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Some Engineering Properties of Selected Ethiopian Chickpea Varieties as Function of Moisture Content

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ABSTRACT
Background and Objective: Ethiopia ranks sixth globally in chickpea production, with chickpeas valued for their nutritional richness and affordability as a protein source. As Ethiopia's food industry progresses, there's ample opportunity for chickpea processing. This study aims to explore how moisture levels (10%, 15% and 20% w.b) affect engineering properties of four chickpea varieties. **Materials and Methods:** Four chickpea varieties (Arertin, Hora, Eshete and Geletu) sourced from Debre Zeit Agricultural Research Centre underwent thorough cleaning to remove impurities and were sorted to exclude damaged seeds. Only normal seeds were utilized. Moisture levels of 10, 15 and 20% (w.b) were attained through conditioning, adjusted according to the initial moisture content of each variety. Various engineering properties of chickpeas were subsequently evaluated. **Results:** The chickpea seed length, width, thickness, geometric mean diameter, arithmetic mean diameter, surface area, volume, hundred seed weigh, porosity, angle of repose and static coefficient of friction on stainless steel for the four varieties increased with the increase in moisture content while the bulk and true density of chickpea seed were decreased with increase moisture content within range of 737.82 to 819.48 kg/m^3 and 1276.79 to 1338.38 kg/m^3, respectively. **Conclusion:** The moisture level of seeds is an important factor to consider when designing equipment for agricultural processing.

KEYWORDS
Ethiopian chickpea variety, moisture level, Arertin, Hora, Eshete and Geletu

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INTRODUCTION
Legumes are a great source of protein and fiber and are low in fat. They are also reach in essential minerals and vitamins which makes them an ideal choice for those looking for an alternative to meat[1]. Chickpea (*Cicer arietinum* L.) is one of the most important grain legumes crops with a wide range of potential nutritional benefits because of its chemical composition[2,3]. It can be used to enhance the nutrient content of staple foods, making them more nutritionally balanced and healthy. Chickpeas will be essential resource in the future since they can provide valuable nutrients for the alarmingly growing global population. Nutritionists in the health and food fields have recently emphasized the value of chickpeas

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in terms of nutrition and bodily health in many countries across the world[4]. Ethiopia is the sixth-largest producer of chickpea in the world and accounts for over 90% of the production in sub-Saharan Africa[5]. It is the most important pulse crops in the country the bulk of which is dominated by the sweet desi type, with the kabuli type also grown in limited areas[6]. In Ethiopia, 213,048.42 hectare of land was under chickpea cultivation with a production of about 401,238.51 ton[7].

Grains' behavior in postharvest scenarios is heavily shaped by their engineering properties, encompassing physical, frictional, mechanical and rheological attributes. Comprehending these features is imperative for designing effective equipment and conducting various harvest and post-harvest tasks such as cleaning, conveying, storage and processing[8]. To meet the demand of the fast-growing population of the country for chickpeas use of mechanization system in the production, handling, storage and processing is indispensable. To design, manufacture and proper use of equipment needed in planting, harvesting, transporting, storage and processing of chickpea seeds, it is vital to know the various engineering properties of the grains. Knowledge of the dependence of these properties on the moisture content are required to properly understand the behaviour of the bulk grain during handling and processing operations and are thus needed as input parameters for the prediction of results of such activities through simulation models[9]. To our understanding, there is a dearth of information and inadequate scientific research regarding the engineering properties of chickpea varieties cultivated under Ethiopian agroecological conditions as function of moisture content. Thus, this study endeavors to explore the influence of variety and grain moisture content on various engineering properties of enhanced chickpea varieties in Ethiopia.

MATERIALS AND METHODS

Sample preparation: This research was conducted at the Food Science and Nutrition Department of the Ethiopian Institute of Agricultural Research from 2022 to 2023, spanning a year. Four selected chickpea varieties namely, Arertin, Hora, Eshete and Geletu (Fig. 1) were sourced from Debre Zeit Agricultural Research Centre, the National Chickpea and Lentil Research Program.

