Engineering properties of common bean (*Phaseolus vulgaris* L.) in perspective of physical and frictional parameters

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Abstract: When designing appropriate machinery systems, equipment, and infrastructures for interacting with, cultivating, gathering, and agriculture-related processing, it is required to have an understanding of the engineering characteristics of agricultural products. This unpredictability makes it difficult to design or develop machines that can efficiently and effectively manage a wide range of product characteristics. Experimental analysis was used to accomplish the study's objective, which was to investigate the implications of variation on the physical characteristics and frictional parameters of common beans (*Phaseolus vulgaris* L.) concerning the design of the threshing machine. The mean average values of physical parameters were determined by analysing the experimental data: length (11.282 ± 0.995 mm); width (7.24 ± 0.673 mm); thickness (5.67 ± 0.794 mm); elongation of width (1.566 ± 0.136 mm); elongation of thickness (2.037 ± 0.282 mm); elongation of vertical (1.301 ± 0.152 mm); arithmetic mean diameter (8.064 ± 0.688 mm); geometrical mean diameter (7.715 ± 0.698 mm); square mean diameter (13.646 ± 1.195 mm); equivalent mean diameter (9.808 ± 0.859 mm); roundness (0.644 ± 0.056); sphericity (0.685 ± 0.044); flakiness ratio (0.784 ± 0.092); aspect ratio (0.643 ± 0.053); cross-sectional area (154.477 ± 26.002 mm^2); projected area (64.508 ± 10.377 mm^2); transverse surface area (32.546 ± 6.683 mm^2); and the seed volume (241.744 ± 0.207 mm^3), respectively. The static coefficient of friction varied between 0.276 and 0.386 on the surface of iron sheets, 0.294 to 0.435 on stainless steel, 0.317 to 0.434 on galvanized iron, 0.321 to 0.451 on medium density fiberboard, 0.319 to 0.480 on aluminum, 0.310 to 0.470 on painted sheets, 0.320 to 0.440 on glass, 0.333 to 0.447 on plastic, and 0.374 to 0.575 on rubber. Perforated sheet surfaces showed the highest static coefficients of friction, followed by rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel, and iron sheet surfaces. These data are not only required for predicting loads in agricultural storage structures, but are also needed to establish useful sources for the development of machinery for handling, cleaning, storing, transporting and drying, among other things.
Keywords: engineering properties, phaseolus vulgaris, static coefficient, threshing machine

Citation: Zewdie, B., A. M. Olaniyan, A. Wako, D. Alemu, and T. Lema. 2024. Engineering properties of common bean (*Phaseolus vulgaris* L.) in perspective of physical and frictional parameters. Agricultural Engineering International: CIGR Journal, 26(4):194-206.

1 Introduction

The common bean is one of the primary worldwide sources of edible legumes (*Phaseolus vulgaris* L.). The leading producers are the US, China, Mexico, Brazil, India, and Mexico (FAO, 2020). In 2021, dry beans produced on 28 million hectares worldwide yielded over 20 million tons. Grain-based legumes are essential for nourishment for humans

Received date: 2024-03-02 **Accepted date:** 2024-08-31
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(Degirmencioglu et al., 2019), particularly for low-income people in underdeveloped countries (Fernando, 2021). Compared to grains, their protein content is almost 2-3 times higher (Wodajo et al., 2021), they are composed of a substantial amount of protein and are often referred to as "poor man's meat." For a sizable segment of the global populace, mostly in developing nations, they also provide an affordable and significant source of starch, dietary fiber, and protein (FAOSTAT, 2020).

According to Amsalu et al. (2018), Ethiopia has been producing and exporting common beans for more than 50 years. The country produces red, white, black, and mottled varieties of common beans (Abera et al., 2020). The most widely available commercial kinds are pure red and white beans; as market demand increases, they are also being grown more frequently (Tekalign et al., 2022). Due to the increased demand for these commodities in the local and international markets, in recent years, there has been a discernible increase in nationwide production area and volume (Kefelegn et al., 2020). This illustrates how inefficient postharvest handling, primarily done by hand, persists in Ethiopia, considering the country's significant worldwide yield of common beans (Befikadu, 2018). To build appropriate systems, equipment, and infrastructures for interacting with, cultivating, gathering, and agriculture-related processing thus, comprehension of the engineering characteristics of agricultural products is essential (Figure 1).

Bayano-Tejero et al. (2023) state that when designing, cleaning, sizing, and grading machines, the three main dimensions of length, breadth, and thickness must be considered (Samrawit, 2023). Aspect ratio (Omobuwajo et al., 1999), projected area (Mirzabe et al., 2013), roundness (Baryeh, 2002), sphericity and surface area (Mohsenin, 1986; Baryeh, 2002), arithmetic mean diameter and geometric mean diameter (Baryeh, 2002; Mpotokwane et al., 2008), and Mohsenin (1986) computation of seeds' volume (V) were among the measurements taken.

When developing the seed metering mechanism of seed drills (Önal and Ertuğrul, 2011), as well as transportation, sorting and sizing systems, bean seed size is a critical parameter (Nciri et al., 2014); Larger-seeded bean varieties absorb water more slowly and take longer to cook than smaller-seeded varieties (Sahin and Sumnu, 2006). During soaking, seed size affects electrical conductivity tests (Chhabra and Kaur, 2017).

Surface area plays a crucial role in heat and mass transfer processes such as drying and various thermal applications. An agricultural product's surface area usually indicates how it will behave in a flowing fluid and how easy it will be to remove unwanted contaminants from the product while cleaning it with a pneumatic tool (Omobuwajo et al., 1999). The surface area helps determine the agricultural products quality and quantity, color, respiration data, and aerodynamic calculations (Singh and Heldman, 2009).

The physical parameters alter the rate of moisture transfer and heat transfer in the approach, which makes them crucial properties in drying and ventilation processes. The bulk density determines the conveyor capacity and amount of produce storage needed. When separating materials, the actual density is taken into account. Grain hopper and storage equipment sizing is determined by porosity (Kakade et al., 2019). The engineering characteristics of agricultural materials are influenced by the moisture content, a physical parameter (Sahin and Sumnu, 2006; Bhise et al., 2014; Degirmencioglu and Srivastava, 1996; Singh and Heldman, 2009). Equipment design that is effective, affordable, and efficient depends on having a comprehension of the traits of agricultural materials at varying moisture levels (Chhabra and Kaur, 2017; Bhise et al., 2014). When constructing storage and solid flow mechanisms (Emrani and Berrada, 2023) and material handling equipment (Pawar et al., 2023), another essential consideration to take into account is the coefficient of resistance (Bako and Aguda, 2023). An essential factor in predicting pressure from seeds on walls (Amin et al., 2004) is the coefficient of friction (Bhise et al., 2014) between the seed and the wall.

