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Determination of the physicomechanical characteristics of black chickpea grains

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Hardness

Abstract — In this study, some physicomechanical characteristics of black chickpea grains, which have rich content, were investigated. Dimensional and volumetric properties, colour characteristics, and frictional and mechanical properties were examined within the physicomechanical properties of the grains. Compression tests were carried out for the behaviour of black chickpea against mechanical force, both force and deformation characteristics of black chickpea grains were determined, and they were used at three different loading speeds (30 mm min^{-1}, 50 mm min^{-1}, 70 mm min^{-1}). The size dimension, such as width, length, and thickness values, were found as 6.68 mm, 8.85 mm, and 6.26 mm, and the mass was 0.25 g, respectively. The highest a^* and b^*, L^* values were determined as 4.31, -0.27, and 18.87, respectively. The values of the static friction coefficient of the black chickpea grains on different friction surfaces (PVC, galvanized sheet, laminate, plywood, and rubber) were observed on the rubber surface with the highest. In the mechanical test results, the highest force value was found on the 50 mm min^{-1} width (Y-) axis, and the highest hardness value was found on the thickness (Z-) axis at the 30 mm min^{-1} loading speed.

Subject Classification (2020):

1. Introduction

The black chickpea is a nutritious plant with a fibrous structure and rich content. Black chickpeas, which are both delicious, satisfying, beneficial and widely used, have recently become very popular. Black chickpeas have rich vitamins and minerals. However, the amount of magnesium and folic acid is also quite high. The amount of iron that needs to be met to prevent anaemia is high in black chickpeas. It also contains higher levels of antioxidants than other legumes. In addition to being richer in terms of nutritional value, black chickpea is more delicious than other legumes in terms of taste [1].

The particles' size, shape, mass, and aerodynamic properties are generally considered in the equipment used for cleaning and separation processes [2]. In addition, knowing these properties is essential in designing and developing systems, machines, equipment, and models for special purposes such as processing, transmission, drying, transportation, and storage of grains [3-7]. In this respect, parameters

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such as grain size, sphericity, mass, projection area, true density, bulk density, friction coefficient and terminal velocity should be determined.

The physicomechanical properties of the black chickpea grains should be studied to design and develop relevant machinery and facilities for harvesting, storage, transportation, and processing. The size dimension, colour, shape, frictional characteristics, and mechanical behaviour of chickpea grains are important in grinding, separation, sizing, transport structures and storage design. Physical properties are essential to optimize the various factors of black chickpea grains, threshing yield, pneumatic conveying, and storage.

The fact that black chickpeas have been very popular recently increases production and creates a desire to obtain quality results. When the articles about black chickpeas were examined, there were few studies related to the subject, and this study was carried out in which physicomechanical properties were combined. This study examines black chickpea grains' physicomechanical properties, linear dimensions, volumetric properties, static friction coefficient on different surfaces, mechanical behaviour, and colour characteristics.

2. Materials and Methods

The broken and immature grains, foreign matter, dust, and dirt in the grains used in the study were manually cleaned. 100 black chickpea grains were used to be used in the study. Length (Ln), width (Wd), and thickness (Th) as three basic dimensional properties among the physical and mechanical properties of the grains, measured with a digital caliper [8] with an accuracy of 0.01 mm, was shown in Figure 1.

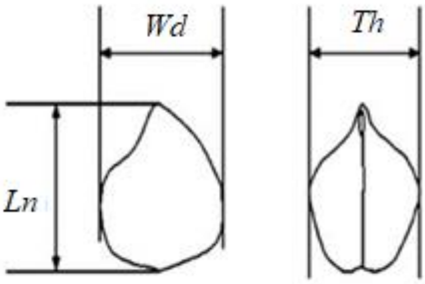

Figure 1. Basic dimensions of a sample black chickpea grain

A precision scale (accuracy of 0.01 g) was used to obtain the mass of each grain. To get a thousand-grain mass (Tm), 100 grains were weighed (accuracy of 0.001 g) by an electronic scale [9].

