Moisture dependent physical and mechanical properties of chickpea seeds

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Abstract: The moisture-dependent physical properties are important in designing and fabricating equipment and structures for handling, transporting, processing and storage, and also for assessing quality. This study was carried out to determine the effect of moisture content on some physical and mechanical properties for two varieties of chickpea seeds (Giza 3, and Giza 195). Four levels of moisture content ranging from 11.6% d.b. (dry basis) to 25.4% d.b. were used. The average length, width, thickness, and geometric mean diameter ranged from (7.92±0.04) mm to (8.14±0.04) mm, (6.10±0.04) mm to (6.37± 0.04) mm, (6.43±0.04) mm to (6.84±0.04) mm and (6.77±0.07) mm to (7.08±0.07) mm, respectively. The average sphericity and roundness ranged from (85.53±0.19)% to (87.00±0.19)% and (93.70±0.35)% to (94.14±0.35)%, respectively. The average measured surface area, calculated surface area, and projected area ranged from (144.73±1.55) mm^2 to (158.78±1.55) mm^2, (146.89±1.58) mm^2 to (159.78±1.58) mm^2, and (46.53±0.50) mm^2 to (48.93±0.50) mm^2, respectively. The average bulk density, true density, porosity and angle of repose ranged from (730.05±11.84) kg/m^3 to (694.17±11.84) kg/m^3, (1,225.12± 19.51) kg/m^3 to (1,308.02±19.51) kg/m^3, (44.13±0.49)% to (43.29±0.49)%, and (25.20±0.41)^o (degrees) to (29.10±0.41)^o (degrees), respectively and also increased linearly with an increase in moisture content. The average seed weight and thousand seeds weight ranged from (0.142±0.002) gm to (0.184±0.002) gm, and (177.38±2.17) gm to (194.75±2.17) gm, respectively. The average static coefficient of friction against wood, stainless steel, galvanized iron and iron surfaces and internal with the same seeds ranged from (0.430±0.016) to (0.460±0.016), (0.321±0.007) to (0.366±0.007), (0.327±0.004) to (0.371±0.004), (0.412±0.011) to (0.496±0.011) and (0.638±0.022) to (0.741±0.022), respectively. The average terminal velocity ranged from (5.18±0.34) m/s to (9.14±0.34) m/s. The average penetration depth at load 6kg and tools diameter 1 mm was determined as mechanical property, and generally increased in magnitude with an increase in moisture content. The physical properties were linearly dependent upon moisture content.

Keywords: moisture, physical properties, mechanical properties, chickpea
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1 Introduction

Chick pea (*Cicer arietnum*), is a seed legume widely grown in Egypt for food. The seed forms an important source of protein. The annual production is about 14,100 ton from 15,000 feddans (1 feddan=0.42 ha)[1].

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To design equipment used in plantation, harvesting, transportation, storage and processing of chickpea, there is a need to know various physical properties as a function of moisture content. The physical properties of chickpea grains are to be known for designing and improve of relevant machines and facilities for harvesting, storing, handling and processing. The size and shape and mechanical behavior of chickpea are important in designing of separating, harvesting, sizing and grinding of storage and transporting structures. The coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures. Limited earlier research works reported some important physical properties of various cultivars of chickpea seeds[2]. The threshing is usually carried out on a hard floor with home made threshing machine. In order to optimize various factors, threshing efficiency, pneumatic conveying and storage pertaining to chickpea seed, the physical properties are essential. Deshpande S D, et al.[3] found a linear decrease in kernel density, bulk density and porosity of Soyabean with an increase in moisture content in the range 8.7%–25% d.b. Various physical properties of lentil seeds including bulk density, porosity, projected area, terminal velocity and coefficient of static and dynamic friction were evaluated[4,5]. Limited research has been conducted on the physical properties of chickpea. Some engineering properties of chickpea seeds, such as density, terminal velocity and coefficient of drag, were reported[6]. Previously, some researchers[7,8] investigated the reasons of variations in the coefficient of friction values of biological materials. The experimental results showed that sliding surface, moisture content, velocity, normal pressure, temperature, humidity and operating technique affected friction values. Therefore, specific conditions should be considered while determining the coefficient of friction values of agricultural products. However, detailed measurements of the principal dimensions of chick pea seed and variations in physical properties at various levels of moisture content have not been investigated. The objective of this study was to investigate some moisture levels dependent physical and engineering properties of the chick pea seed, namely linear dimensions, unit weight for individual seed and thousand seeds, sphericity, density, porosity, measured and calculated surface area, projected area, angle of repose, terminal velocity, penetration depth and coefficient of static friction against five structural surfaces at four levels of moisture content.

2 Materials and methods

2.1 Sample preparation

This study was conducted at Department of Agricultural Engineering, Shibin El-kom, Egypt. Dried Giza 3 and Giza 195 varieties of chickpea seeds were collected from the Gemaza Research Centre, Egypt. The initial moisture content as 11.06% determined by drying chickpea sample in an air ventilated oven at (100 ± 3)℃ for 72 h[9]. Four levels of moisture contents of chickpea seeds were selected, 11.06%, 14.52%, 20.10% and 25.40% (d.b.). The samples at the selected moisture contents were prepared by adding a calculated amount of distilled water and sealing them in separate polythene bags and storing them in a refrigerator at 7℃ for 72 h. Before each experiment, the required sample was taken out from the refrigerator and kept sealed in an ambient environment for 24 h to reach equilibrium. The sample was kept in the ambient environment in sealed conditions so there is no chance for change moisture. Static coefficients of friction were determined at the moisture contents of 11.06%, 14.52%, 20.10% and 25.40% (d.b.).

According to the present investigation aims and the work plan sequences, the following instruments, equipments, and materials were used.

2.2 Determination of physical properties

A random sample of one hundred seeds from each variety at four moisture content has been used. The dimensions of major (L), intermediate (W), and minor (T), diameter of all particles in the sample, which means length, width, and thickness, respectively, were measured using digital caliper. Figure 1 shows the shape and the three mutually perpendicular diametrical dimensions L, W, and T of seed of chickpea. The obtained data were studied in terms of geometric mean diameter (D_g), percent of roundness of seed (R %) and sphericity (S %), of individual seed.

The geometric mean diameter, D_g is given[10] as:

$$D_g = (LWT)^{1/3} \tag{1}$$

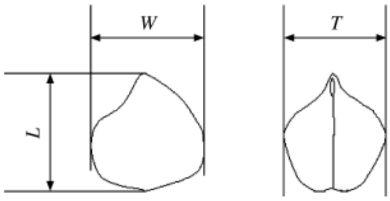

Figure 1 Principal dimensions of chickpea

According to[7], the degree of sphericity can be expressed as Equation (2).

$$S = \frac{(LWT)^{1/3}}{L} \tag{2}$$

Where, L is seed length; W seed width; T seed thickness.

