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Physical Properties of Chickpea (*C. arietinum*) Cultivars

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Abstract. *Physical attributes and some moisture dependent physical properties of chickpea (large kabuli, small kabuli (chico) and desi) were measured. The major, intermediate, minor and geometric diameter, unite mass and volume of seeds measured at moisture content of about 10% w.b. The particle and bulk densities, porosity, projected area, emptying and filling angle of reposes, static coefficient of friction on various surfaces, cohesion and terminal velocity of chickpea seed were measured at different levels of moisture content (7.5 -14% w.b.).*

The analysis of variance (ANOVA) and comparison of means were performed using PROC GLM to evaluate the effect of moisture content on the physical properties of various chickpea samples. The relationship between physical properties and moisture content were shown by appropriate models. The comparison means indicated that at each moisture level, the mean values of physical properties for various chickpea samples were significantly different ($p<0.05$).

Keywords. *Physical property, chickpea, dimension, density, friction, terminal velocity, cohesion*

Introduction

Chickpea (*Cicer arietnum*), an important source of protein and starch is grown as specialty crop in Saskatchewan and Canada exported around the world. According to Saskatchewan Agriculture and Food (2002), chickpea production in Saskatchewan was 446.8 thousand tonnes in 2001, while world production was 6063 thousand tonnes at the same time (FAO 2002).

There are two main types of chickpeas, namely desi and kabuli. The desi type (Indian origin) has a thick, colored seed coat while the kabuli type (Mediterranean and Middle Eastern origin) has thin, white seed coat. The kabuli type has larger seed than the desi type and is preferred by consumers (Salunkhe et al. 1985).

Physical properties data of agricultural materials are required in the design of machines for planting, harvesting and various postharvest operations such as cleaning, conveying and storage. Limited earlier research works reported some important physical properties of various cultivars of chickpea seeds. Some physical attributes such as size, shape, true and bulk densities and porosity as well as angle of repose and airflow resistance of various material including chickpea var. “desi” were reported by Tabil et al. (1999). Rai and Kumar (1995) determined dimensions, shape and some moisture dependent physical properties of chickpea (kabuli chana) grown in India. Several physical properties of chickpea (cv. ‘Kocbosi’) including dimensions, shape, bulk and kernel density, porosity, dynamic angle of repose, terminal velocity, rupture strength and coefficients of friction against various surfaces were reported by Konak et al.(2002).

Physical characteristics of various cultivars of a crop usually differ. For example, the major dimension of chickpea was reported to be 10.42 mm at 9.9 moisture content (%w.b.) for a desi type cultivar by Tabil et al. (1999), while it was reported to be 9.72 mm at 9.05 moisture content (% d.b.) for kabuli type chana chickpea by Rai and Kumar (1995).

Different techniques can be used for measuring physical properties. Researchers have measured dimensions of seed by using machine vision system (Tabil et al. 1999; and Song and Litchfield 1991). Carman (1996) and Konak et al. (2002) used the free fall method to determine the terminal velocity of seeds while Joshi et al. (1993) and Singh and Goswami (1996) determined the terminal velocity values of pumpkin and cumin seed, respectively, by using a wind column.

Previously, some researchers (Mohsenin 1986; Zhang and Kushwaha 1993) investigated the reasons of variation 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. Zhang and Kushwaha (1993) and Tabil and Sokhansanj (1997) used the Wykeham Farrace shear box apparatus to determine grain friction and cohesion of alfalfa, respectively.

The objective of this study was to determine and evaluate some physical properties of various cultivars of (large and small kabuli and desi) chickpea. Seed dimensions, shape, unit mass and volume, particle and bulk densities, porosity, terminal velocity, emptying and filling angles of repose, cohesion and coefficient of static friction against various surfaces (galvanized steel, plexiglass and concrete) at three levels of moisture content were measured.

Materials and Methods

Material

In this study, various dry chickpea (large and small kabuli and desi) samples were procured from Canadian Select Grain (Eston, SK). The seed was kept in a cold storage at 5^oC for one month. The moisture content of samples was determined by following AACC 44-15A method (AACC 1999).