These chickpeas varieties were grown in same agro-ecological condition, same location and same season. And also Arertin and Hora are kabuli type of chickpea whereas; Eshete and Geletu are Desi type of chickpea. The samples were cleaned by removing foreign matter such as dust, debris, stones and immature seeds and sorted to remove broken and spoilt seeds. Care was taken to ensure that only normal seeds were used. The initial moisture content of the seeds was determined by oven drying at 105±1°C for 24 hrs on wet basis[10,11]. Based on the initial moisture content of the seeds of each chickpea variety desired moisture levels of 10, 15 and 20% (w.b) were attained by adding the required amount of distilled water in a fine spray, which were calculated by using the (Eq. 1)[11]:

$$Q = \frac{W_i\,(M_f - M_i)}{100 - M_f} \quad (1)$$

Where:

Q = Mass of water to be added, in g
W_i = Initial mass of sample in g
M_i = Initial moisture content of sample in % w.b
M_f = Final (desired) moisture content of sample % w.b

The conditioned chickpea seed samples were packed separately in polyethylene bags and stored in a refrigerator at a low temperature of 4-5°C for one week. For each test, the required quantity of sample

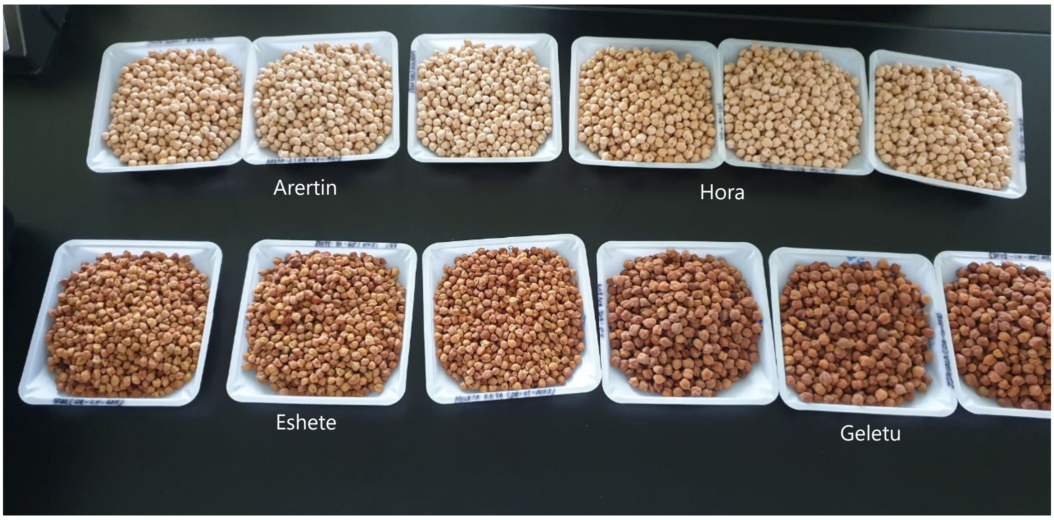

Fig. 1: Chickpea varieties

was taken out and allowed to warm up in the ambient temperature (25°C) for approximately 2 hrs[11]. The new moisture contents were checked and verified using same procedure indicated above.

Determination of physical dimensions of chickpea seeds: To determine the physical dimensions of chickpea seed, a sample of hundred seeds were randomly selected from the prepared lot of each chickpea variety and three principal linear dimensions namely length (L), width (W) and thickness (T) were measured using a digital vernier caliper (TA, M5 0-300 mm, China) with reading to an accuracy of 0.01 mm. The geometric mean diameter (Dg) and arithmetic mean diameter (Da) of the seeds were calculated by using the (Eq. 2 and 3) respectively[12,13]:

$$Dg = (LWT)^{\frac{1}{3}} \tag{2}$$

$$Da = \frac{L + W + T}{3} \tag{3}$$

The volume and surface area of chickpea seeds at different moisture contents were calculated by using the (Eq. 4 and 5) respectively[14]:

$$V = \frac{\pi B^2 L^2}{6\,(2L - B)} \tag{4}$$

$$S = \frac{\pi B L^2}{2L - B} \tag{5}$$

Where:
V = Volume of chickpea
S = Surface area of chickpea

$$B = \sqrt{WT}$$

Determination of gravimetric properties of chickpea seeds: The thousand seeds mass was determined using a digital electronic balance (Model Pag2102c, Ohaus Corporation, USA) having an accuracy of

0.001g following the procedure as described by Unal *et al.*[14] Thousand randomly selected seeds of the desired variety and moisture content were counted and weighed. Measurements were done for three replicated samples.