According to[7], the degree of roundness can be expressed as Equation (3).

$$R = \frac{A_P}{A_C} \tag{3}$$

Where, A_P is the largest projected area; A_C is the smallest circumscribing circle.

According to[7], the calculated surface area, S_{ac}, can be expressed as follows:

$$S_{a.c} = \pi D_g^2 \tag{4}$$

Surface area was defined as the total area over outside of the seeds. The surface area was measured by wrapping aluminum foil around the seed and then cutting the foil into small pieces. These pieces were then passed through an area meter to find the area of the foil, which represents the surface area of the seeds. The area meter was measured only the apparent area of foil submitted and was not affected by creases in the foil[11].

True density was measured for five randomly samples of seeds for each variety of the investigated crop as follows:

$$\rho_t = M/V_t \tag{5}$$

Where: ρ_t is the true density of the bulk seeds, kg/m^3; M weight of the bulk seeds, kg; V_t real volume of the bulk seeds, m^3.

Bulk density was calculated for the seed of the investigated crop varieties, by dividing the weight of a quantity of seeds of each variety on its volume, which measured by using graduate cylinder as follows:

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

Where: ρ_b is the bulk density of the bulk seeds, kg/m^3; V_b is bulk volume of the weight sample of bulk seeds, m^3.

Porosity of the investigated crop varieties was determined as the percentage of densities of bulk seeds according to[12] as follows:

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \tag{7}$$

Where: P is the porosity of seeds, %; ρ_t the real density of the bulk seeds, kg/m^3; ρ_b is the bulk density of the bulk seeds, kg/m^3.

The projected area of seed was measured by placing it under a transparent paper and using planimeter to measure the area of shadow.

The terminal velocity of the investigated varieties was measured where the particles under study were placed at the front of the blower at the net inlet side of the transparent tube. After operating the blower, increasing the air stream by opening the gate slowly, until the floating air suspend the particle in the vertical active part of the transparent tube, the measured air velocity represents the terminal velocity of the particles.

Seed friction angle was measured of each seed variety on five surfaces (stainless steel, galvanized steel, iron, plywood, and the same variety of seeds) at four different moisture content. Seed samples were placed in the tray over the surface, which has tested. While operating, the tray, which has the seed sample, was tilted up around its side pivot, the tray was stopped and the angle of friction was measured when 75% of the seeds reached the bottom. The coefficient of friction for the mentioned samples was obtained from the Equation (8). The friction angle of the seed samples was the average of five replicates.

According to[13], static coefficient of friction (μ) was calculated as the following formula:

$$\mu = \tan\Phi \tag{8}$$

Where: Φ is the angle of tilt.

A quantity of seed from each variety was used to determine repose angle. The seeds were then poured under gravity from a suitable height to form a cone at the same spot. More seeds were let to be fallen on the top of the formed cone until the angle between the cone surface and the horizontal plan become constant. The angle between the cone surface and the horizontal plan was recorded to represent repose angle of seed. The recorded angle was the average of five replicates.

Rupture strength meter was used with an accuracy of ±0.1 kg. The penetration end with 1 mm diameter of the device penetrated a seed at load of 6 kg and measured the penetration depth using digital caliper with an accuracy of ±0.01 mm. The penetration depth simplifies the rupture strength for seed. Only one reading was recorded of each seed for 100 grains of the sample of chickpea grains.

2.3 Statistical analysis.

The data analysis of this experiment was carried out by using the Statistical Analysis System GLM procedures[14]. This system was a two-way analysis of variance with the following model:

$$y_{ijk} = \mu_O + A_i + B_j + (AB)_{ij} + e_{ijk}$$

Where: y_{ijk} is an individual observation; μ_O is overall mean; A_i is effect of ith treatment i.e. i=1 for Giza 3 and 2 for Giza 135 chickpea seeds; B_j is effect due to moisture content jth = 11.06, 14.52, 20.10, and 25.40 (d.b); $(AB)_{ij}$ is effect due to interaction of ith treatment with the jth moisture content; e_{ijk} is random effect.

Furthermore the simple correlation coefficients were calculated. The differences between the mean values of physical and mechanical chickpea seeds characteristics were tested for significance using Duncan test[15].

The coefficient of multiple regression and the mean square error (MSE) of models and the variation of predicted values with respect to measured values as well as the distribution of the residuals with respect to the estimated coefficients were used to evaluate the fit of the models to the experimental data.

3 Results and discussion

3.1 Influences of varieties and moisture content on physical measurements of individual chickpea seeds

3.1.1 Variety differences

Mean square values for measured and calculated variables for chickpea seeds varieties are presented in Tables 1a and 1b. There were highly significant differences among varieties for length, width; thickness, and geometric mean diameter, surface area (calculated and measured) projected area and weight of seed. The mean values and standard error for length, width, thickness, geometric mean diameter, and surface area (calculated and measured), projected area and weight of seed are presented in Tables 2a and 2b.

3.1.2 Moisture content differences

Mean values for measured and calculated variables are presented in Tables 1a, 1b and 2a, 2b according to moisture content. For all traits, there were highly significant differences among these variables at ($P \leq 0.01$) except roundness.

3.1.3 Interaction effects

Seeds varieties and moisture content interactions for some physical properties of individual seeds show no significant differences as shown in Tables 1a and 1b, except for penetration depth that were highly significant differences at ($P \leq 0.01$).

3.2 Influences of varieties and moisture content on physical measurements of bulk chickpea seeds

3.2.1 Varieties differences

Mean square values for measured and calculated variables are presented in Table 3 according to varieties of chickpea seeds. There were significant differences among varieties for true density, porosity, and weight of thousand seeds had highly significant difference ($P \leq 0.01$). The mean values and standard error for these variables are presented in Table 4.

3.2.2 Moisture content differences

Mean values for measured and calculated variables are presented in Tables 3 and 4 according to moisture content levels. For each of angle of repose and weight of seed there were highly significant differences among their values due to the variation in moisture content, where the differences for true density were significant at ($P \leq 0.05$).

3.2.3 Interaction effects

The differences for the interaction between seed varieties and moisture content, for some physical properties of bulk seeds, were not significant as shown in Table 3.

Table 1a Mean square, F value, and Probability for some physical properties of individual chickpea seeds

Items	Length *L*/mm	Width *W*/mm	Thickness *T*/mm	Geometric diameter D_g/mm	Surface area	
					Measured S_{am}/mm^2	Calculated S_{ac}/mm^2
Mean square						
V.	3.947	3.108	3.626	3.636	6753.602	6561.08
M.C.	1.668	2.706	6.094	3.372	6341.931	5891.282
V. M.C.*	0.168	8.44E-02	0.139	6.44E-02	182.466	156.291
Error	0.359	0.269	0.271	0.255	481.379	496.306
F value and probability						
V.	10.987**	11.542**	13.382**	14.242**	14.030**	13.220**
M.C.	4.644**	10.052**	22.489**	13.211**	13.175**	11.870**
V. M.C.*	0.468N.S.	0.313N.S.	0.514N.S.	0.252N.S.	0.379N.S.	0.315N.S.