Sample Preparation

The samples were dried by spreading them in thin layer in convection oven set at 50^oC. The desired moisture content was obtained by controlling the sample mass during drying. The seeds with higher moisture contents were prepared by adding calculated amounts of distilled water. In order to allow the moisture to distribute uniformly throughout the seeds, a concrete mixer was used to mix the samples during wetting. The samples were then sealed in separate polyethylene bags and kept at 5^oC in a refrigerator for 7 days. Before starting each test, the required amounts of seeds at different levels of moisture content were allowed to warm up to room temperature for 2 h in separate pouches (Singh and Goswami 1996).

Size and Shape

One hundred fifty seeds of each chickpea cultivar were randomly selected from the bulk sample with different initial moistures. To determine the size and shape of chickpea seeds which comprise a sample, the length and width of the seeds were measured by using a computer imaging system, while the third dimension was determined by using a caliper (Song and Litchfield 1991). Several sample seeds were placed on the black backplate under the camera and the image was acquired and analyzed by the images using a Sony DXC-151A CCD color video camera (Sony Corporation, Japan), light stand, Matrox Meteor RGB capture card, Pentium III 700 PC, and Matrox Inspector Software version 2.1 (Matrox Electronic Systems, Quebec, Canada). In order to increase the accuracy of the material size and shape, significant contrast between the samples and background was required. This was obtained by using a black sheet under the samples as background and the lights, camera height, brightness, zoom and focus were adjusted. Each chickpea seed was individually placed on a black sheet in its natural position with its length parallel to the y-coordinate. Features of each seed in the image including area, feret x, feret y (the dimensions of the minimum bounding box of seeds in the horizontal and vertical direction, respectively) were saved in MS Excel Workbook format for further analysis. Ferets y and x of each seed in images were reported as major and intermediate dimensions (mm) of chickpea seeds, respectively.

Sizes of materials usually have a significant role under approximately the same operating conditions, so the bulk seed sample was classified into three categories, namely small, medium and large based on the major diameter of seeds. Distribution of seeds by number and size for each category was determined and reported.

The geometric mean diameter (D_p) of the seeds was calculated by using the following relationship (Mohsenin 1986):

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

where L is the length, W is the width and T is the thickness (mm).

The sphericity (ϕ) was calculated using the following equation (Mohsenin 1986):

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

Particle Density, Bulk Density and Porosity

To determine the unit mass and volume of chickpea seeds, fifty seeds of each chickpea cultivar were randomly selected from the bulk sample with different initial moisture. The volume of each seed was measured individually by the gas comparison multi pycnometer (Quanta Chrome Corporation, Boynton Beach, FL).

The pycnometer had cell cups of volume 6, 18, and 150 cm^3. Each seed occupied partially the small cell, so a more accurate calibration of the system was needed. Actual and measured volumes of different particle sizes were compared by using known volume steel spheres of known volume. Average diameter of each sphere was measured by a digital caliper (resolution of 0.01 mm), to calculate its actual volume. Combinations of spheres were placed in different cell cups for volume determination by gas pycnometer. This measurement was repeated three times. The data was analyzed to find relationship between actual and measured volume by using different cells for different particle sizes.

The unit mass of each seed was measured individually by using an electronic weighing balance (Ohaus Scale Corp. G 160D, W. Germany) reading to 0.0001 (g).

The particle density is defined as the ratio of the mass of the seeds in air to its volume (Joshi et al. 1993). The average value of the densities was taken from three replications for each moisture contents for each chickpea cultivar.

The bulk density was calculated from the mass of the 0.5 L steel cup that was filled with chickpea seeds (Canadian Grain Commission 1993). The seeds were dropped from a funnel which had an opening of 31.8 mm. The bottom of the funnel was 51.75 mm above the cup. The excess seeds were removed by passing a wooden stick across the top surface using 5 zigzag motions (Madamba et at. 1993).

The porosity (ε) of bulk seeds expressed in percent was calculated from bulk and particle densities by using the relationship as follows (Jha 1999):

$$\varepsilon = \frac{\rho_p - \rho_b}{\rho_p} \tag{3}$$

where (ρ_b) is the bulk density (kg/m^3) and (ρ_p)is the particle density (kg/m^3).