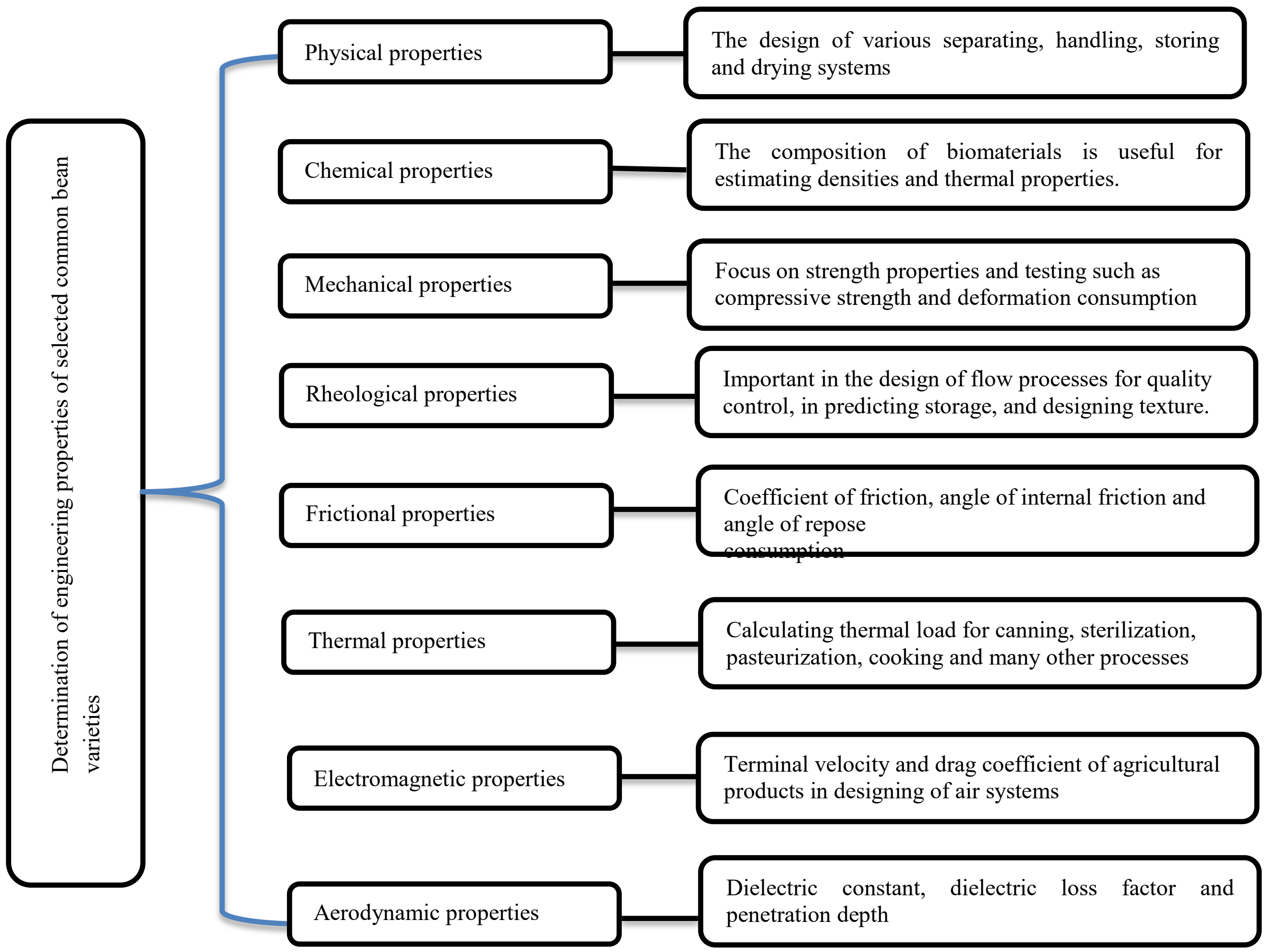

Figure 1 Conceptual study model of engineering properties common bean seeds

Hence, agricultural products have inherent variability in their engineering parameters, including moisture contents, size, shape, surface area, sphericity, density (both bulk and true), porosity, volume of seed, coefficient (both static and dynamic), and angle of repose (Jahanbakhshi, 2018; Ertuğrul et al., 2022). This variability poses challenges in designing, modification, improvement, or development of machines efficiently and effectively. A lack of thorough data, inconsistent testing procedures, and a poor comprehension of the relationship between the agricultural product and the machine are a few additional challenges (Elijah et al., 2018). The aim of this manuscript is to find out how the physical and frictional characteristics of common beans (*Phaseolus vulgaris* L.) influence the design of a thresher for a particular bean variety. This will help to establish the convenient reference data required to develop equipment for handling, cleaning, storing, transportation, drying, and other processes involving the seed.

2 Materials and methods

2.1 Materials

Awash Melkassa Research Center, Oromia regional State, Ethiopia, provided seven improved varieties of common beans that grow in several regions of the country: Awash-1, Awash-2, Awash-Tikur, Awash Meten, Nasir, SER-119, and SER-125 (Figure 2). For further investigation, the sample seeds were manually picked and cleaned of foreign elements such as dust, stones, dirt, immature seeds, damaged seeds, and other contaminants. Then, in an airtight plastic vessel, the healthy seeds that had been chosen were kept at 5°C. The seeds were allowed to attain the room temperature before the test began.

Figure 2 Awash Melkassa Research Center's national common bean research programs improved varieties

2.2 Instrumentation

Digital caliper: With the following specifications: Mitutoyo 500-197 model; Mitutoyo brand; measurement range 0-200 mm; resolution 0.0005 in; repeatability 0.01 mm or 0.0005 in.

Electronic balance: This analytical electronic balance and digital scale (Figure 3) has the following features: Brand Name-JYCTD; stainless steel and ABS; made in China from 100 to 2000 grams is its capacity. Units: 0.01g, lb, oz, g, and ct precisely, it can support up to 5 kg of load. TARE, CAL, PCS, POWER, and UNIT are function buttons.

Grain moisture meter: The approximate dimensions of the device are 19.0 × 12.5 × 8.0 cm, and its weight, including batteries, is 700 g (Figure 4). Using two 1.5 V AA type batteries (LR6) as the power source, the sample volume is 270 mL, and the power consumption ranges from 15.2 mA to 84 mA when the backlight intensity is set; manual filling of the measurement chamber with a special dispenser; Accuracy of moisture measurement is ±1% in the range up to 10% and ±1.5% in the range above 10%, and it may rise in proportion to sample moisture; and accuracy is ± 0.5°C / ± 0.9°F.

Laboratory: All of the tests were carried out at the Agricultural Engineering Laboratories at Melkassa Agricultural Research Center (MARC), Haramaya University, and Adama Science & Technology University's Science, Technology, Engineering, & Mathematics (ASTU STEM) Center's Chemistry laboratory.

2.3 Experimental procedure

2.3.1 Finding the dimensional characteristics

The dimensions of seven hundred (100 for each variety) randomly chosen bean seeds were determined. Using an electronic vernier caliper with a precision of 0.01 mm, the three fundamental axial dimensions (length (L), mm; width (W), mm; thickness (T), mm) of Phaseolus vulgaris were measured. Phaseolus vulgaris mean diameters were computed as geometric mean (D_g), arithmetic mean (D_a), square mean (D_{sq}), and equivalent mean (D_{eq}) were determined using Equations 1-5 (Fraser et al., 1978; Mohsenin, 1986; Baryeh, 2002; Hacıseferoğulları et al., 2003; Altuntaş and Yıldız, 2007; Sundaram et al., 2014).