To determine the moisture content of the grains, they were dried in an oven at 105°C for 24 hours and calculated concerning the dry basis [10].

$$M_d = \frac{mw - md}{md} 100$$

Here,
mw: wet mass of the grain
md: dry mass of the grain
M_d: moisture content (dry basis %)

The following equations were used to calculate the geometric mean diameter, sphericity, surface area, and volume of the grains [11].

$$Gm = (LnWdTh)^{\frac{1}{3}} \tag{2.1}$$

$$Sa = \pi(Gm)^2 \tag{2.2}$$

$$Sp = \frac{Gm}{Ln}100 \tag{2.3}$$

$$Vl = \frac{\pi}{6}LnWdTh \tag{2.4}$$

Here,

Gm: Geometric mean diameter (mm)

Ln: Length (mm)

Wd: Width (mm)

Th: Thickness (mm)

Sa: Surface area (mm^2)

Sp: Sphericity (%)

Vl: Volume (mm^3)

To determine the bulk density (Bd) of the grain, the hectoliter method was used, and to determine the true density (Td), the liquid displacement method was used [11]. Pure water was used as the fluid. The porosity value (Pr) was calculated according to Mohsenin [11], considering the bulk density and true density values.

The colour characteristics of the grains, a^* $[green(-\infty) - red\ (\infty)]$, $b^*[blue(-\infty) - yellow(\infty)]$, and $L^*[brightness\ (0 - 100)]$ were determined with a colourimeter [Minolta (CR- 3000)]. Chroma (Cr) defines the purity and saturation of the colour, and hue angle describes the angle of the colour [12]. Chroma and hue angle (ha) values [13] stated the following equations were obtained.

$$Cr = [(a^*)^2 + (b^*)^2]^{\frac{1}{2}} \tag{2.5}$$

$$ha = \tan^{-1} \frac{b^*}{a^*} \tag{2.6}$$

In addition, the ΔE value for the general colour value of black chickpeas was calculated using Equation (2.7) [14]. The lower the ΔE value, the darker the colour.

$$\Delta E = \sqrt{(L^{*2} + a^{*2} + b^{*2})} \tag{2.7}$$

PVC, galvanized, laminate, plywood and rubber materials were used as different friction surfaces for the mechanical properties of the grains. Static friction coefficients were found using a friction measurement scheme. The friction coefficient value (μ) was calculated by considering the angle of inclination ($\tan\alpha$) at the moment the grains started moving from the surface inclined with a lever [15]. Trials were applied with ten repetitions.

A biological material test measuring device is used for compression testing of mechanical properties and operated with a computer program. This device has a pressure and draws dynamometer (Sundoo draw dynamometer (Model SH-500, 0.1 N precision, China), a digital velocity unit, and a measuring ruler stand. It is a motorized and automatically controlled device. Experiments carried out by applying mechanical force to the grains at three different deformation rates (30 mm min^{-1}, 50 mm min^{-1} and 70 mm min^{-1}) and in three different axes (length, thickness, and width) are provided in Figure 2. The values are read by keeping the speeds determined by the speed adjustment and fixation panel in the test device constant and are manifested in Figure 3. The values of rupture energy (Re), hardness (Hr) and rupture force (Rp) are determined with the help of the following equations [16-17].