Terminal Velocity

The terminal velocities of chickpea seed samples were measured by using an air column (Song and Litchfield 1991). Five medium seeds of each chickpea variety were randomly selected from dry bulk samples and tested. For each experiment the selected seeds were dropped from the top of a 75-mm diameter, 1m long plexiglass tube (Fig.1). The air was blown upwards in the tube while its velocity was adjusted by using an inverter–type motor speed control until the major fraction of the sample remained suspended in the air stream. Air velocity was measured by using a cross pitot-tube and reported as terminal velocity. Three replications were taken for each sample. This procedure was done at three levels of moisture content of the samples.

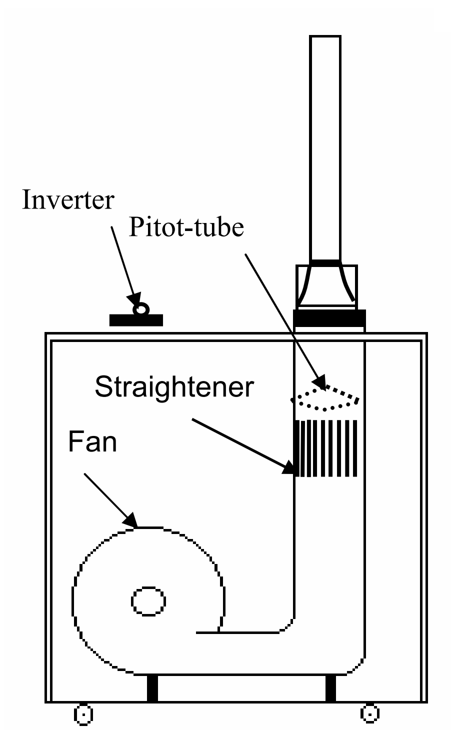

Figure 1. Schematic diagram of air column used for measurement of terminal velocity.

Static Coefficient of Friction

The static coefficient of friction was determined for various chickpea samples against four surfaces namely galvanized steel, glass, smooth and rough concrete (steel trowelled concrete and wood floated concrete). A galvanized box with neither base nor lid and with dimensions 150$\times$100$\times$40 mm was placed on the test surface and filled with the sample while the test surface sit on adjustable tilting plate (Fig.2). The box was raised slightly so as not to touch the surface. The tilting plate was inclined gradually with a cable that was pulled up by a rotating pulley. A DC electric motor was used to rotate the pulley smoothly until the box just started to slide down and the coefficient of static friction (μ) was calculated from the following equation:

$$\mu = \tan^{-1}\left(\frac{H}{L}\right) \tag{4}$$

where H and L are values of rise and length of tilt plate respectively, mm. The experiment was replicated three times at three levels of moisture content.

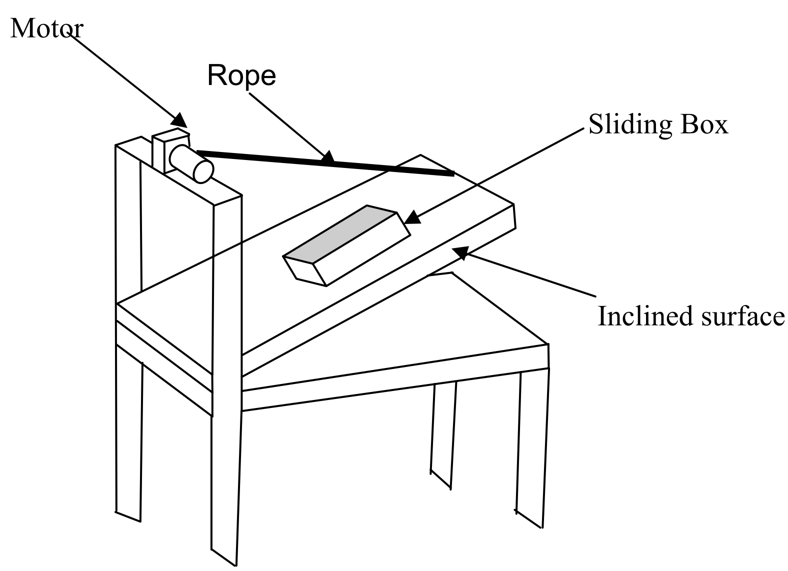

Figure. 2. Schematic diagram of the device used for measuring static coefficient of friction.