Note: ** Significant at level P≤0.01, * significant at level P≤0.05, N.S. non-significant. Where:*V* is varieties, *M.C.* moisture content (%), (d.b.).

Table 1b Mean square, F value, and Probability for some physical properties of individual chickpea seeds

Items	Sphericity *S*/%	Projected area *P.A.* /mm^2	Roundness *R*/%	Seed weight M_g/g	Penetration depth *P.D.* /mm
Mean square					
V.	4.484	664.739	16.655	1.85E-02	4.14E-03
M.C.	85.603	199.286	6.57	6.13E-02	178.74
V. M.C.*	8.428	30.761	1.034	8.59E-04	0.499
Error	7.52	50.021	23.815	1.24E-03	6.33E-02
F value and probability					
V.	0.596N.S.	13.289**	0.699N.S.	14.930**	0.065N.S.
M.C.	11.384**	3.984**	0.276N.S.	49.396**	2824.340**
V. M.C.*	1.121N.S.	0.615N.S.	0.043N.S.	0.692N.S.	7.886**

Note: ** Significant at level P≤0.01, * significant at level P≤0.05, N.S. non significant. Where:*V* is varieties, *M.C.* Moisture content (%), (d.b.).

Table 2a Mean ± Standard error for some physical properties of individual chickpea seeds

Items	Length *L.*/mm	Width *W.*/mm	Thickness *T.*/mm	Geometric diameter D_g./mm	Surface area	
					Calculated S_{ac}/mm^2	Measured S_{am}/mm^2
Variety						
Giza 3	7.95±0.03^{B}	6.17±0.03^{B}	6.56±0.03^{B}	6.85±0.03^{B}	148.13±1.10^{B}	150.21±1.11^{B}
Giza 195	8.09±0.03^{A}	6.29±0.03^{A}	6.70±0.03^{A}	6.98±0.03^{A}	153.94±1.10^{A}	155.93±1.11^{A}
M.C.						
11.06%	7.92±0.04^{B}	6.10±0.04^{C}	6.43±0.04^{C}	6.77±0.07^{C}	144.73±1.55^{C}	146.89±1.58^{C}
14.52%	8.00±0.04^{BA}	6.18±0.04^{CB}	6.58±0.04^{B}	6.87±0.07^{CB}	149.00±1.55^{CB}	151.22±1.58^{CB}
20.10%	8.03±0.04^{BA}	6.27±0.04^{BA}	6.68±0.04^{B}	6.95±0.07^{BA}	152.34±1.55^{B}	154.40±1.58^{BA}
25.40%	8.14±0.04^{A}	6.37±0.04^{A}	6.84±0.04^{A}	7.08±0.07^{A}	158.07±1.55^{A}	159.78±1.57^{A}
V.*M.C.						
Giza 3						
11.06%	7.89±0.06	6.06±0.05	6.35±0.05	6.72±0.05	142.85±2.19	144.99±2.23
14.52%	7.92±0.06	6.13±0.05	6.53±0.05	6.81±0.05	146.57±2.19	148.75±2.23
20.10%	7.94±0.06	6.19±0.05	6.63±0.05	6.88±0.05	149.08±2.19	151.27±2.23
25.40%	8.05±0.06	6.29±0.05	6.74±0.05	6.99±0.05	154.02±2.19	155.82±2.23
Giza 195						
11.06%	7.95±0.06	6.14±0.05	6.50±0.05	6.82±0.05	146.60±2.19	148.79±2.23
14.52%	8.07±0.06	6.23±0.05	6.62±0.05	6.93±0.05	151.43±2.19	153.66±2.23
20.10%	8.12±0.06	6.35±0.05	6.72±0.05	7.02±0.05	155.60±2.19	157.53±2.23
25.40%	8.22±0.06	6.45±0.05	6.94±0.05	7.17±0.05	162.13±2.19	163.73±2.23

Note: Means within the same column carry different small superscripts are significant at level P≤ 0.05, Means within the same column carry different capital superscripts are significant at level P≤ 0.01.

Table 2b Mean ± Standard error for some physical properties of individual chickpea seeds

Items	Sphericity *S*/%	Projected area *P.A.*/mm^2	Roundness *R.*/%	Seed weight M_g./g	Penetration depth *P.D.*/mm
Variety					
Giza 3	86.21±0.14	46.71±0.35^{B}	93.78±0.24	0.157±0.002^{B}	1.14±0.01
Giza 195	86.36±0.14	48.53±0.35^{A}	94.06±0.24	0.167±0.002^{A}	1.13±0.01
M.C.					
11.06%	85.53±0.19^{C}	46.53±0.50^{B}	94.14±0.35	0.142±0.002^{D}	0.24±0.02^{D}
14.52%	85.98±0.19^{CB}	47.34±0.50^{BA}	93.93±0.35	0.155±0.002^{C}	0.58±0.02^{C}
20.10%	86.63±0.19^{BA}	47.69±0.50^{BA}	93.91±0.35	0.167±0.002^{B}	1.35±0.02^{B}
25.40%	87.00±0.19^{A}	48.93±0.50^{A}	93.70±0.35	0.184±0.002^{A}	2.37±0.02^{A}
*V.*M.C.*					
Giza 3					
11.06%	85.22±0.27	46.19±0.71	94.09±0.49	0.140±0.004	0.27±0.03^{D}
14.52%	86.03±0.27	46.41±0.71	93.77±0.49	0.151±0.004	0.63±0.03^{C}
20.10%	86.77±0.27	46.48±0.71	93.76±0.49	0.161±0.004	1.34±0.03^{B}
25.40%	86.82±0.27	47.76±0.71	93.48±0.49	0.176±0.004	2.31±0.03^{A}
Giza 195					
11.06%	85.84±0.27	46.88±0.71	94.19±0.49	0.145±0.004	0.20±0.03^{D}
14.52%	85.94±0.27	48.26±0.71	94.10±0.49	0.159±0.004	0.53±0.03^{C}
20.10%	86.48±0.27	48.89±0.71	94.05±0.49	0.172±0.004	1.37±0.03^{B}
25.40%	87.17±0.27	50.09±0.71	93.92±0.49	0.191±0.004	2.43±0.03^{A}

Note: Means within the same column carry different small superscripts are significant at level $P\leq0.05$, Means within the same column carry different capital superscripts are significant at level $P\leq0.01$.

Table 3 Mean square, F value, and Probability for some physical properties of bulk chickpea seeds

	Mean square				
Items	Bulk density ρ_b/kg · m^{-3}	True density ρ_t/kg · m^{-3}	Thousand seed weight M_{1000}/g	Angle of repose *A.R.*./deg	Porosity *P.*/%
V.	192.019	43,884.663	897.472	5.625	112.527
M.C.	2,195.223	11,688.447	550.124	30.825	1.206
V. M.C.*	52.663	144.563	9.777	0.758	4.072E-02
Error	1,402.711	3,805.663	47.180	1.637	2.384
	F value and probability				
V.	19.022**	3.435N.S.	47.206**	11.531**	0.137N.S.
M.C.	11.660**	18.824**	0.506N.S.	3.071*	1.565N.S.
V. M.C.*	0.207N.S.	0.463N.S.	0.017N.S.	0.038N.S.	0.038N.S.