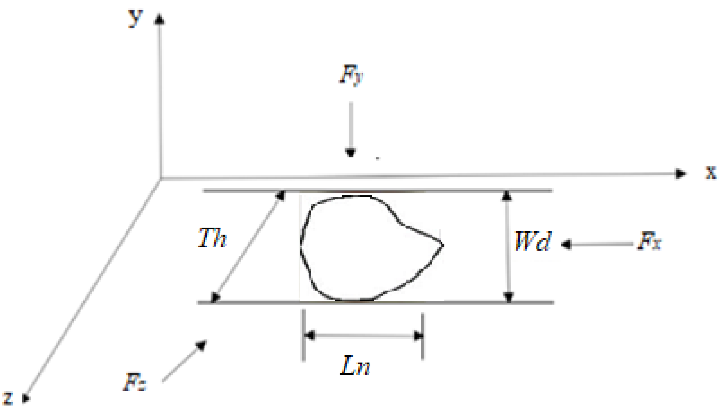

Figure 2. Representation of the axial dimensions (F_x, F_y, F_z) forces of a sample black chickpea grain

$$Re = \frac{RfDf}{2} \tag{2.8}$$

$$Hr = \frac{Rf}{Df} \tag{2.9}$$

$$Rp = \frac{ReLs}{60000\,Df} \tag{2.10}$$

Here,

Hr: Hardness

Re: Rupture energy (N mm)

Rf: Rupture force (N)

Df: Deformation (mm)

Rp: Rupture power (W)

Ls: Loading speed (mm min^{-1})

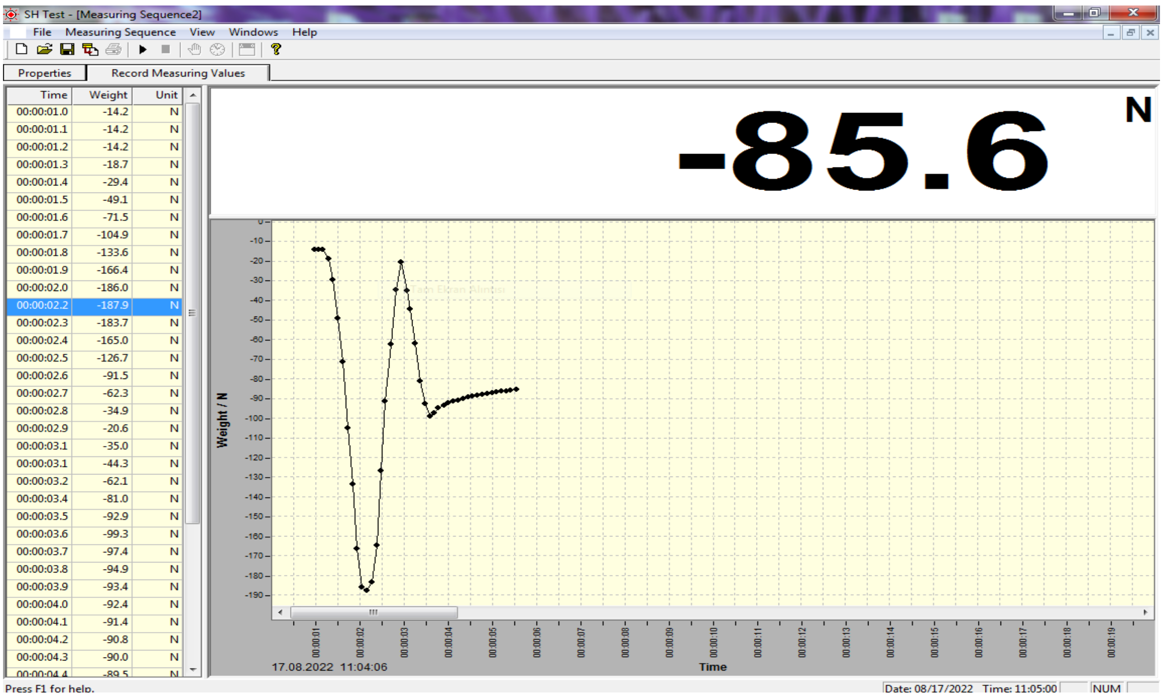

Figure 3. Test measurement of the rupture force of black chickpea grain

In the statistical evaluations of the research results, SPSS (Statistical Package for Social Sciences) program was used. Apart from general statistical calculations, an analysis of variance was performed since loading speed and axes were also used in force, deformation, hardness, energy, and rupture power, in which mechanical behaviour was determined. A multiple comparison (Duncan) test was also applied to determine the differences related to the parameters examined.