Angle of Repose

To determine the emptying or dynamic angle of repose, a plexiglass box measuring 300×300×300 mm, having a removable front panel was used (Joshi et al. 1993). The box was filled using a 50-mm square opening hopper located 120 mm above the center of the top of the box. The seed was leveled and then the front panel was quickly removed and the seeds were allowed to flow. The emptying angle of repose was calculated from the measurement of the maximum depth of the free surface of the sample and length of the box.

Cohesion

The Wykeham Farrace shear box apparatus with a 100-mm square concrete surface was used to determine cohesion of chickpea samples at initial moisture content (Fig.3). The values of cohesion were obtained from the intercept of extrapolated shear stress at zero normal stress (Tabil and Sokhansanj 1997). The test was done in three replicates at five different normal loads of 100, 300, 500, 700 and 900 N.

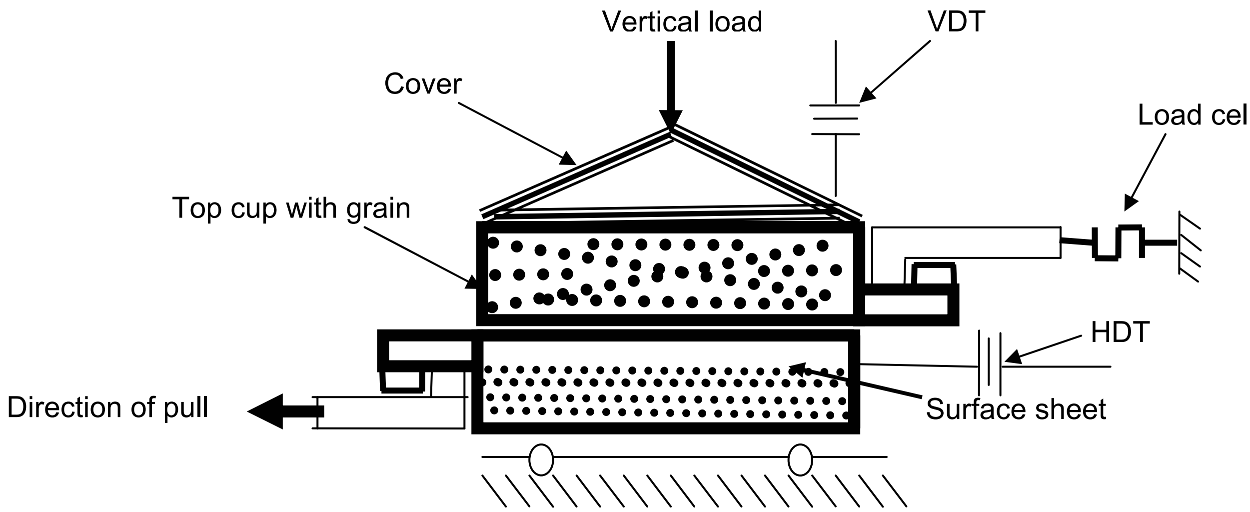

Figure 3. Shear box apparatus used to measure cohesion. (VDT- vertical displacement transducer and HDT– horizontal displacement transducer).

Statistical Analysis

SAS PROC MEANS, FREQ and CORR were used to determine the maximum and minimum values, mean, standard error, and frequency distribution of seed dimensions. The Relationship between the physical properties of seeds and moisture content was established using regression analysis.

Model coefficients were determined using the SAS routines, REG for linear models and NLIN for non-linear models (SAS 2001). The analysis of variance (ANOVA) and comparison of means were performed using PROC GLM. The coefficient of multiple determinations (R^2) 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.

Results and Discussion

Dimensions and Size Distribution

Average values of the initial moisture content of samples were 9.85, 10.25 and 10.27% wet basis for large kabuli and small kabuli and desi chickpeas, respectively, which did not significantly differ ($P<0.05$).

The size distribution of various chickpea samples at initial moisture content are presented in Table 1. The mean values of hundred fifty measurements for the major, intermediate and minor dimensions as well as projected area, unit mass and unit volume of chickpea samples in each category (small, medium and large sizes) are shown in Table1.

Table1. Size and distribution of three types of chickpea at initial moisture content*.