The bulk density was determined by filling a cylindrical container of 500 mL capacity with the seeds up to its brim by pouring from a height of about 150 mm. The excess material was removed by striking off the top with plank of wood to make it level and weighing the content of cylinder. The bulk density (ρ_b) was calculated by dividing the mass by the volume of chickpea and expressed in kg/m^3[14]:

$$\rho_b = \frac{M}{V_b} \tag{6}$$

True density of the chickpeas was determined by liquid displacement method (using toluene; C_7H_8 as the liquid). Toluene was used because it has lower surface tension so that it fills even shallow dips in seeds and lower specific mass when compared to water. 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 chickpea seed in the toluene. True density was then calculated using (Eq.7)[15]:

$$\rho_t = \frac{M}{V_2 - V_1} \tag{7}$$

Where:
M = Mass of seeds (kg)
V_1 = Initial volume of toluene (m^3)
V_2 = Final volume of toluene (m^3)

Porosity is defined as the ratio of the volume of pores to the total volume. The porosity (ε) of chickpeas seed at different moisture contents was calculated from the mean values of bulk density (ρ_b) and true density (ρ_t) using the (Eq. 8)[16]:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_t} \times 100 \tag{8}$$

Angle of repose of the chickpea seed was determined using a topless and bottomless cylinder of 10 cm diameter and 15 cm height. The cylinder was placed on levelled surface of a table and filled with the seeds to the brim. Then it was raised off the table slowly until the grain mass flows down forming a conical heap on the table surface. The diameter (d) of the base and height (h) of conical heap measured. The angle of repose "θ" was calculated by using the (Eq. 9)[17]:

$$\theta = \tan^{-1}\left(\frac{2h}{d}\right) \tag{9}$$

Static coefficient of friction of chickpeas seed at different moisture content against one surface material, namely stainless steel was determined. A PVC cylindrical pipe measuring 50 mm in diameter and 100 mm in height was positioned on a tilting plate that could be adjusted. It was oriented towards the test surface and filled with the grain sample. The cylinder was then elevated slightly to avoid contact with the surface. Using a screw device, the structural surface supporting the cylinder was gradually raised until the cylinder began to slide down the surface. The degree of inclination of the surface was determined by reading from a graduated scale positioned alongside the test surface[18]. The coefficient static of friction was calculated using the (Eq. 10)[19]:

$$\mu = \tan\alpha \tag{10}$$

Statistical analysis: All data collected in the study were averaged over three replications at each moisture level and were analyzed by Analysis of Variance (ANOVA) using SAS. A statistical difference, were tested at $p<0.05$ and the difference between means were compared using the Least Significance Difference (LSD). The relationships existing between these properties and grain moisture content were determined using regression models.

RESULTS AND DISCUSSION

The mean values for the length (L), width (W), thickness (T), geometric (D_g) and arithmetic mean diameter (D_a), surface area (S_a) and volume (V) of chickpea measured at different moisture contents in the range of 10-20% (w.b) for the four varieties were shown in Table 1. The values of the physical dimensions for the four varieties increased as the moisture content increased from 10-20% (w.b). As a result of the moisture content's increase from 10 to 20% (w.b), the increase of length was range from 8.98 to 9.42, 9.15 to 9.47, 7.88 to 8.38 and 9.71 to 10.12 mm. Whereas, the width of four chickpea variety was increased from 6.95 to 7.33, 7.33 to 7.80, 5.98 to 6.35 and 7.75 to 8.28 mm. The thickness of chickpea varieties also increased from 6.96 to 7.29, 7.48 to 7.85, 6.11 to 6.51 and 7.74 to 8.24 mm for Arertin, Hora, Eshete and Geletu respectively. Three different soybean varieties exhibited a similar pattern of increase in physical dimensions. Specifically, as the length, width and thickness of the soybeans ranged from 4.23 to 5.90 mm, 4.20 to 5.23 mm and 3.02 to 4.93 mm, respectively, their moisture content rose from 6.25% to 11.60% (dry basis)[18]. Similarly, this trend was observed in gram, with its length expanding from 7.968 to 8.758 mm, width from 5.864 to 6.554 mm and thickness from 5.713 to 6.359 mm, as moisture content increased from 10.83% to 31.20% (dry basis). Likewise, the white speckled red kidney bean experienced an increase in length from 12.84 to 13.52 mm, width from 9.22 to 9.94 mm and thickness from 7.06 to 7.99 mm under similar moisture content conditions[20,21]. The three physical dimensions increased with increase in moisture content which indicates that the swelling of the seed cells is in all three dimensions as the result of moisture uptake. The chickpea seed physical dimensions indicate that seed used in this study is larger than soybean but smaller than white speckled red kidney bean[18,21]. Therefore clearance between cylinder (drum) and concave of threshing machines is determined by the length, width and thickness of chickpea seeds.