Note: ** Significant at level $P\leq0.01$, * significant at level $P\leq0.05$, N.S. non significant. Where: *V* is varieties, *M.C.* moisture content (%), (d.b.).

Table 4 Mean ± Standard error for some physical properties of bulk chickpea seeds

Items	Bulk density ρ_b/kg · m^{-3}	True density ρ_t/kg · m^{-3}	Porosity *P.*/%	Angle of repose *A.R.*/deg	Thousand seed weight M_{1000}./g
Variety					
Giza 3	710.83±8.38	1301.10±13.80^{A}	45.38±0.35^{A}	26.70±0.29	189.81±1.54^{A}
Giza 195	715.21±8.38	1234.85±13.80^{B}	42.03±0.35^{B}	27.45±0.29	180.34±1.54^{B}
M.C.					
11.06%	730.05±11.84	1308.02±19.51^{a}	44.13±0.49	25.20±0.41^{B}	177.38±2.17^{C}
14.52%	716.35±11.84	1274.97±19.51^{ab}	43.76±0.49	26.10±0.41^{B}	181.82±2.17^{CB}
20.10%	711.50±11.84	1263.80±19.51^{ab}	43.65±0.49	27.90±0.41^{A}	186.36±2.17^{BA}
25.40%	694.17±11.84	1225.12±19.51^{b}	43.29±0.49	29.10±0.41^{A}	194.75±2.17^{A}
V.*M.C.					
Giza 3					
11.06%	727.62±16.75	1343.44±27.59	45.86±0.69	25.00±0.57	180.88±3.07
14.52%	715.47±16.75	1309.64±27.59	45.38±0.69	25.40±0.57	187.34±3.07
20.10%	711.36±16.75	1298.76±27.59	45.27±0.69	27.40±0.57	191.92±3.07
25.40%	688.85±16.75	1252.56±27.59	45.02±0.69	29.00±0.57	199.11±3.07
Giza 195					
11.06%	732.47±16.75	1272.59±27.59	42.40±0.69	25.40±0.57	173.87±3.07
14.52%	717.22±16.75	1240.31±27.59	42.14±0.69	26.80±0.57	176.31±3.07
20.10%	711.63±16.75	1228.83±27.59	42.02±0.69	28.40±0.57	180.79±3.07
25.40%	699.49±16.75	1197.68±27.59	41.56±0.69	29.20±0.57	190.38±3.07

Note: Means within the same column carry different small superscripts are significant at level $P\leq 0.05$, Means within the same column carry different capital superscripts are significant at level $P\leq 0.01$.

3.3 Influences of varieties and moisture content on engineering measurements of bulk chickpea seed

3.3.1 Varieties differences

Mean square values for measured and calculated variables are presented in Table 5 according to varieties of chickpea seeds. There were highly significant differences among varieties for coefficient of static friction with wood ($P \leq 0.01$). For the other traits there were no significant differences among varieties. The mean values and standard error for engineering properties of bulk chickpea seeds were presented in Table 6.

3.3.2 Moisture content differences

Mean values for measured and calculated variables are presented in Tables 5 and 6 according to moisture content. For each trait values there were highly significant differences among them due to the variation in moisture content at ($P \leq 0.01$), but for coefficient of static internal friction (on surface of the same seeds) was significantly differences at ($P \leq 0.05$), and was not significant differ for coefficient of static friction with wood.

3.3.3 Interaction effects

The differences for the interactions between seed varieties and moisture content, for some engineering properties of bulk seeds, were not significant as shown in Table 5.

Table 5 Mean square, F value, and probability for some engineering properties of bulk chickpea seeds

Items	Mean square.					Terminal velocity $T.V.$/m · s^{-1}
	Coefficient of static friction					
	Wood μ_W (tanΦ)	Stainless steel μ_S (tanΦ)	Galvanized iron μ_{Gi} (tanΦ)	Iron μ_{Ir} (tanΦ)	Internal μ_{In} (tanΦ)	
V.	3.699E-02	1.550E-03	2.102E-07	3.428E-04	1.341E-03	1.444E-02
M.C.	5.996E-03	3.697E-03	3.623E-03	5.810E-03	1.901E-02	28.310
*V.**	1.493E-05	7.044E-05	2.589E-05	7.873E-06	6.955E-05	0.273
Error	2.501E-03	5.044E-04	1.746E-04	1.248E-03	4.684E-03	1.149
	F value and probability					
V.	14.790**	3.073N.S.	0.001N.S.	0.275N.S.	0.286N.S.	0.013N.S
M.C.	2.398N.S.	7.330**	20.754**	4.656**	4.059*	24.630**
*V.**	0.006N.S.	0.140N.S.	0.148N.S.	0.006N.S	0.015N.S.	0.237N.S.

Note: ** Significant at level $P \leq 0.01$, * significant at level $P \leq 0.05$, N.S. non significant. Were, *V* is varieties; *M.C.* Moisture content (%), (d.b.).

Table 6 Mean ± Standard error for some engineering properties of bulk chickpea seeds

Items	Coefficient of static friction					Terminal velocity $T.V.$/m · s^{-1}
	Wood μ_W (tanΦ)	Stainless steel μ_S (tanΦ)	Galvanized iron μ_{Gi} (tanΦ)	Iron μ_{Ir} (tanΦ)	Internal μ_{In} (tanΦ)	
Variety						
Giza	0.466±0.011^{A}	0.340±0.005	0.353±0.003	0.448±0.008	0.692±0.015	6.93±0.24
Giza 195	0.405±0.011^{B}	0.353±0.005	0.353±0.003	0.442±0.008	0.703±0.015	6.90±0.24
M.C.						
11.06%	0.403±0.016	0.321±0.007^{B}	0.327±0.004^{C}	0.412±0.011^{B}	0.638±0.022^{b}	5.18±0.34^{C}
14.52%	0.433±0.016	0.344±0.007^{BA}	0.352±0.004^{B}	0.444±0.011^{BA}	0.695±0.022^{ba}	6.22±0.34^{CB}
20.10%	0.447±0.016	0.355±0.007^{A}	0.362±0.004^{BA}	0.456±0.011^{BA}	0.716±0.022^{a}	7.11±0.34^{B}
25.40%	0.460±0.016	0.366±0.007^{A}	0.371±0.004^{A}	0.469±0.011^{A}	0.741±0.022^{a}	9.14±0.34^{A}
V.*M.C						
Giza 3						
11.06%	0.433±0.022	0.317±0.010	0.329±0.006	0.417±0.016	0.636±0.031	5.13±0.48
14.52%	0.465±0.022	0.340±0.010	0.352±0.006	0.447±0.016	0.690±0.031	6.10±0.48
20.10%	0.476±0.022	0.347±0.010	0.360±0.006	0.458±0.016	0.709±0.031	7.11±0.48
25.40%	0.490±0.022	0.357±0.010	0.370±0.006	0.471±0.016	0.732±0.031	9.40±0.48
Giza 195						
11.06%	0.373±0.022	0.325±0.010	0.325±0.006	0.408±0.016	0.641±0.031	5.23±0.48
14.52%	0.401±0.022	0.348±0.010	0.352±0.006	0.441±0.016	0.701±0.031	6.35±0.48
20.10%	0.418±0.022	0.362±0.010	0.364±0.006	0.454±0.016	0.723±0.031	7.11±0.48
25.40%	0.430±0.022	0.376±0.010	0.372±0.006	0.466±0.016	0.749±0.031	8.89±0.48