Type	Physical attributes	Size category**			
		Ungraded	Small	Medium	Large
Large kabuli			<10(mm)	10-11(mm)	>11(mm)
	Percent of sample				
	By number	100	24	50	26
	By mass	100	24	44	32
	Average dimensions				
	Major (a), mm	10.42±0.04	9.76 ± 0.03	10.47 ± 0.03	11.28 ± 0.07
	Intermediate (b), mm	8.35±0.03	8.14 ± 0.04	8.38 ± 0.03	8.55 ± 0.09
	Minor (c), mm	8.25±0.03	8.1±0.04	8.27 ± 0.03	8.45 ± 0.08
	Projected area†(A), mm^2	66.09±0.39	60.87 ± 0.47	66.48 ± 0.32	72.84 ± 1.10
	Unit mass (M), g	0.507±0.007	0.451 ± 0.005	0.508 ± 0.003	0.566 ± 0.006
	Unit volume (V), mm^3	392±6.1	356 ± 9.3	401 ± 4.7	426 ± 13.8
Small kabuli			<8(mm)	8-9(mm)	>9(mm)
	Percent of sample				
	By number	100	37.33	38.67	24
	By mass	100	19.07	40.99	39.94
	Average dimensions				
	Major (a), mm	8.53±0.05	7.69 ± 0.04	8.51 ± 0.03	9.35 ± 0.04
	Intermediate (b), mm	7.06±0.03	6.73 ± 0.07	7.12 ± 0.04	7.26 ± 0.06
	Minor (c), mm	6.81±0.03	6.49 ± 0.06	6.84 ± 0.04	7.06 ± 0.06
	Projected area†(A), mm^2	46.21±0.48	39.32 ± .0.57	46.38 ± 0.43	52.24 ± 0.58
	Unit mass (M), g	0.215±0.004	0.160 ± 0.01	0.210± 0.002	0.243 ± 0.004
	Unit volume (V), mm^3	170±5.4	147±8.4	165±8.1	195±7.5
Desi			<7.5(mm)	7.5-8.5(mm)	>8.5(mm)
	Percent of sample				
	By number	100	16.67	56.66	26.67
	By mass	100	28	44	28
	Average dimensions				
	Major (a), mm	8.08±0.05	7.25 ± 0.04	8.00 ± 0.03	8.79 ± 0.03
	Intermediate (b), mm	6.46±0.04	6.38 ± 0.48	6.42 ± 0.05	6.61 ± 0.06
	Minor (c), mm	5.89± 0.11	5.74 ± 0.08	5.95 ± 0.17	5.88 ± 0.36
	Projected area†(A), mm^2	38.28 ± 0.33	34.66 ± 0.56	37.41 ± 0.33	42.39 ± 0.47
	Unit mass (M), g	0.279±0.006	0.224 ± 0.006	0.276± 0.003	0.324±0.006
	Unit volume (V), mm^3	206±4.5	170±4.8	207±0.003	242± 4.7

N=150, *Initial moisture contents were 9.85, 10.25 and 10.27% w.b. for large kabuli, small kabuli and desi chickpeas, respectively, **Based on major dimension, † major projected area.

Dimensions and major projected area of the large kabuli were the highest and small kabuli (chico) had the least mean values for both mass and volume.

The geometric mean diameter and sphericity of chickpea samples were calculated. Table 2 shows range and mean values for sphericity and geometric mean diameter of variation type of chickpea samples. Konak et al. (2002) reported the mean values for three dimensions, unit mass, unit volume and geometric mean diameter of chickpea seeds (cv. ‘Kocbasi’) which were lower than the results of corresponding values in this study for large kabuli and were higher than those for small kabuli (chico) and desi.

The value of sphericity of small kabuli was 87% which is quite close to the value reported by Konak et al.(2002).

Table 2. Geometric mean diameter and sphericity of chickpea samples at initial moisture content*.

	Geometric mean diameter (mm)		Sphericity	
Type	Range	Mean	Range	Mean
Large kabuli	8.39 - 9.72	8.95 (0.3)	0.77 - 0.93	0.86 (0.03)
Small kabuli	6.20 - 8.28	7.43 (0.4)	0.78 - 0.95	0.87 (0.03)
Desi	5.87- 10.3	6.73 (0.4)	0.73 - 1.24	0.83 (0.06)

N=150, The standard deviation is given in parentheses. *Initial moisture contents were 9.85, 10.25 and 10.27% w.b. for large kabuli, small kabuli and desi chickpeas, respectively.