Geometric mean diameter, mm

$$D_g = \sqrt[3]{L \times W \times T} \quad (1)$$

Arithmetic mean diameter, mm

$$D_a = \frac{L+W+T}{3} \quad (2)$$

Square mean diameter, mm

$$D_{sq} = \sqrt{LW + WT + TL} \quad (3)$$

Equivalent mean diameter, mm

$$D_{eq} = \frac{D_g+D_a+D_{sq}}{3} \quad (4)$$

$$D_{eq} = \left[\frac{L(W+T)^2}{4}\right]^{\frac{1}{3}} \quad (5)$$

Using Equations 6-14 adopted by Mohsenin (1986), Baryeh (2002), Gupta et al. (2007), Sirisomboon et al. (2007) and Mirzabe et al. (2013), the surface area, projected area, specific surface area, transverse surface area, cross-section area, and volume of the seeds were calculated.

Surface area seed, mm^2

$$A_s = \pi {D_g}^2 \tag{6}$$

$$A_s = (36\pi)^{\frac{1}{3}} V^{\frac{2}{3}} \tag{7}$$

$$A_s = \frac{\pi B^2 L^2}{2L-B};\ B = (WT)^{1/2} \tag{8}$$

Projected area, mm^2

$$A_p = \left(\frac{\pi}{4}\right) L * W \tag{9}$$

Specific surface area, mm^2

$$S_s = {}^{A_s \rho_b}/_{m} \tag{10}$$

Specific surface area, mm^2

$$S_s = {}^{A_s \rho_b}/_{m} \tag{11}$$

Cross-section area, mm^2

$$CSA = \frac{\pi}{4}\left[\frac{(L+W+T)^2}{3}\right] \tag{12}$$

Volume of the seed, mm^3

$$V = \frac{\pi}{6} D_g^3 = \frac{\pi}{6} LWT \tag{13}$$

$$V = \frac{\pi B^2 L^2}{6(2L-B)};\ B = (WT)^{1/2} \tag{14}$$

Where; $B = (WT)^{1/2}$; the seeds' *length (L)*, width (*W)* and thickness (*T)*, are measured in mm.

Using the algorithms described by several references (Mohsenin, 1986; Omobuwajo et al., 1999; Baryeh, 2002; Chhabra and Kaur, 2017; Saparita et al., 2019), the flakiness ratio, aspect ratio, shape index, shape factor, sphericity, and roundness of the common beans were computed using the following Equations (15)-(22).

Flakiness ratio, %

$$R_f = {}^{T}/_{W} \times 100\% \tag{15}$$

Aspect ratio, %

$$R_a = {}^{W}/_{L} \times 100\% \tag{16}$$

Shape index

$$SI = L/\sqrt{(W * T)} \tag{17}$$

Shape factor

$$SF = {}^{4\pi P_A}/_{P^2} \tag{18}$$

Sphericity

$$\varphi = \frac{D_g}{L} \tag{19}$$

$$\varphi = \left(\frac{WT}{L^2}\right)^{1/3} \tag{20}$$

Roundness

$$R = \left\{\frac{{}^{W}/_{L} + {}^{T}/_{L} + {}^{T}/_{W}}{3}\right\} \tag{21}$$

$$R = \left\{\frac{{}^{1}/_{E_w} + {}^{1}/_{E_t} + {}^{1}/_{E_v}}{3}\right\} \tag{22}$$

Using the following Equations (23)-(25) adopted by Mohsenin (1986), the elongation at the width orientation (Gupta et al., 2007), elongation at the thickness orientation (Mirzabe et al., 2013), and elongation at the vertical orientation (Chhabra and Kaur, 2017) of the *Phaseolus vulgaris* were determined.

Elongation at the width orientation

$$E_w = {}^{L}/_{W} \tag{23}$$

Elongation at the thickness orientation

$$E_t = {}^{L}/_{T} \tag{24}$$

Elongation at the vertical orientation

$$E_v = {}^{W}/_{T} \tag{25}$$

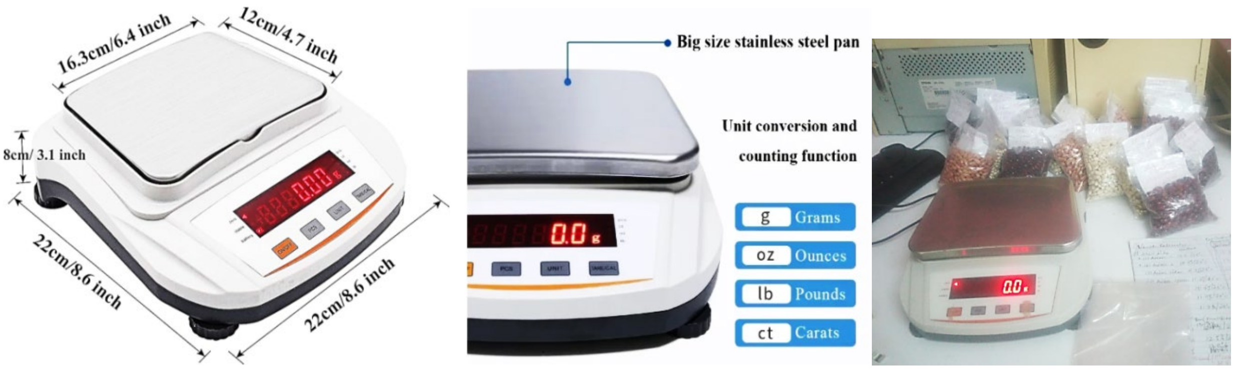

Figure 3 Digital scale analytical electronic balances (Readability 0.01g, Chinese origin)

Figure 4 Grain moisture meter (Model: GMM mini DRAMINISKI, which is Origin Poland)

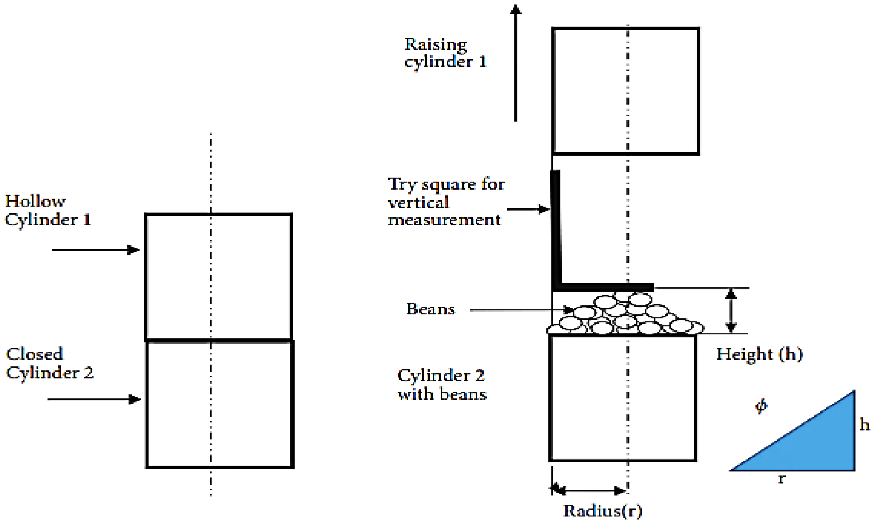

Figure 5 Experimental setup for repose angle measurements

2.3.2 Determination of gravimetric parameters

The true density and seed volumes were determined using the liquid displacement technique. Water was not utilized since the seed absorbs water more readily than toluene (C_7H_8). To measure the amount of toluene displaced from the weighted seed, the amount of the product that was displaced was measured using a graduated scale on the cylinder. Once the weight of the seeds was divided by the volume of displaced toluene, their true density was found. Bulk density, true density, and porosity were calculated using Equations 26–32 (Mohsenin, 1986; Deshpande et al., 1993; Omobuwajo et al., 1999; Singh and Heldman, 2009; Saparita et al., 2019).