3. Results and Discussions

The initial moisture content of the black chickpea grains was determined as 12.01% (db). Data on the geometric properties of black chickpea grains are given in Table 1. When we look at the results table, the highest porosity and surface area values were found to be 93.31% and 221.29 mm^2.

Table 1. Some physical properties of black chickpea grains

Physical Properties	Mean (*)	Maximum	Minimum	Variation coefficient	Standard error
Ln (mm)	8.85 ± 0.61	10.36	6.83	6.83	0.19
Wd (mm)	6.68 ± 0.39	7.75	5.53	5.81	0.12
Th (mm)	6.26 ± 0.49	7.70	5.01	7.89	0.16
Gm (mm)	7.16 ± 0.38	8.39	6.23	5.30	0.12
Sp (%)	81.07 ± 3.83	93.31	72.66	4.72	1.21
Sa (mm^2)	161.44 ± 17.11	221.29	121.91	10.60	5.42
m (g)	0.25 ± 0.04	0.36	0.14	17.18	0.01
Tm (g)	229.08 ± 4.90	234.20	222.55	2.14	1.55
Vl (mm^3)	194.84 ± 31.12	311.51	127.27	15.97	9.85
Bd (kg m^{-3})	632.26 ± 9.61	647.02	615.08	1.52	3.04
Td (kg m^{-3})	1241.05 ± 113.98	1434.60	1049.43	9.18	36.07
Pr (%)	48.68 ± 4.66	56.53	40.05	9.57	1.47

Here, ± values indicate standard deviation. Moreover, *Ln*: Length (mm). *Wd*: Width (mm) *Th*: Thickness (mm). *Gm*: Geometric mean diameter (mm). *Sp*: Sphericity (%). *Sa*: Surface area (mm^2). *m*: grain mass (g). *Tm*: Thousand-grain mass. *Vl*: Volume (mm^3). *Bd*: Bulk density (kg m^{-3}). *Td*: True density (kg m^{-3}). *Pr*: Porosity (%).

Eissa et al. [18] determined some physical properties of moisture content for two types of chickpea grains (Giza 3 and Giza 195) and used four moisture content levels ranging from 11.6% db to 25.4% db. The width, length, thickness and geometric mean diameter between 6.10 ± 0.04 mm and 6.37 ± 0.04 mm, between 7.92 ± 0.04 mm and 8.14 ± 0.04 mm, between 6.43 ± 0.04 mm and 6.84 ± 0.04 mm, between 6.77 ± 0.07 mm and 7.08 ± 0.07 mm, the sphericity ranged from between 85.53 ± 0.19 and 87.00 ± 0.19, respectively. They determined the mean measured surface area as (144.73 ± 1.55) mm^2. Although there are differences in terms of variety and moisture content, close and similar values, have emerged when the grains are compared with the study.

In the same study, Eissa et al. [18] determined that the physical properties of chickpea grains at 11.6% db moisture content, namely bulk density, true density, and porosity, were 730.05 kg m^{-3}, 1.308.02 kg m^{-3} and, 44.13%, respectively.

The colour values (L^*, a^*, b^*, $Chroma$, $hue\ angle$) of the black chickpea grain measured over the shell surface are given in Table 2. The mean L^*, a^*, and b^* colour values of black chickpea grains were measured as 17.86, 3.64, and -0.95, respectively.

Table 2. Colour characteristics of black chickpea grains.

Colour characteristics	Mean (*)	Maximum	Minimum	Variation coefficient	Standard error
L^*	17.86 ± 0.76	18.87	16.70	4.26	0.24
a^*	3.64 ± 0.70	4.31	2.30	19.33	0.22
b^*	-0.95 ± 0.40	−0.27	−1.50	−42.32	0.13
Cr	3.77 ± 0.73	4.35	2.38	19.22	0.23
ha	-14.79 ± 5.22	−3.58	−20.99	−35.30	1.65
ΔE	62.65 ± 31.10	102.46	21.17	49.63	9.84

Here, ± values indicate standard deviation.

