | 0.77 ± 0.03   |
| Hydration coefficient (%)   | 1.72 ± 0.01   | 1.75 ± 0.02   | 1.71 ± 0.02   | 1.77 ± 0.03   |
| Swelling capacity (mL/seed) | 0.81 ± 0.03   | 0.40 ± 0.01   | 0.27 ± 0.00   | 0.38 ± 0.01   |
| Swelling index              | 1.11 ± 0.02   | 1.11 ± 0.04   | 1.07 ± 0.02   | 1.09 ± 0.02   |
| Swelling coefficient (%)    | 2.11 ± 0.02   | 2.11 ± 0.04   | 2.07 ± 0.02   | 2.09 ± 0.02   |

Values are means ± SD and values in the same row with different superscript letters were significantly different from each other (p < 0.05).
### Functional properties

The effect of variety on functional properties of four improved haricot bean varieties is presented in Table 4. Hydration capacity varied significantly from 0.14 to 0.36 g/seed among the improved haricot bean varieties. SAB 632 had the highest, whereas Awash 2 had the lowest hydration capacity. Shimelis and Rakshit\(^2\) reported hydration capacity in the range of 0.081 to 0.194 g/seed for different dry bean varieties.

The hydration index also displayed significant differences among the varieties. This parameter varied from 0.71 to 0.77. SER 125 had the maximum hydration index followed by SER 119, SAB 632, and Awash 2 varieties. Hydration capacity and hydration index of some Indian kidney bean cultivars have been reported to vary between 0.12 and 0.42 g/seed and 0.48 and 0.93, respectively\(^{[16]}\).

Significant differences were observed in hydration coefficient and swelling capacity among the varieties and were varied from 1.71% to 1.77% and 0.28 to 0.81 mL/seed, respectively. SAB 632 showed the highest swelling capacity, while the lowest was found in Awash 2 among the improved haricot bean varieties. A similar trend was reported by Wani et al.\(^{[16]}\) in some Indian kidney bean cultivars. The swelling index and swelling coefficient did not show significant differences among the improved haricot bean varieties.

### CONCLUSION

The effect of variety on the geometric characteristics and mass-volume-area properties of improved haricot beans was reported, and the following conclusions were drawn from this investigation. The moisture content, seeds weights, 1000 mass, true and bulk density were significantly different among the varieties. The effect of variety on the dimensional properties, such as length, width, thickness, arithmetic, and geometric mean diameter of the haricot bean, was significant (\(p < .05\)) indicating that these would require some variation in the processing equipment design. In addition, the results showed that the aspect ratio, flakiness ratio, projected and surface area, and volume of the improved haricot beans ranged between 0.54 and 0.73\(^9\), 0.76 and 0.83, 47.08 and 97.54 mm\(^2\), 731.95 and 1726.29 mm\(^2\), and 112.99 and 287.72 mm\(^3\), respectively. Hydration capacity varied significantly from 0.14 to 0.36 g/seed among the improved haricot bean varieties. The hydration index also displayed significant differences among the varieties. In conclusion, this paper deals with the geometric characteristics and mass-volume-area properties of improved haricot beans, enlarging the knowledge about these varieties and providing useful data for their post-harvest handling and further industrial processing. Further studies should be conducted to explore the moisture-dependent geometric characteristics and mass-volume-area of these improved haricot bean varieties.

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