Thousand seed mass, *g*

$$100\ seed\ weight = \left(\frac{100 - MC\ records}{(100-10)}\right) \times 100\% \quad (26)$$

$$TSM = \frac{\text{Weight of sample,g}}{Number\ of\ grains\ in\ sample} \times 10 \quad (27)$$

Bulk density, kg m^{-3}

$$\rho_b = \frac{weight\ of\ sample\ (kg)}{volume\ of\ occupied\ (m^3)} \quad (28)$$

True density, kg m^{-3}

$$\rho_t = \frac{weight\ of\ the\ sample\ (kg)}{volume\ of\ toluene\ displaced\ (m^3)} \quad (29)$$

Density ratio, %

$$R_\rho = \left(\frac{\rho_b}{\rho_t}\right) \times 10(\%) \quad (30)$$

Density ratio, %

$$R_\rho = \left(\frac{\rho_b}{\rho_t}\right) \times 10(\%) \quad (31)$$

Porosity, %

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100(\%) \quad (32)$$

$$\varepsilon = 1 - R_d \times 100(\%) \quad (33)$$

2.3.3 Determination of angle of repose

Two cylindrical diameter containers, one hollow and placed on top of a closed side, were used in the setup for the experiment for measurements of the repose angle (Figure 5). Conical-shaped beans began to trickle down the closed container when the hollow container was gradually removed in an upward orientation. Using Equation 33 as provided by Baryeh (2002), Mohsenin (1986), and Saparita et al. (2019), likewise the repose angle (υ) and the apex height were taken into consideration were computed using the trigonometry rule.

2.3.4 Coefficient of static friction determination

Ten surfaces' coefficient of static friction was computed using the inclined plane approach (Figure 6). The angle of inclination (ϕ) was found using the protractor attached to the apparatus after the table had been gently raised to the horizontal at which the seeds began to slide. Equation 34 was utilized to compute the static friction coefficient (μ), following the method outlined by Mohsenin (1986) and Saparita et al. (2019), albeit with some adjustments.

Angle of repose

$$\phi = \tan^{-1}\left[{h}/{b}\right] \quad (33)$$

Coefficient of static friction

$$\mu = tan\phi \quad (34)$$

2.4 Statistical analysis

The standard deviation (SD) and mean of the results were displayed. Using IBM SPSS Statistics 27.0.1_IF026 and the Statistical Package for Social Science, version 22, way analysis of variance (ANOVA) was performed on the data.

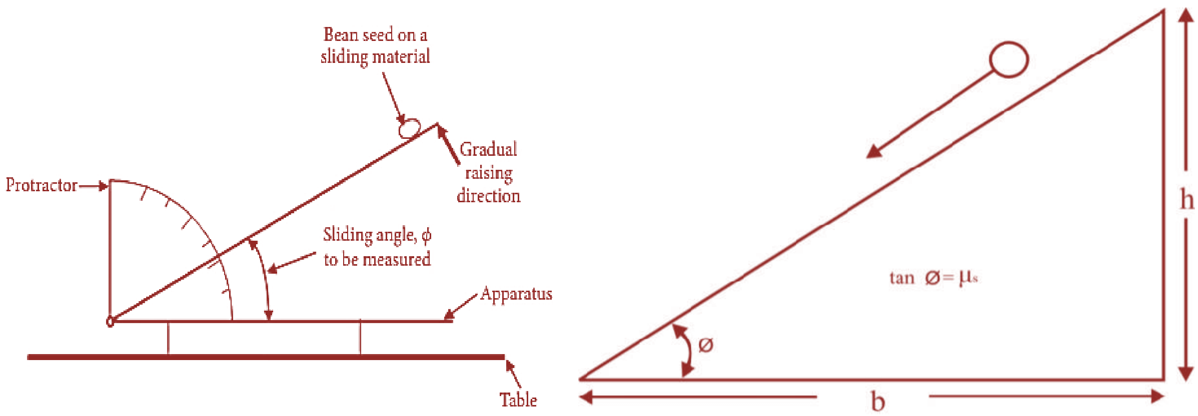

Figure 6 A setup for measuring and computing the coefficient of sliding friction of common beans using the inclined plane method

3 Results and discussion

3.1 Dimensional characteristics

Table 1 shows a summary of the measured and determined dimensional parameters tested across multiple bean types (Awash-1, Awash-2, Awash Tikur, Awash Meten, Nasir, SER-119, and SER-125) are shown in the table along with their respective means, standard deviations (STDEV), and coefficients of variation (CV%). The findings verified that the seeds' longitudinal dimensions ranged from 7.841 to 11.894 mm, with an average mean value (AMV) of 9.847 ± 0.802 mm; their width varied from 5.061 to 7.746 mm, with an AMV of 6.316 ± 0.502 mm; their seed thickness ranged from 3.547 to 6.013 mm, with an AMV of 4.962 ± 0.500 mm; their elongation of width (*Ew*) varied from 1.208 to 1.881 mm, with an AMV of 1.560+0.120 mm; their elongation of thickness (*Et*) varied from 1.558 to 2.710 mm, with an AMV of 2.007+0.234 mm; and their elongation of vertical (*Ev*) varied from 1.042 to 1.687 mm, with an AMV of 1.284+0.124 mm. The significance of axial dimensions in machine design was emphasized by Mohsenin (1986). However, symmetric projections towards process equipment adaption can be made by comparing the results with previous research on other seeds.