The results of the static friction coefficient values on PVC (Polyvinyl Chloride), laminate, galvanized metal, plywood, and rubber surfaces as different friction surfaces of black chickpea grains are given in Figure 4.

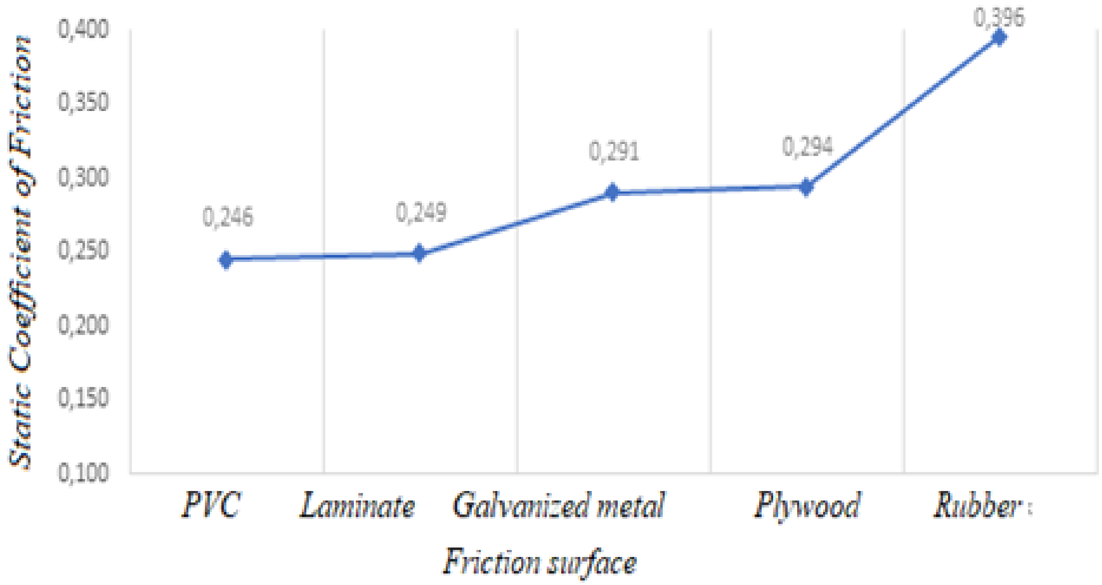

Figure 4. Static friction coefficient values of black chickpea grains on different surfaces.

Tabatabaeefar et al. [19] found the highest static friction value of chickpeas on the rubber surface as 0.33 in a study carried out by the chickpea cultivar grown in Iran to separate the foreign materials in the chickpea grain. Looking at the results, the black chickpea grain also shows the highest value on the rubber surface.

In Table 3, in the statistical results of black chickpea grains, the rupture force and the power required for rupture were obtained in the width axis at the highest speed of 50 mm min^{-1}. Statistically, significant differences in rupture force, hardness and rupture power values of black chickpea grains were obtained at different loading speeds and axes. In their study, Jaliliantabar and Lorestani [20] determined the rupture force of chickpea grains in F_y and F_z to be 318 N and 230.27 N, respectively, at a loading speed of 5 mm min^{-1}. When compared with the results of the study, close values were found in both studies due to their rupture forces.