Note: Means within the same column carry different small superscripts are significant at level $P \leq 0.05$, Means within the same column carry different capital superscripts are significant at level $P \leq 0.01$.

3.4 Correlation coefficients of evaluating chickpea trait

Phenotypic correlation coefficients among the chickpea traits are presented in Table 7. Concerning chickpea dimensions (length, width and thickness) relationships with other studied traits, it was noticed that some features can be detected from these illustrated correlations. First feature is that length of chickpea had positive and significant correlations with width (0.816), thickness (0.726), geometric mean diameter (0.907), calculated surface area (0.907), measured surface area (0.900), projected area (0.940), weight of seed (0.872) and penetration depth (0.118). Width of chickpea also had positive and significant correlation with thickness (0.829), geometric mean diameter (0.954), calculated surface area (0.953), measured surface area (0.952), sphericity (0.315), projected area (0.910), roundness (0.274), weight of seed (0.926) and penetration depth (0.180). Concerning chickpea thickness relationships with other studied traits, it had positive and significant correlations with geometric mean diameter (0.921), calculated surface area (0.919), measured surface area (0.919), sphericity (0.449), projected area (0.780), roundness (0.161), weight of seed (0.908) and penetration depth (0.269). These results mean that increasing dimensions (length, width and thickness) was associated with increasing in these traits.

Table 7 Correlation between some physical properties of individual chickpea seeds

Items	L/mm	W/mm	T/mm	D_g/mm	$S_{a.c.}$/mm^2	$S_{a.m.}$/mm^2	S/%	$P.A.$/mm^2	R/%	M_g/g
W/mm	0.816**									
T/mm	0.726**	0.829**								
D_g/mm	0.907**	0.954**	0.921**							
$S_{a.c.}$/mm^2	0.907**	0.953**	0.919**	0.999**						
$S_{a.m.}$/mm^2	0.900**	0.952**	0.919**	0.996**	0.997**					
S/%	-0.219**	0.315**	0.449**	0.210**	0.206**	0.216**				
$P.A.$/mm^2	0.940**	0.910**	0.780**	0.943**	0.945**	0.945**	0.002N.S.			
R/%	-0.175**	0.274**	0.161**	0.106**	0.102**	0.120**	0.655**	0.163**		
M_g/g	0.872**	0.926**	0.908**	0.973**	0.977**	0.973**	0.226**	0.908**	0.090*	
$P.D.$/mm	0.118**	0.180**	0.269**	0.206**	0.207**	0.196**	0.201**	0.117**	-0.010N.S.	0.533**

Note: ** Significant at level $P \le 0.01$, * significant at level $P \le 0.05$, N.S. non significant.

Second feature is that there were negative correlations observed between length of chickpea and both of sphericity (-0.219) and roundness (-0.175). These results mean that increasing length was associated with decreasing in these traits.

These results indicate that dimensions of chickpea can be utilized to predict some other traits without penetrate the chickpea seeds.

Geometric mean diameter showed highly significant relationships with other studied traits, positively with calculated surface area (0.999), measured surface area (0.996), sphericity (0.210), projected area (0.943), roundness (0.106), weight of seed (0.973) and penetration depth (0.206).

Concerning measured surface area and its correlations with other traits it was noticed that most of these correlations were positive and significant, as with calculated surface area (0.997), sphericity (0.216), projected area (0.945), roundness (0.120), weight of seed (0.973) and penetration depth (0.196).

It was also noticed that calculated surface area trait had significant and positive correlations with sphericity (0.206), projected area (0.994), roundness (0.102), weight of seed (0.977) and penetration depth (0.207).

Sphericity is highly correlated with some studied traits, positively with roundness (0.655), weight of seed (0.226) and penetration depth (0.201), while it was not significant correlated with projected area (0.002).

Weight of seed showed highly significant relationships with other studied traits; positively with projected area (0.908), roundness (0.090) and penetration depth (0.533). Similar results were been reported by[16-19].

3.5 Physical properties of chickpea seeds

3.5.1 Linear dimensions

The variations of length, width, thickness and geometric diameter of the seeds with seed moisture content are displayed in Figure 2. All the dimensions increase with increasing seed moisture content.

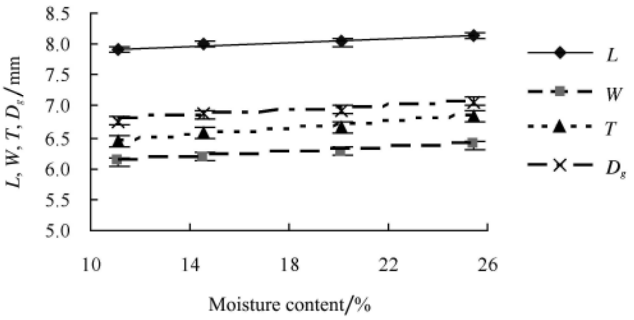

Figure 2 Linear dimensions versus moisture content

Very high correlation was observed between these dimensions and seed moisture content. This indicates that, on moisture absorption, the seeds expand in length, width, thickness and geometric diameter within the moisture range of 11.06% to 25.4% (d.b.). Konak M et al.[6] also found the linear dimensions of chickpea to increase in liner manner with moisture content up to 16.5% d.b. The total average expansions from 11.06% to 25.4% moisture content were largest along the seed width and least along its length. Konak M et al.[6] however, found the expansion of chickpea seeds to be largest along their width and least along the seed thickness. This could be due to the different studied varieties. The (L/W, L/T and L/Dg) ratio variations with moisture content are shown in Figure 3 L/W exhibits the highest ratios, followed by L/T and L/D_g in descending order. The relationship for principle dimensions (L, W, and T) and geometric mean diameter with seed moisture can be represented as follows:

$$L=7.768+0.0142\,M.C. \quad (R^2=0.954) \quad (9)$$

$$W=5.902+0.0184\,M.C. \quad (R^2=0.997) \quad (10)$$

$$T=6.144+0.0274\,M.C. \quad (R^2=0.978) \quad (11)$$

$$D_g=6.553+0.0204\,M.C. \quad (R^2=0.984) \quad (12)$$

Based on the data of seed measurements for the three main seed dimensions the frequency distribution curves for chickpea seeds for length, width and thickness are shown in Figure 4. The frequency distribution curves show the trend towards normal distribution. The overlapping between the frequency distribution curves plays important role for separating the seeds based on their dimensions (L, W and T).