The seeds' arithmetic mean diameter ranged from 5.664 to 8.142 mm, with an AMV of 7.042±0.473 mm; their geometrical mean diameter varied from 5.379 to 7.763 mm, with an AMV of 7.715±0.69 mm; their square mean diameter varied from 9.559 to 13.749 mm, with an AMV of 11.914±0.805 mm; their equivalent mean diameter varied from 6.871 to 9.885 mm, with an AMV of 8.565±0.579 mm; their roundness ranged from 0.537 to 0.760 mm, with an AMV of 0.651±0.047; their sphericity varied from 0.595 to 0.803 with an AMV of 0.789±0.072; their flakiness ratio varied from 0.594 to 0.966 with an AMV of 0.649±0.052; their aspect ratio varied from 0.539 to 0.847, with an AMV of 0.649±0.052 mm; cross-sectional area varied from 76.403 to 156.528 mm^2 with the mean value of 117.793±15.576 mm^2, the projected area ranged from 32.827 to 67.175 mm^2 with the AMV of 49.194±6.715 mm^2, the transverse surface area varied from 14.828 to 34.343 mm^2 with the mean value of 24.699±3.809 mm^2, and the seed volume varied from 83.752 to 245.872 mm^3 with the mean value of 162.689±3.777 mm^3, respectively. The values should be given for arithmetic, geometric, and sphericity were comparable to those of Ozturk et al. (2009), Amin et al. (2004), and Kumar and Sharma (2021); Nonetheless, they were lower than those reported by Cetin (2007) and Altuntaş and Yıldız (2007), but greater than common beans (Ozturk et al., 2009) and lower than red kidney beans with speckles (Isik and Unal, 2011).

The relative variability within each parameter is revealed by the coefficient of variation (CV %). Each variety's relative variability is shown by the dimensions parameters (*L*, *W*, and *T*), which often have lower CV% values (between 5% and 10%). On the other hand, some metrics show larger CV% values (up to 20%), indicating greater variability in these features. These parameters include volume (*V*), surface area (*As*), and shape index (*SI*). With regard to sorting, processing, and packing, among other uses, this data offers a thorough grasp of the dimensions and shape-related characteristics of the various bean varieties.

3.2 Gravimetric characteristics

Table 2 presents an overview of the outcomes for the gravimetric characteristics that were measured and determined. The statistical description of the gravimetric properties of the selected Phaseolus vulgaris (common bean) varieties based on the information provided in the table. The average moisture content values were found to be 11.214%±1.185% on a dry basis, mass of one thousand seed (227.714 ± 41.339 kg), bulk density (781.20 ± 25.34 kg m^{-3}), true density (1347.03 ± 143.0 kg m^{-3}), and porosity (41.385% ± 7.05%) for selected varieties. Similar trends were reported for common beans by Amin et al. (2004), faba beans by Altuntaş and Yıldız (2007), barbunia beans by Cetin (2007), white speckled red kidney beans by Isik and Unal (2011), and for red bean grain and common bean seed by Saparita et al. (2019). Nevertheless, compared to the studies of Altuntaş and Yıldız (2007) and Cetin (2007), these increases in the bulk and dimensions of the size variants as influenced by moisture content were smaller. The research indicates that whereas bulk density and density ratio exhibit somewhat lesser variability, the Phaseolus vulgaris cultivars exhibit relatively significant variability in moisture content, thousand seed mass, porosity, and true density.

Table 3 shows static coefficient of friction for different sliding surface materials with a single seed/minimum value and the remaining seeds/maximum value sliding on a selected surface. The static coefficient of friction on the iron sheet surface varied from 0.276 to 0.386 with AMV of 0.355 ± 0.129, on the stainless steel from 0.294 to 0.435 with AMV of 0.385 ± 0.107, on the galvanized iron from 0.317 to 0.434 with AMV of 0.392 ± 0.109, on the MDF sheet from 0.321 to 0.451 with AMV of 0.388 ± 0.115, on the aluminum from 0.319 to 0.480 with AMV of 0.786 ± 0.462, on the perforated sheet from 0.462 to 1.048, on the painted sheet from 0.310 to 0.470 with AMV of 0.412 ± 0.125, on the glass from 0.320 to 0.440 with AMV of 0.395 ± 0.088, on the plastic from 0.333 to 0.447 with AMV of 0.396 ± 0.085) and on the rubber from 0.374 to 0.575 were AMV of 0.529 ± 0.161, respectively.

The moisture content and the coefficient of friction generally have a proportional relationship on all surfaces. Perforated sheet surfaces showed the highest static coefficients of friction, followed by rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel and iron sheet surfaces. Similar patterns have been found for black-eyed peas (Deshpande et al., 1993), cumin seed (Singh and Heldman, 2009), red kidney beans, soybeans, unshelled peanuts, black-eyed peas (Mohsenin, 1986), and lentil seeds (Saparita et al., 2019).

Table 1 Mean and coefficient of variation of measured and determined dimensional parameters

Varieties	Awash - 1			Awash - 2			Awash Tikur			Awash Meten		
parameter	Mean	STDEV	CV (%)	Mean	STDEV	CV(%)	Mean	STDEV	CV (%)	Mean	STDEV	CV (%)
L, mm	8.263	0.616	7.461	8.605	0.756	8.78a*	10.392	0.793	7.627	9.188	0.982	10.69a*
W, mm	5.910	0.639	10.82b*	6.107	0.439	7.19b*	6.651	0.466	7.01b*	6.091	0.653	10.72b*
T, mm	4.926	0.472	9.57c*	5.247	0.480	9.14c*	5.138	0.549	10.69c*	4.948	0.395	7.98c*
Da mm	6.366	0.414	6.506d*	6.653	0.463	6.95d*	7.394	0.411	5.564	6.742	0.604	8.96d*
Dg, mm	6.207	0.420	6.77e*	6.501	0.449	6.9e*	7.067	0.401	5.673	6.510	0.558	8.57e*
Dsq, mm	10.880	0.723	6.640	11.384	0.786	6.901	12.506	0.695	5.556	11.463	1.005	8.766
Deq, mm	7.818	0.518	6.626	8.179	0.565	6.910	8.989	0.500	5.561	8.238	0.722	8.76f*
φ, %	0.754	0.055	7.34g*	0.757	0.037	4.86g*	0.682	0.042	6.147g*	0.711	0.033	4.67g*
V, mm^3	126.992	26.097	20.550	143.913	0.047	0.033	184.855	0.034	0.018	144.509	0.091	0.063
As, mm^2	121.534	16.525	13.597	132.703	0.632	0.476	156.952	0.505	0.322	133.069	0.978	0.735
Ap, mm^2	38.380	5.404	14.079	41.397	5.738	13.862	54.379	6.757	12.426	44.363	9.095	20.501
At, mm^2	23.001	4.260	18.523	25.234	3.493	13.844	26.857	3.649	13.587	23.772	3.843	16.166
SI	1.544	0.166	10.76h*	1.523	0.111	7.30h*	1.788	0.166	9.274	1.676	0.116	6.94h*
CSA, mm^2	95.839	12.597	13.144	104.732	14.265	13.620	129.134	14.407	11.156	107.896	18.998	17.607