The geometric and arithmetic mean diameter of four chickpea varieties increased as moisture content increased from 10-20% w.b. This is contributed by the increment of the principal demission of chickpea. This same increase was also observed for mung bean the geometric and arithmetic mean diameter increased from 4.10 to 4.89 mm and 4.14 to 4.97 mm for an increase in moisture content from 7.28 to 17.77% d.b respectively[14]. The chickpea seeds geometric and arithmetic mean diameter indicate that seed varieties used in this study is larger than mung bean but smaller than haricot beans varieties[14,17]. The arithmetic and geometric diameters were lower than the length and higher than the width and thickness. In the design of separate systems for seeds from extraneous materials, geometric mean diameters can be used to estimate the projected area of particles moving through turbulent or near-turbulent areas of an air stream[17].

The seed surface area and volume increased for varieties Arertin, Hora, Eshete and Geletu respectively (Table 1) as the moisture content increased from 10 to 20 % (w.b). The value of surface area and volume of Chickpea varieties seeds were range from 159.99 to 176.61 mm^2, 185.45 to 215.16 mm^3, 178.69 to 198.41 mm^2, 220.57 to 258.89 mm^3, 121.19 to 137.08 mm^2, 122.04 to 146.78 mm^3, 196.51 to 221.63 mm^2, 253.75 to 305.02 mm^3 respectively, as the moisture content increased from 10 to 20 % (w.b) for Arertin, Hora, Eshete and Geletu, respectively. This same increase was also observed for white speckled red kidney bean, the surface area increased from 120.09 to 182.87 mm^2 and volume increased from 93.84 to 194.30 mm^3 for an increase in moisture content from 9.12 to 17.06 d.b %. The chickpea varieties surface area and volume indicate that seed used in this study is larger than white speckled red kidney bean[21].

The thousand seed mass (m_{1000}) of the four chickpea varieties also increased within the moisture content range for varieties Arertin, Hora, Eshete and Geletu. The values for thousand seed mass of chickpea are in similar range that of black eyed pea, which is 253.53 to 273.97 g except of Geletu varieties and larger than that of gram seeds, which is 137.9 to 172.73 g and smaller than that of white speckled red kidney bean, which is 521.8 to 560 g while thousand seed mass for black eyed pea, 253.53 to 273.97 g[20-22]. The linear regression equation was developed for thousand seeds mass and moisture content was shown in Table 2.

In the four varieties of chickpea, bulk and true density decreased with increasing moisture content (Table 1). This might be attributed to the fact that the volumetric expansion was more than the grain mass. The linear regression equation were developed for true density (ρ_t) and bulk density (ρ_b) as function of moisture content of the four chickpea varieties are shown in Table 2.

The values for the bulk and true density of chickpea are larger than that of soybean seeds, which is 809 to 740 kg/m^3 and 1203 to 964 kg/m^3 and that of dry sweet corn 765 to 698 kg/m^3 and 1315 to 1232 kg/m^3 and that of Tef seed 840 to 696 kg/m^3 and 1361 to 1207 kg/m^3 [12,20-24]. The true densities for chickpea varieties are in similar range to true density for gram, which is 1398 to 1250 kg/m^3 while bulk densities for soybean, which is 809 to 740 kg/m^3 and bulk and true density for lentil seed, 832 to 768 kg/m^3 and 1270 to 1212 kg/m^3 are larger than that of chickpea[20,23-25]. The bulk and true density decreased with increase in moisture content like that of soybean, gram, some grain legume, Tef and lentil seeds[16,20,22-25]. The bulk and true density for the chickpea seeds reported by Konak *et al.*[26] also decreased with increase in moisture content. These values were in good agreement with those found in this study.

The porosity (ε) of the chickpea varieties increased as moisture content increased from 10 to 20 % w.b. (Table 1). The values for the porosity of chickpea are higher than mung bean, 30.43 to 46.57% and that of gram seed, which is 33.17 to 35.85%[12,22]. The porosity for white speckled red kidney bean, 46.40 to 46.57% and for faba bean, which is 63.09 to 67.21%, is larger than that of chickpea[21,27]. The grain cell structure cohesiveness presumably decreased with increased moisture content and variations in bulk and true densities also contributed to the increase in porosity. The load that is placed on drying and storage structures is influenced by the porosity. It should be considered to take into account the bulk density and porosity of grains when designing aeration and drying system since these characteristics affect the resistance to airflow through the grain mass. The correlation between porosity and moisture content are shown in Table 2. The angle of repose (AR) increased for varieties Arertin, Hora, Eshete and Geletu as moisture content increased from 10 to 20% w.b. The change in the angle of repose as a result of moisture content is attributable to the existence of a layer of moisture on the surface of the seeds, which connects the grain aggregate through surface tension[28]. The angle of repose of chickpea ranged from 28.15 to 37.09° which is higher than 25.87 to 29.38° for mung bean and 24.80 to 27.78° for lentil seed[14,25]. The variations of the angle of repose with moisture content were indicated in Table 2.