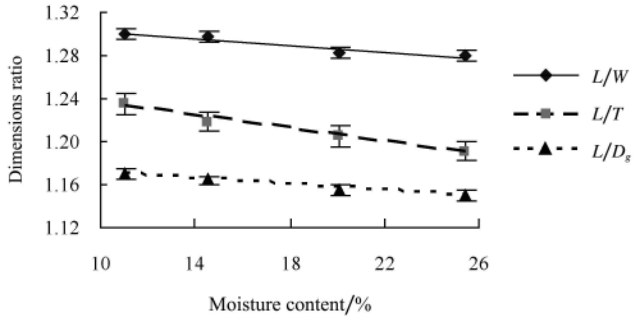

Figure 3 Effect of moisture content on dimensions ratio for chickpea seeds

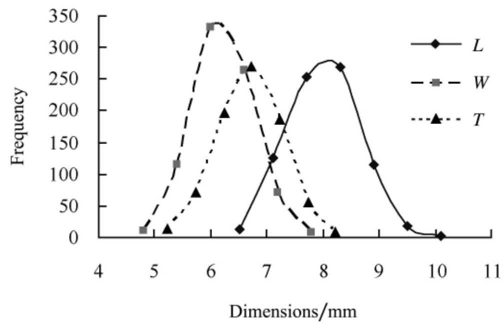

Figure 4 Frequency of dimensions for chickpea seeds for all moisture contents

3.5.2 Surface area

The variation of calculated surface area of the seeds with moisture content is shown in Figure 5. The Figure indicates that the calculated surface area increases linearly with seed moisture content up to 25.4% (Equation (4)). The relationship between seed moisture content and calculated surface area appears linear and can be represented by the regression equation:

$$S_{a.c} = 135.29 + 0.886\,M.C. \quad (R^2 = 0.984) \quad (13)$$

Linear increase in surface area with increase in moisture content have been observed by[20] for oil bean seed[21].

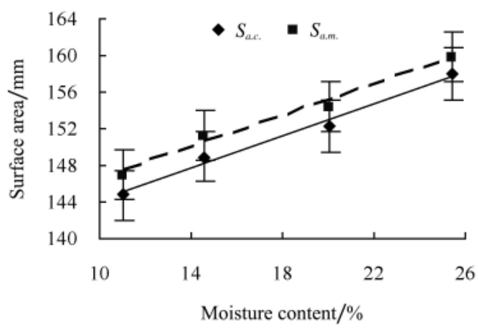

Figure 5 Effect of moisture content on surface area for chickpea seeds

The variation of measured surface area of the seeds with seed moisture content is displayed in Figure 5. Measured surface area increased with seed moisture content up to 25.4%. But the measured surface area had a high value than the calculated surface area this return to the experimental error. The relationship between measured surface area and seed moisture can be represented by following equation:

$$S_{a.m.} = 137.91 + 0.853\ M.C. \quad (R^2 = 0.982) \qquad (14)$$

Figure 6 shows the variation of the measured surface area (S_{am}) with calculated surface area (S_{ac}) for all seed moisture content. The relationship between measured and calculated surface area may be given by the following expression:

$$S_{a.m} = 0.569+1.0097\ S_{ac} \quad (R^2 = 0.995) \qquad (15)$$

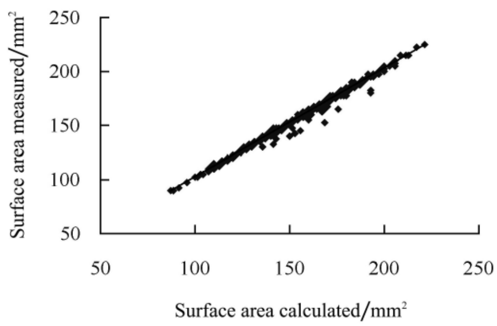

Figure 6 Relationship between surface area calculated and surface area measured of chickpea for all moisture content

3.5.3 Sphericity

The sphericity variation with the seed moisture content is shown in Figure 7. Sphericity increased with increasing seed moisture content up to 25.40% moisture content as shown in Figure 7. The sphericity of chickpea seeds ranged from 85.53% to 87.00% when the moisture content ranged from 11.06% to 25.40% d.b., using Equation (2). The relationship between sphericity and seed moisture appear linear can be represented as follows:

$$S = 84.456 + 0.1029\ M.C. \quad (R^2 = 0.983) \qquad (16)$$

[6] However, found the mean sphericity of chickpea seed (*cv. Koc¸ basi*) was 87.589% at seed moisture content 5.2%d.b.

3.5.4 Projected area

The variation of projected area of the seeds with seed moisture content as displayed in Figure 8 is projected area increase with increasing seed moisture content up to 25.4%. This returns to the extension in length and width with increasing in moisture content. The relationship between projected area and seed moisture can be represented by following equation:

$$P.A. = 44.88+ 0.1542\ M.C. \quad (R^2 = 0.949) \qquad (17)$$

This similar result was found by[6].

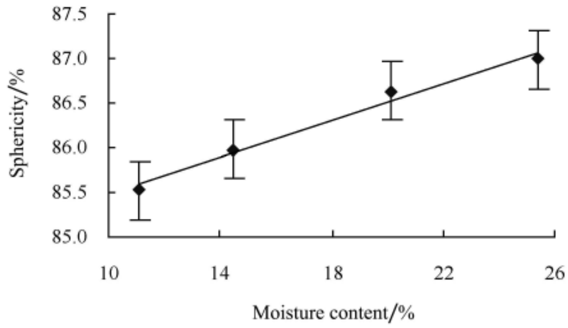

Figure 7 Effect of moisture content on sphericity for chickpea seeds

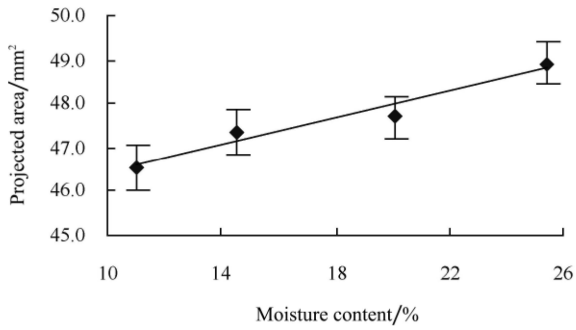

Figure 8 Effect of moisture content on projected area for chickpea seeds

3.5.5 Roundness

The variation of roundness of the seeds with seed moisture content is displayed in Figure 9. Roundness decreased with increasing seed moisture content up to 25.40%. The roundness of chickpea seeds ranges from 94.14% to 93.70%, when the moisture content ranges from 11.06% to 25.40%, d.b. The relationship between roundness and seed moisture can be represented by following equation:

$$R = 94.403 - 0.0273\ M.C. \quad (R^2 = 0.898) \qquad (18)$$

3.5.6 Weight of seeds

The variation of weight of seeds with seed moisture content is displayed in Figure 10. Weight of seed was increased with increasing seed moisture content up to 25.4%. The relationship between weight of seeds and seed moisture can be represented by following equation:

$$M_g = 0.1122 + 0.0028\,M.C. \quad (R^2 = 0.992) \quad (19)$$

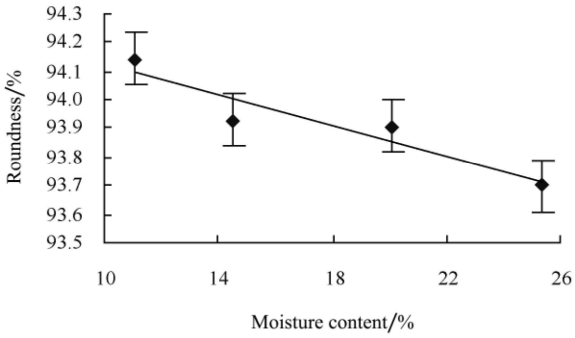

Figure 9 Effect of moisture content on roundness for chickpea seeds

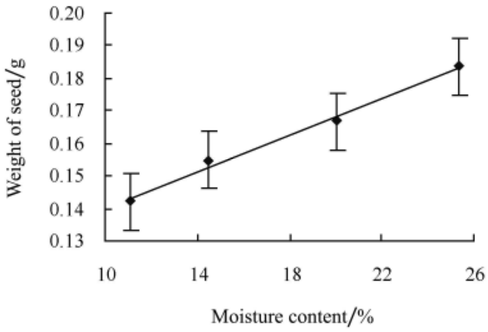

Figure 10 Effect of moisture content on weight of seed for chickpea seeds

3.5.7 Bulk and true densities

The experimental results of the bulk and true densities for chickpea seed at different moisture levels are shown in Figure 11. As the moisture content increased from 11.06% to 25.40% d.b., the bulk and true densities decreased from 730.05 kg/m^3 to 694.17 kg/m^3 and from 1,308.02 kg/m^3 to 1,225.12 kg/m^3, respectively.

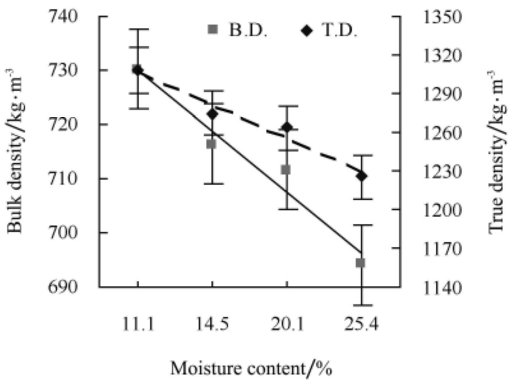

Figure 11 Effects of moisture content on bulk and true density for chickpea seeds

The relationship between bulk and true densities was found to be linear with the moisture content and the relationship between them can be expressed as follows:

$$\rho_b = 753.62 - 2.285\,M.C. \quad (R^2 = 0.945) \quad (20)$$

$$\rho_t = 1361.6 - 5.2684\,M.C. \quad (R^2 = 0.944) \quad (21)$$

The reduction indicates that there is a small increase in the seed weight in comparison to its volume increase as its moisture content increases. This is similar with the findings of [6].

These discrepancies could be due to the cell structure and the volume and the weight increase characteristics of the seeds and seeds as moisture content increases.

3.5.8 Porosity

Since the porosity depends on the bulk as well as true densities, the magnitude of variation in porosity depends on these factors only. The porosity of chickpea seeds decreased with increase in moisture content from 11.06% to 25.40% as shown in Figure 12. The relationship exiting between moisture content and porosity is linear relationship and relationship between them can be represented as follows:

$$P = 44.653 - 0.0532\,M.C. \quad (R^2 = 0.935) \quad (22)$$

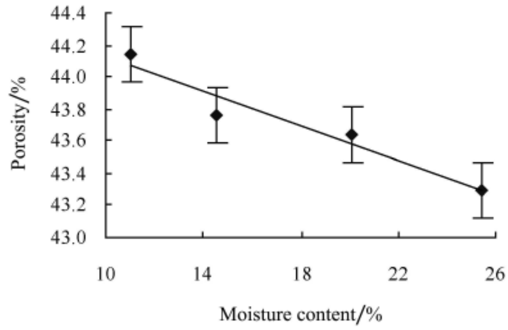

Figure 12 Effect of moisture content on porosity for chickpea seeds

3.5.9 Thousand seed weight

The variation of weight of thousand seed with seed moisture content is plotted in Figure 13. Thousand seed weight increases with seed moisture content from 177.38 g to 194.75 g, when the seed moisture content increases from 11.06% to 25.40% d.b. The relationship existing between moisture content and weight of thousand seed is linear relationship and the relationship between them can be represented by the following regression equation:

$$M_{1000} = 164.36 + 1.166M.C. \quad (R^2 = 0.982) \quad (23)$$

The linear increase in the weight of thousand seed as the seed moisture content increases has bean noted by[22] for vetch seed.

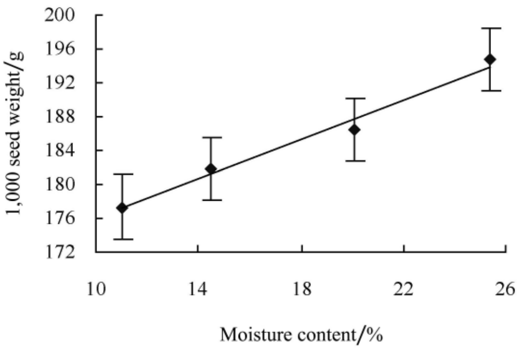

Figure 13 Effect of moisture content on thousand seed weight for chickpea seeds

3.6 Mechanical properties of chickpea seed

3.6.1 Penetration depth

The variation of penetration depth (*P.D.*) of the chickpea seeds with seed moisture content at a load of 6kg is presented in Figure 14. The graph shows that the penetration depth increased with increasing seed moisture content up to 24.9%. The large depth of penetration at higher moisture content might have resulted from the fact that the kernel tended to be very soft in high moisture content. The relationship between penetration depth and seed moisture can be expressed by following equation:

$$P.D. = -1.511 + 0.1488\,M.C. \quad (R^2 = 0.985) \quad (24)$$

The high penetration depth at higher moisture content might have resulted from the fact that the chickpea seed might have soft texture at high moisture content. The results are similar to these reported by[23] for apricot pit.