Varieties	**Nasir**			**SER-119**			**SER-125**		
parameter	Mean	STDEV	CV (%)	Mean	STDEV	CV (%)	Mean	STDEV	CV (%)
L, mm	10.039	0.665	6.620	10.770	0.876	8.138	11.676	0.930	7.963
W, mm	6.452	0.538	8.336b*	6.438	0.398	6.178	6.568	0.379	5.766
T, mm	4.647	0.634	13.642c*	4.778	0.552	11.559c*	5.050	0.418	8.273c*
Da mm	7.046	0.439	6.234	7.329	0.519	7.087	7.764	0.462	5.953
Dg, mm	6.686	0.490	7.331e*	6.910	0.505	7.303e*	7.281	0.416	5.721
Dsq, mm	11.877	0.802	6.752	12.304	0.876	7.116	12.985	0.746	5.746
Deq, mm	8.536	0.575	6.733	8.848	0.632	7.143	9.344	0.540	5.775
φ, %	0.668	0.053	7.976g*	0.643	0.028	4.359g*	0.625	0.029	4.666g*
V, mm^3	156.555	0.062	0.039	172.843	0.067	0.039	202.157	0.038	0.019
As, mm^2	140.365	0.754	0.537	149.939	0.800	0.533	166.446	0.545	0.327
Ap, mm^2	50.910	6.039	11.862	54.595	6.763	12.388	60.335	7.207	11.945
At, mm^2	23.723	4.764	20.080	24.227	3.615	14.923	26.082	3.037	11.643
SI	1.854	0.223	12.013h*	1.948	0.126	6.483h*	2.032	0.151	7.438h*
CSA, mm^2	117.365	14.608	12.447	127.114	17.209	13.538	142.471	16.949	11.897

Note: *a, b, c, d, e, f, g, h* is a higher degree of relative variability, STDEV =standard deviation, CV=coefficient of variation, *L* = length, *W*=width, *T*=thickness, *Da* =arthematic mean diameter, *Dg*=geometric mean diameter, *Dsq*=square mean diameter, *Deq*=equivalent mean diameter, *Ra*=aspect ratio, R_f=flakiness ratio, *φ*=sphericity, *V*=volume, *As* = surface area, *Ap*=projected area, *At*=area of transverse surface, *R*=roundness, *SI*=shape index, *CSA*=cross-section area.

Table 2 Statistical description of gravimetric properties of selected Phaseolus vulgaris

Variety	Mc, db%	TSM, g	Porosity, %	Bulk density, kg m^{-3}	True density, kg m^{-3}	Density ratio
Awash-1	13.00	177.00	44.230	795.200	1425.860	0.558
Awash-2	10.90	174.00	32.930	817.600	1219.020	0.671
Awash-Tikur	9.30	256.00	46.553	740.800	1386.045	0.534
Awash Meten	11.20	206.00	29.559	759.200	1077.786	0.704
Nasir	10.40	246.00	45.716	782.600	1441.667	0.543
SER-119	11.90	271.00	44.462	795.400	1432.167	0.555
SER-125	11.80	264.00	46.249	777.600	1446.667	0.538
Mean	11.214	227.714	41.385	781.200	1347.030	0.586
STDEV	1.185	41.339	7.048	25.343	143.031	0.070
CV%	10.569a*	18.154b*	17.029c*	3.244d*	10.618e*	12.024f*

Note: Mc = moisture content, TSM =thousand seed mass; CV = coefficient of variance; "a*", "b*", "c*", "d*", "e*", and "f*" indicates higher relative variability or Significant at $p\leq 0.05$.

Table 3 Statistical description frictional properties of *Phaseolus vulgaris* on various types of sliding surface materials

Surface		Angle of inclination (Ø),degrees			Coefficient of friction (μs)		
		Min.	Max.	Avg.	Min	Max.	Avg.
Iron sheet	Mean	14.786	24.000	19.393	0.264	0.446	0.355
	Variance	5.358	6.259	5.303	0.002	0.003	0.002
	CV%	15.656a*	10.424	11.874	16.353d*	11.713e*	12.855f*
Stainless steel	Mean	15.381	22.476	18.929	0.275	0.414	0.345
	Variance	2.571	4.328	3.138	0.001	0.002	0.001
	CV%	10.426	9.256	9.358	10.989d*	10.361e*	10.211f*
Galvanized iron	Mean	17.476	25.095	21.286	0.315	0.469	0.392
	Variance	4.291	2.323	2.340	0.002	0.001	0.001
	CV%	11.853	6.073	7.186	12.520d*	6.945e*	7.803f*
Plywood, MDF	Mean	15.905	26.000	20.952	0.285	0.488	0.387
	Variance	6.101	2.704	3.553	0.002	0.001	0.001
	CV%	15.529	6.324	8.996	16.528d*	7.169e*	9.707f*
Aluminum	Mean	17.905	27.286	22.595	0.324	0.517	0.420
	Variance	8.508	7.238	6.925	0.003	0.003	0.003
	CV%	16.291	9.860	11.646	17.094d*	11.431e*	12.734f*
Perforated sheet	Mean	24.571	46.619	35.595	0.459	1.113	0.786
	Variance	10.026	92.127	33.888	0.004	0.132	0.039
	CV%	12.887	20.589	16.354	14.263d*	32.644e*	25.118f*
Painted sheet	Mean	17.619	26.000	21.810	0.318	0.489	0.403
	Variance	6.831	6.778	6.124	0.002	0.003	0.002
	CV%	14.834	10.013	11.347	15.709d*	11.219e*	12.313f*
Glass	Mean	17.048	25.333	21.190	0.307	0.474	0.391
	Variance	3.757	6.000	4.217	0.001	0.003	0.002
	CV%	11.369	9.669	9.691	12.103d*	10.987e*	10.676f*
Plastic/Maica	Mean	17.238	25.238	21.238	0.311	0.472	0.391
	Variance	8.323	2.545	4.647	0.003	0.001	0.002
	CV%	16.736	6.321	10.150	17.744d*	7.139e*	10.920f*
Rubber	Mean	18.905	30.857	24.881	0.345	0.599	0.472
	Variance	23.138	7.698	13.673	0.009	0.004	0.006
	CV%	25.444a*	8.992	14.862	27.358d*	10.943e*	16.509f*

Note: CV = coefficient of variance; "a*", "d*", "e*", and "f*" indicates Significant at $p \leq 0.05$: It suggests that the values have a wider spread around the mean, indicating more diversity or fluctuation.

Table 3 includes a number of materials that are frequently used for sliding surfaces, such as rubber, plywood/MDF, aluminum, perforated sheet, painted sheet, glass, stainless steel, galvanized iron, and plastic/Maica. Specifications for each surface material include the lowest, maximum, and average angles of inclination. Significant variance in the sliding behavior across the surfaces is indicated by the average angle of inclination, which varies from 18.929° (stainless steel) to 35.595° (perforated sheet). According to Mohsenin (1986), the angle of repose for common bean seed was determined to be between 27.1º and 35.4º, which are still below the maximum angle of repose of 45^0 for the majority of agricultural commodities. A lower range of values, from 6.073% to 16.736%, is indicated by the coefficient of variation for the angle of inclination, indicating reasonably consistent values within each surface material. The perforated sheet's average coefficient of friction is 0.786, whereas the average coefficient of friction for stainless steel is 0.345, indicating the considerable variation in frictional qualities between the surfaces.

The coefficient of variation for the coefficient of friction varies more, from 6.945% to 32.644%, suggesting that there is more variety in the behavior of the friction within each surface material. The asterisk-designated CV% values ("a*", "d*", "e*", and "f*") in the table indicate statistical significance at the $p \leq 0.05$ level. In summary, this extensive table offers significant insights into *Phaseolus vulgaris's* frictional characteristics on a range of sliding surface materials. These insights may find application in agricultural engineering, processing, and handling systems. In order to build and optimize handling and transportation systems for this agricultural commodity, it is vital to take into account the notable differences in the angle of inclination and coefficient of friction among the various surface types, as highlighted by the data.