The static coefficient of friction obtained experimentally on stainless steel surface against moisture content in the range of 10 to 20% w.b. was presented in Table 1. As the moisture content of chickpea varieties increased, the static coefficient of friction increased. The value of static coefficient of friction ranged from 0.26 to 0.48 while the static coefficient of friction for mung bean on stainless steel surface, 0.34 to 0.38 is similar to static coefficient of friction of chickpea[14]. It was observed that moisture had more effect on the static coefficient of friction of chickpea varieties. This is owing to the increased adhesion between the seeds and the material surface, as moisture increased.

Table 1: Some selected engineering properties of chickpea seed

Variety	Arertin			Hora			Eshete			Geletu		
Moisture content (% w.b.)	10	15	20	10	15	20	10	15	20	10	15	20
Length (mm)	8.98 (0.13)	9.22 (0.05)	9.42 (0.04)	9.15 (0.01)	9.31 (0.07)	9.47 (0.02)	7.88 (0.15)	8.16 (0.02)	8.38 (0.01)	9.71 (0.01)	9.83 (0.04)	10.12 (0.04)
Width (mm)	6.95 (0.05)	7.14 (0.03)	7.33 (0.10)	7.33 (0.05)	7.58 (0.10)	7.80 (0.07)	5.98 (0.14)	6.20 (0.02)	6.35 (0.05)	7.75 (0.13)	7.96 (0.01)	8.28 (0.02)
Thickness (mm)	6.96 (0.08)	7.12 (0.01)	7.29 (0.01)	7.48 (0.07)	7.66 (0.07)	7.85 (0.06)	6.11 (0.02)	6.34 (0.09)	6.51 (0.06)	7.74 (0.08)	7.92 (0.07)	8.24 (0.07)
Geometric mean (mm)	7.57 (0.08)	7.77 (0.01)	7.95 (0.05)	7.95 (0.02)	8.15 (0.08)	8.34 (0.04)	6.60 (0.09)	6.85 (0.04)	7.02 (0.01)	8.35 (0.07)	8.52 (0.02)	8.84 (0.04)
Arithmetic mean (mm)	7.63 (0.08)	7.83 (0.01)	8.01 (0.05)	7.99 (0.02)	8.19 (0.07)	8.38 (0.04)	6.65 (0.09)	6.90 (0.04)	7.08 (0.01)	8.40 (0.06)	8.57 (0.02)	8.88 (0.04)
Surface area, mm^2	159.99 (2.92)	168.23 (0.13)	176.61 (2.47)	178.69 (1.38)	188.66 (3.75)	198.41 (2.41)	121.19 (3.05)	130.53 (1.87)	137.08 (0.55)	196.51 (3.99)	205.47 (1.49)	221.63 (1.83)
Volume (mm^3)	185.45 (4.89)	199.87 (0.32)	215.16 (4.61)	220.57 (2.77)	239.71 (7.29)	258.89 (4.92)	122.04 (4.42)	136.46 (3.14)	146.78 (0.99)	253.75 (8.22)	271.84 (3.34)	305.02 (3.81)
m_{1000}	283.45	297.75	304.00	342.90	353.10	362.40	176.10	190.35	192.85	380.35	385.90	395.35
Bulk density (kg/m^3)	779.77	754.58	729.31	772.94	753.45	739.55	819.48	791.81	758.10	764.64	737.82	707.99
True density (kg/m^3)	1322.81	1303.75	1277.89	1306.86	1297.75	1288.93	1338.38	1314.48	1290.48	1315.22	1296.05	1276.79
Porosity (%)	41.0	42.12	42.93	40.86	41.94	42.62	38.77	39.76	41.25	41.86	43.07	44.55
Angle of repose (°)	28.15	29.64	31.72	34.11	35.55	36.24	36.24	37.09	37.94	32.28	33.22	34.28
Coefficient of friction	0.31	0.33	0.34	0.26	0.30	0.33	0.33	0.36	0.37	0.39	0.43	0.48

Values in brackets are standard deviation

Table 2: Relationship for some engineering properties of chickpea variety as function moisture content