Table 3. The mechanical characteristics of black chickpea grains vary according to loading speeds and axes

Loading speeds (Ls, mm min^{-1})	Loading axess	Rupture force (Rf, N)	Deformation (Df, mm)	Rupture energy (Re, N mm)	Hardness (Hr, N mm^{-1})	Rupture power (Rp, W)
30	*X-*	$230.01 \pm 40.03b^{**}$	4.31 ± 0.74^{ns}	503.84 ± 147.39^{ns}	$54.34 \pm 10.34b^{*}$	$0.058 \pm 0.010b^{**}$
	Y-	$329.38 \pm 52.60a^{**}$	4.01 ± 1.09^{ns}	658.97 ± 206.03^{ns}	$89.16 \pm 32.95a^{*}$	$0.082 \pm 0.013a^{**}$
	Z-	$317.64 \pm 81.33a^{**}$	3.77 ± 1.18^{ns}	603.88 ± 262.88^{ns}	$94.03 \pm 44.26a^{*}$	$0.079 \pm 0.020a^{**}$
	F value	**8.05**	**0.71**	**1.39**	**4.46**	**8.05**
50	*X-*	$243.67 \pm 57.16a^{**}$	$6.10 \pm 0.44a^{**}$	739.80 ± 173.85^{ns}	$40.34 \pm 10.44b^{**}$	$0.122 \pm 0.029b^{**}$
	Y-	$350.10 \pm 55.82b^{**}$	$5.39 \pm 0.54b^{**}$	947.74 ± 209.01^{ns}	$65.28 \pm 10.68a^{**}$	$0.175 \pm 0.028a^{**}$
	Z-	$348.66 \pm 79.58b^{**}$	$4.71 \pm 0.66c^{**}$	828.64 ± 237.10^{ns}	$74.56 \pm 17.08a^{**}$	$0.174 \pm 0.040a^{**}$
	F value	**8.79**	**15.91**	**2.51**	**18.25**	**8.79**
70	*X-*	$222.71 \pm 71.87b^{**}$	$5.71 \pm 0.68a^{*}$	$607.39 \pm 291.01b^{*}$	$39.08 \pm 11.93b^{*}$	$0.162 \pm 0.063b^{**}$
	Y-	$345.03 \pm 28.11a^{**}$	$4.95 \pm 0.53b^{*}$	$851.42 \pm 97.36a^{*}$	$70.59 \pm 9.99a^{*}$	$0.259 \pm 0.021a^{**}$
	Z-	$327.62 \pm 37.98a^{**}$	$1.08 \pm 0.34b^{*}$	$749.70 \pm 194.52ab^{*}$	$77.67 \pm 32.88a^{*}$	$0.246 \pm 0.028a^{**}$
	F value	**17.76**	**5.10**	**3.41**	**9.57**	**15.98**

***: $p < 0.01$. *: $p < 0.05$, ns: non significant, ± values indicate standard deviation.*

4. Conclusion

Within the scope of the research, the physicomechanical properties of black chickpea grains were examined.

- The moisture content of the black chickpea grains used in the study was 12.01% compared to the dry basis.

- The length, width, and thickness values of the size properties were determined as 8.85 mm, 6.68 mm, and 6.26 mm, and their mass was 0.25 g, respectively.

- The bulk density, true density and porosity values were determined as 632.26 kg m^{-3}, 1241.05 kg m^{-3}, and 48.68%, respectively.

- The highest L^*, $a^*$and b^*values were determined as 18.87, 4.31, and −0.27, respectively.

-The static friction coefficient values of black chickpea grains on different friction surfaces (PVC, galvanized sheet, laminate, plywood, and rubber) were shown on the rubber surface with the highest.

- When the compression test was applied, the highest force value in the grains was measured as 350.10 N in the 50 mm min^{-1} width (*Y*-) axis. The highest hardness value was found with 94.03 N mm^{-1} in the thickness (*Z*-) axis at a loading speed of 30 mm min^{-1}.

Considering the importance of the black chickpea, which is progressing towards becoming popular in our country, the results of the biotechnological features of the equipment of the systems and facilities to be used in the cleaning, classification according to the dimensions, packaging and packaging of the product in industrial applications, depending on the production areas, can be determined by the results of harvest and post-harvest product quality of black chickpea. It is thought that together, they can increase their commercial value.

Author Contributions

All the authors contributed equally to this work. They all read and approved the last version of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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