The angle of repose for common bean determined with respect to stainless, plywood and mild steel and glass sheet surfaces increased with increasing moisture content. The angle of repose increases with increase in coefficient of friction and grain moisture content (Figure 7). According to the statistical analysis, at the 0.05 level, the impact of moisture content on the angle of repose of the seed was significant. The average suggested angle of repose for common bean seeds should be within 27.1º to 32.4º based on the results. According to Mohsenin (1986), the angle of repose for common bean seed was determined to be between 27.1º and 35.4º, which are still below the maximum angle of repose of 45^0 for the majority of agricultural commodities.

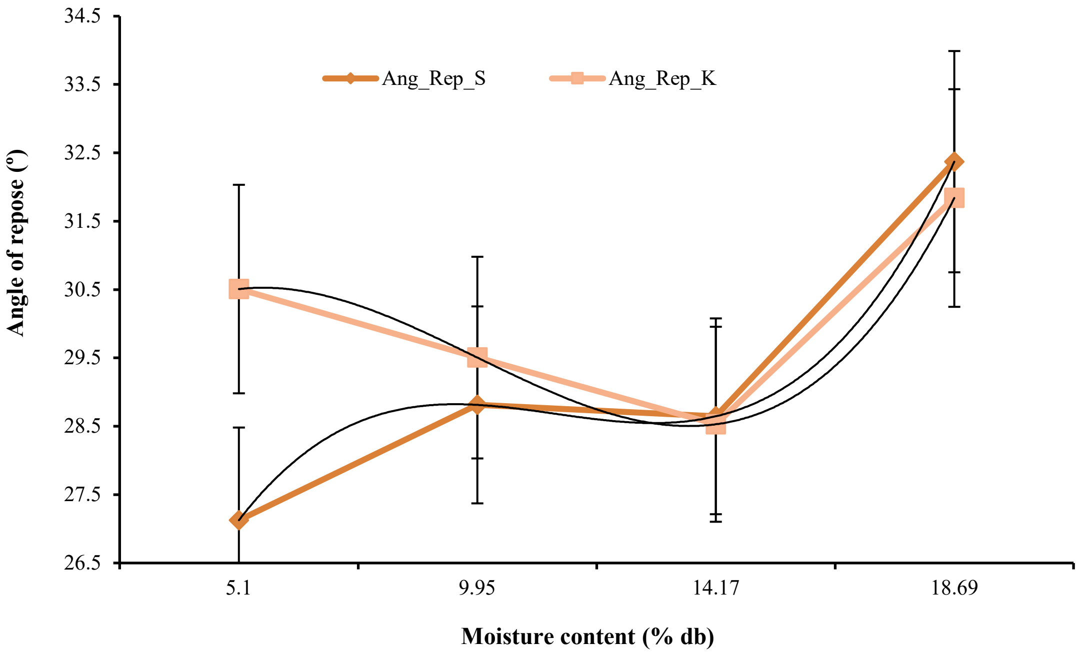

Figure 7 Effect of moisture content on angle of repose for common bean Seed

4 Conclusions

In this study, the engineering properties of *Phaseolus vulgaris* seeds are determined that may provide opportunities to design construct and develop harvesting, handling, and processing machinery for *Phaseolus vulgaris* seeds by considering their physical and frictional characteristics. In this process, the gravimetric variables impact the exchange rate between heat and moisture, making them essential characteristics in drying and ventilation processes. The bulk density establishes the required amount of produce storage and the conveyor capacity. The true density of a material is considered throughout the separation process. The size of grain hoppers and storage equipment must be determined by taking into account the porosity. The engineering qualities of the agricultural materials are influenced by the moisture content, one gravimetric parameter. Designing affordable, efficient, and successful equipment requires an understanding of the characteristics of agricultural materials at varying moisture levels. Perforated sheet surfaces showed the highest static coefficients of friction, followed by rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel and iron sheet surfaces. These data are frequently needed to establish a convenient reference required to develop equipment for handling, cleaning, storing, transporting, drying, and other processes, as well as for predicting loads in agricultural storage structures and resolving flow issues in agro-processing. More research ought to be done to investigate the enhanced *Phaseolus vulgaris* cultivars' moisture-dependent engineering characteristics.

Acknowledgments

Biniam Zewdie Ghebrekidan, the author, expresses gratitude to the Department of Agricultural Engineering from Awash Melkassa Agricultural Research Center; Haramaya University; and Science, Technology, Engineering, & Mathematics (ASTU STEM) CENTER, Chemistry laboratory from Adama science &Technology University for the provision of the improved common bean seed varieties and laboratory facilities, respectively.

References

Abera, T. A., J. Heiskanen, P. K. E. Pellikka, H. Adhikari, and E. E. Maeda. 2020. Climatic impacts of bushland to cropland conversion in Eastern Africa. *Science of the Total Environment*, 717: 137255.

Altuntaş, E., and M. Yıldız. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. *Journal of Food Engineering*, 78(1): 174-183.

Amin, M. N., M. A. Hossain, and K. C. Roy. 2004. Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering*, 65(1): 83-87.

Amsalu, B., K. Negash, T. Shiferaw, K. Tumssa, D. Tsegaye, R. J. Claude, and C. M. Mukankusi. 2018. Progress of common bean breeding and genetics research in Ethiopia. *Ethiopian Journal of Crop Science*, 6(3): 115-128.

Bako, T., and A. C. Aguda. 2023. Effect of moisture content on the engineering properties of African yam bean (*Sphenostylis stenocarpa*) seed. *Journal of Horticulture and Postharvest Research*, 6(1): 15-26.

Baryeh, E. A. 2002. Physical properties of millet. *Journal of Food Engineering*, 51(1): 39-46.

Bayano-Tejero, S., M. Karkee, A. Rodríguez-Lizana, and R. R. Sola-Guirado. 2023. Estimation of harvested fruit weight using volume measurements with distance sensors: A case study with olives in a big box. *Computers and Electronics in Agriculture*, 205: 107620.

Befikadu, D. 2018. Postharvest losses in Ethiopia and opportunities for reduction: a review. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, 38: 249-262.

Bhise, S. R., A. Kaur, and M. R. Manikantan. 2014. Moisture dependent physical properties of wheat grain (PBW 621). *International Journal of Engineering Practical Research*, 3(2): 40-45.

Cetin, M. 2007. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbunia') seed. *Journal of Food Engineering*, 80(1): 353-358.

Chhabra, N., and A. Kaur. 2017. Studies on physical and engineering characteristics of maize, pearl millet and soybean. *Journal of Pharmacognosy and Photochemistry*, 6(6): 01-05.

Degirmencioglu, A., and A. K. Srivastava. 1996. Development of screw conveyor performance models using dimensional analysis. *Transactions of the ASAE*, 39(5): 1757-1763.