	Arertin variety		Hora variety		Eshete variety		Geletu variety	
Parameter	Equation	R^2	Equation	R^2	Equation	R^2	Equation	R^2
Length (L)	$8.545+0.04\ M_C$	0.8732	$8.819+0.03\ M_C$	0.9406	$7.384+0.05\ M_C$	0.8901	$9.280+0.04\ M_C$	0.9223
Width (W)	$6.573+0.04\ M_C$	0.8810	$6.868+0.05\ M_C$	0.9032	$5.622+0.04\ M_C$	0.8016	$7.205+ 0.05\ M_C$	0.9143
Thickness (T)	$6.623+0.03\ M_C$	0.9003	$7.104+0.04\ M_C$	0.8916	$5.719+0.04\ M_C$	0.9025	$7.223+0.05\ M_C$	0.9004
Geometric mean (D_g)	$7.247+0.04\ M_C$	0.9329	$7.551+0.04\ M_C$	0.9413	$6.192+0.04\ M_C$	0.9216	$7.847+0.05\ M_C$	0.9437
Arithmetic mean (D_a)	$7.192+0.04\ M_C$	0.9337	$7.597+0.04\ M_C$	0.9426	$6.242+0.04\ M_C$	0.9212	$7.903+0.05\ M_C$	0.9428
Surface area (S_a)	$143.3+1.66\ M_C$	0.9342	$159.0+1.97\ M_C$	0.9339	$105.8+1.59\ M_C$	0.9342	$170.2+2.51\ M_C$	0.9327
Volume (V)	$155.6+2.97\ M_C$	0.9428	$182.2+3.83\ M_C$	0.9318	$97.97+2.47\ M_C$	0.9325	$200.0+5.12\ M_C$	0.9332
Φ	$82.38+0.17\ M_C$	0.9018	$84.69+0.19\ M_C$	0.8523	$81.06+0.19\ M_C$	0.9822	$83.86+0.19\ M_C$	0.9801
m_{1000}	$264.2+2.06\ M_C$	0.9006	$323.6+1.95\ M_C$	0.7831	$161.3+1.68\ M_C$	0.7814	$364.7+1.500M_C$	0.8920
Bulk density (ρ_b)	$830.2 - 5.05\ M_C$	0.9602	$805.4 - 3.34\ M_C$	0.9425	$881.9 - 6.14\ M_C$	0.9618	$821.8 - 5.67\ M_C$	0.9534
True density (ρ_T)	$1369 - 4.49\ M_C$	0.8738	$1325 - 1.79\ M_C$	0.7435	$1386 - 4.79\ M_C$	0.9019	$1354 - 3.84\ M_C$	0.9434
Porosity (ε)	$39.22+0.19\ M_C$	0.9910	$39.16+0.18\ M_C$	0.9728	$36.20+0.25\ M_C$	0.9731	$39.13+0.27\ M_C$	0.9536
Angle of repose (AR)	$24.49+0.36\ M_C$	0.9926	$32.28+0.23\ M_C$	0.9118	$34.53+0.17\ M_C$	0.9842	$30.26+0.20\ M_C$	0.9907
Coefficient of friction (μ_{steel})	$0.2755+0.0034\ M_C$	0.9110	$0.2028+0.006\ M_C$	0.9412	$0.2913+0.0041\ M_C$	0.9543	$0.3107+0.0083\ M_C$	0.9436

M_C: Moisture content

CONCLUSION

According to the study, the average length, width and thickness of chickpea seed varieties increased with increasing moisture content. While the moisture content of chickpea seeds is increased, the hundred seed weight, porosity, angle of repose and static coefficient of friction also increase. The increase in these parameters was found to be more pronounced at higher moisture contents. In contrast, true density and bulk density decreased as moisture content increased. Based on the average density of chickpea seeds, it is possible to utilize water for processes such as separation, cleaning and transportation. This research demonstrated that moisture content is important factor in the physical properties of chickpea seeds.

SIGNIFICANCE STATEMENT

Understanding the significance of chickpea variety and moisture content is crucial for designing and operating post-harvest equipment efficiently. Variations in seed types directly influence engineering properties, affecting processing methods and equipment needs. Tailoring processing equipment to seed varieties and moisture levels boosts productivity, reduces energy use and maintains product quality. This knowledge fosters optimized processing protocols, benefiting agriculture by cutting losses, improving quality and meeting market demands. Thus, recognizing the importance of chickpea variety and moisture content is vital for advancing post-harvest technologies and practices.

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