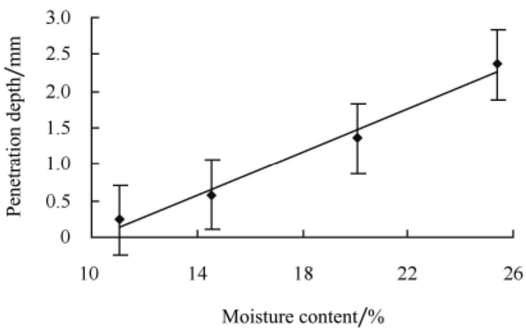

Figure 14 Effect of moisture content on penetration depth at a load of 6kg for chickpea seeds

3.6.2 Coefficient of friction

The variation of coefficient of static friction with seed moisture content is displayed in Figure 15 for surfaces of different materials.

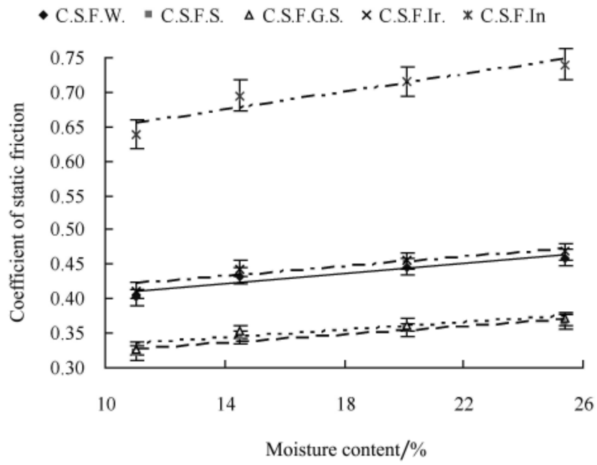

Figure 15 Effect of moisture content on coefficient of static friction for chickpea seeds

The coefficient of friction for all moisture contents considered is highly for a surface of the same seed followed by iron, plywood, galvanized iron, and then stainless steel surface. Coefficient of static friction was increased with increasing seed moisture content up to 25.4%, for wood, stainless steel, galvanized iron, iron, and seed surface of the same seeds variety at same moisture content. It was observed that the moisture content had a more significant on coefficient of static friction than effect the material surface. This owes to the increased adhesion between the seed and the surface at higher moisture values. The largest coefficient of static friction was the coefficient of internal friction (the coefficient of static friction between the seeds and a surface of the same seeds at the same moisture content). The following equations represented the relationship between coefficient of static friction for wood, stainless steel, galvanized iron, iron, and surface of seed at same moisture content and seed moisture:

$$\mu_W = 0.3703 + 0.0037M.C. \quad (R^2 = 0.900) \quad (25)$$

$$\mu_S = 0.2954 + 0.0029M.C. \quad (R^2 = 0.920) \quad (26)$$

$$\mu_{Gi} = 0.303 + 0.0028M.C. \quad (R^2 = 0.871) \quad (27)$$

$$\mu_{Ir} = 0.3816 + 0.0036M.C. \quad (R^2 = 0.881) \quad (28)$$

$$\mu_{In} = 0.582 + 0.0065M.C. \quad (R^2 = 0.885) \quad (29)$$

3.6.3 Angle of repose

The variation of angle of repose of the seed with seed moisture content is displayed in Figure 16. The angle of repose increases linearly with increasing seed moisture content from 25.20° at 11.06% to 29.10° at 25.40% moisture content.

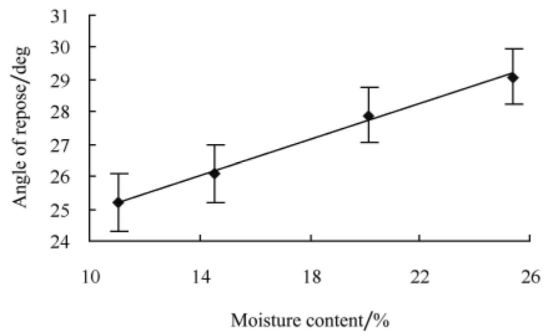

Figure 16 Effect of moisture content on angle of repose for chickpea seeds

The variation is somewhat similar to pumpkin seeds[24] and oil bean[20,25,26]. The following equation represented the relationship between angle of repose and seed moisture:

$$\theta = 22.138+ 0.2778\ M.C. \quad (R^2 = 0.995) \quad (30)$$

3.6.4 Terminal velocity

The variation of terminal velocity of the seeds with seed moisture content is displayed in Figure 17. Terminal velocity was increased with increasing seed moisture content up to 25.4%. The increase in terminal velocity with increase in moisture content can be attributed to the increase of individual seed weight per unit frontal area represented to air stream. Following equation can be represented the relationship between terminal velocity with seed moisture:

$$T.V. = 3.5595+0.1399\ M.C. \quad (R^2 = 0.9622) \quad (31)$$

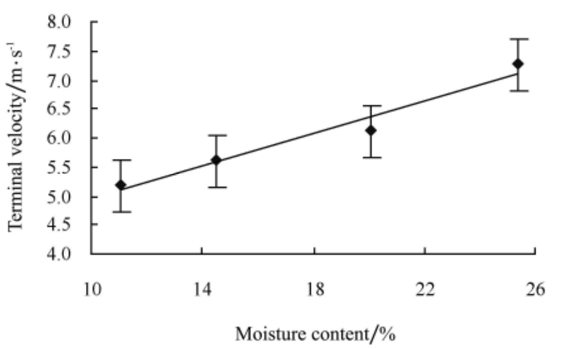

Figure 17 Effect of moisture content on terminal velocity for chickpea seeds

The Figure reveals a linear increase in terminal velocity from 5.18 m/s to 9.14 m/s when increasing seed moisture content from 11.06% to 25.40%, d.b.

Konak M et al.[6] reported a linear increase in terminal velocity for chickpea with increasing seed moisture content.

4 Conclusions

The physical properties of the seed determined as a function of moisture content varied significantly with increase in moisture content.

Length, width, thickness, projected area, surface area, porosity, mass of 1,000 seeds, angle of repose and penetration depth linearly increased with increase in moisture content but bulk density and true density, decreased linearly with increase in moisture content.

The static coefficients of friction for Chickpea seeds increased with increase in moisture content and the highest static coefficients of friction were found on a same surface of seeds (internal friction) and the lowest on a stainless steel among the materials tested. In this study, the physical parameters of chickpea seeds are expressed in the form of regression equations as a function of moisture content.

The bulk and true density and porosity decreased from 730.05 kg/m^3 to 694.17 kg/m^3, from 1,308.02 kg/m^3 to 1,225.12 kg/m^3 and from 44.13% to 43.29%, respectively.

The angle of repose and terminal velocity increased linearly from 25.2° to 29.1° and from 5.18 m/s to 9.14 m/s, respectively.

The relationships between physical properties of various chickpeas and moisture content were established by linear and second degree polynomial models.

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