Degirmencioglu, A., R. H. Mohtar, B. T. Daher, G. Ozgunaltay-Ertugrul, and O. Ertugrul. 2019. Assessing the sustainability of crop production in the Gediz Basin, Turkey: a water, energy, and food nexus approach. *Fresenius Environmental Bulletin*, 28(4): 2511-2522.

Deshpande, S. D., S. Bal, and T. P. Ojha. 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research*, 56(2): 89-98.

Elijah, O., T. A. Rahman, I. Orikumhi, C. Y. Leow, and M. N. Hindia. 2018. An overview of internet of things (IoT) and data analytics in agriculture: Benefits and challenges. *IEEE Internet of Things Journal*, 5(5): 3758-3773.

Emrani, A., and A. Berrada. 2023. Structural behavior and flow characteristics assessment of gravity energy storage system: Modeling and experimental validation. *Journal of Energy Storage*, 72(Part A): 108277.

Ertuğrul, Ö., M. Yılar, H. Kır, and C. Kömekçi. 2022. Some physical, chemical, and germination properties of *Peganum harmala* L. seeds. *Journal of Food Process Engineering*, 45(2): e13967.

FAO. 2020. Food and Agriculture Organization Crop Production and Trade Data. Available at: http://www.fao.org/faostat/en/#data/ (Accessed December 30, 2023).

FAOSTAT. 2020. Food and agriculture data: Crops and livestock products. Available at: https://www.worldatlas.com/articles/the-worlds-top-dry-bean-producing-countries. (Accessed December 30, 2023).

Fernando, S. 2021. Production of protein-rich pulse ingredients through dry fractionation: A review. *LWT*, 141: 110961.

Fraser, B. M., S. S. Verma, and W. E. Muir. 1978. Some physical properties of faba beans. *Journal of Agricultural Engineering Research*, 23(1): 53-57.

Gupta, R. K., G. Arora, and R. Sharma. 2007. Aerodynamic properties of sunflower seed (*Helianthus annuus* L.). *Journal of Food Engineering*, 79(3): 899-904.

Hacıseferoğulları, H., İ. Gezer, Y. Bahtiyarca, and H. O. Mengeş. 2003. Determination of some chemical and physical properties of Sakız faba bean (*Vicia faba* L.

Var. *major*). *Journal of Food Engineering*, 60(4): 475-479.

Isik, E., and H. Unal. 2011. Some engineering properties of white kidney beans (*Phaseolus vulgaris* L.). *African Journal of Biotechnology*, 10(82): 19126-19136.

Jahanbakhshi, A. 2018. Determine some engineering properties of snake melon (*Cucumis melo* var. flexuosus). *Agricultural Engineering International: CIGR Journal*, 20(1): 171-176.

Kakade, A., S. Khodke, S. Jadhav, M. Gajabe, and N. Othzes. 2019. Effect of moisture content on physical properties of soybean. *International Journal of Current Microbiology and Applied Sciences*, 8(4): 1770-1782.

Kefelegn, N., F. Mekibib, and Y. Dessalegn. 2020. Genetic advancement and variability of released common bean (*Phaseolus vulgaris* L.) varieties from 1974–2009 GC in Ethiopia. *Advances in Agriculture*, 2020(1): 1315436.

Kumar, N., and A. K. Sharma. 2021. Study on engineering properties of chickpea (Cicer arietinum) seeds in relation to design of threshing mechanism. *The Pharma Innovation*, 10(9): 455-458.

Mirzabe, A. H., J. Khazaei, G. R. Chegini, and O. Gholami. 2013. Some physical properties of almond nut and kernel and modeling dimensional properties. *Agricultural Engineering International: CIGR Journal*, 15(2): 256-265.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics and Mechanical Properties*.

Mpotokwane, S. M., E. Gaditlhatlhelwe, A. Sebaka, and V. A. Jideani. 2008. Physical properties of bambara groundnuts from Botswana. *Journal of Food Engineering*, 89(1): 93-98.

Nciri, N., F. El-Mhamdi, H. B. Ismail, A. B. Mansour, and F. Fennira. 2014. Physical properties of three white bean varieties (*Phaseolus vulgaris* L.) grown in Tunisia. *Journal of Applied Science and Agriculture*, 9(11 Special): 195-200.

Omobuwajo, T. O., E. A. Akande, and L. A. Sanni. 1999. Selected physical, mechanical and aerodynamic properties of African breadfruit (*Treculia africana*) seeds. *Journal of Food Engineering*, 40(4): 241-244.

Ozturk, I., M. Kara, C. Yildiz, and S. Ercisli. 2009. Physico-mechanical seed properties of the common Turkish bean (*Phaseolus vulgaris*) cultivars 'Hinis' and 'Ispir'. *New Zealand Journal of Crop and Horticultural Science*, 37(1): 41-50.

Önal, İ., and Ö. Ertuğrul. 2011. Seed flow and in-row seed distribution uniformity of the top delivery type fluted roller for onion, carrot and canola seeds. *Journal of Agricultural Sciences*, 17(2011): 10-23.

Pawar, P., V. Shinde, A. Raut, S. Suke, K. Kolpe, and A. Manna. 2023. An automated combined system for crop prediction and yield prediction using deep hybrid learning technique. In *2023 7th International Conference On Computing, Communication, Control and Automation (ICCUBEA)*, 1-5. Pune, India, 18-19 August 2023.

Sahin, S., and S. G. Sumnu. 2006. Physical properties of foods: Springer science & Business media. *Journal of Applied Science and Agriculture*, 9(1):185-200.

Samrawit, T. 2023. Design and numerical analysis of rice grading machine for Ethiopian rice varieties. Ph.D. diss., Bahir Dar University.

Saparita, R., D. D. Hidajat, and S. I. Kuala. 2019. Statistical analysis on the geometric, physical and mechanical properties of dried robusta coffee cherry resulting from natural system processing. *IOP Conference Series: Earth and Environmental Science*, 251(1): 012041.

Singh, R. P., and D. R. Heldman. 2009. Psychrometrics. In *Introduction to Food Engineering*, 4th ed, eds. R. P. Singh, and D. R. Heldman, ch. 9, 571-593. Burlington, MA, USA: Academic Press.

Sirisomboon, P., P. Kitchaiya, T. Pholpho, and W. Mahuttanyavanitch. 2007. Physical and mechanical properties of *Jatropha curcas* L. fruits, nuts and kernels. *Biosystems Engineering*, 97(2): 201-207.

Sundaram, P. K., A. K. Singh, and S. Kumar. 2014. Studies on some engineering properties of faba bean seeds. *Journal of AgriSearch*, 1(1): 4-8.

Tekalign, A., T. Tadesse, and B. Asmare. 2022. Registration of Hora, Small-red Seed Food Type Common Bean (*Phaseolus vulgaris*) Varieties for Midland Areas of Bale and East Bale, Southeast Ethiopia. *Plant*, 10(1): 36-39.

Wodajo, D., S. Admassu, and B. Dereje. 2021. Geometric characteristics and mass-volume-area properties of haricot beans (Phaseolus vulgaris L.): Effect of Variety. *International Journal of Food Properties*, 24(1): 885-894.