Particle Density

The particle density of various chickpea samples at different moisture levels varied from 1437.68 to 1379.65 kg/m^3 which were close to the values that Konak et al.(2002) had reported (Table 3). Relationships between moisture content and particle density for various types of chickpea samples were significant (P<0.01) and were expressed by second order polynomial models (Table 4). Konak et al.(2002) showed the effect of moisture content on particle density of chickpea by polylinear model.

Bulk Density

The bulk density of various types of chickpea samples at different moisture levels varied from 829.6 kg/m^3 for small kabuli to 726.17 kg/m^3 for desi (Table 3) and decreased with increasing moisture content. Table 4 shows the effect of moisture content on bulk density for various types of chickpea samples. Konak et al. (2002) obtained values of bulk density for chickpea (cv. ‘Kocbasi’) from 800 to 741.4 kg/m^3 at different moisture levels which are close to the results of this study.

Porosity

The porosity of various types of chickpea samples linearly increased with moisture content (Table 4).

The values of porosity for chickpea samples at different moisture contents were from 47.74% for desi to 41.16% for small kabuli (Table 3). Konak et al.(2002) reported logarithmic model to express the effect of moisture content on the porosity of chickpea (cv. ‘Kocbasi’).

Table 3. Values of moisture dependent physical properties of chickpeas.

Type	Moisture content (%w.b.)	Particle density (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)	Coefficient of friction				Angle of repose		Projected area(mm^2)	Terminal velocity (m/s)
					Galvanized steel	Plexiglass	Smooth Concrete	Rough concrete	Emptying	Filling		
Large kabuli	7.5	1427.16	806.31	43.50	0.42	0.27	0.43	0.44	24.40	28.33	62.41	13.05
		(4.31)	(3.99)	(0.45)	(0.05)	(0.01)	(0.01)	(0.03)	(0.18)	(0.58)	(0.18)	(0.09)
	8.91	1437.68	808.11	43.79	0.27	0.31	0.48	0.39	27.11	31.66	64.32	13.30
		(9.48)	(1.92)	(0.35)	(0.01)	(0.01)	(0.03)	(0.13)	(0.17)	(0.58)	(0.37)	(0.08)
	13.42	1412.38	778.54	44.87	0.43	0.40	0.53	0.51	33.05	32.33	66.90	13.89
		(5.00)	(2.37)	(0.03)	(0.01)	(0.03)	(0.01)	(0.08)	(0.20)	(0.58)	(0.35)	(0.04)
Small kabuli (chico)	7.82	1410.08	829.60	41.16	0.36	0.32	0.42	0.41	24.15	24.00	41.75	12.99
		(2.00)	(2.63)	(0.20)	(0.09)	(0.01)	(0.01)	(0.08)	(0.26)	(1.00)	(±1.08)	(0.02)
	9.32	1422.75	823.31	42.13	0.32	0.35	0.45	0.40	26.32	29.67	44.97	13.17
		(6.60)	(2.37)	(0.11)	(0.09)	(0.07)	(0.03)	(0.11)	(0.43)	(0.58)	(0.37)	(0.04)
	13.67	1408.85	792.96	43.71	0.38	0.39	0.46	0.44	28.98	32.67	50.86	13.57
		(3.05)	(1.36)	(0.21)	(0.04)	(0.06)	(0.04)	(0.07)	(0.41)	(0.58)	(0.90)	(0.04)
Desi												
	7.59	1379.65	782.95	43.25	0.35	0.32	0.52	0.46	29.21	31.67	35.40	11.08
		(3.12)	(5.53)	(0.53)	(0.01)	(0.01)	(0.01)	(0.10)	(0.41)	(0.57)	(0.53)	(0.06)
	9.21	1394.89	780.74	44.03	0.19	0.34	0.55	0.39	31.72	35.33	37.37	11.33
		(3.31)	(3.38)	(0.33)	(0.02)	(0.02)	(0.00)	(0.22)	(0.39)	(0.58)	(0.62)	(0.18)
	14.82	1389.59	726.17	47.74	0.39	0.38	0.58	0.51	34.53	40.00	42.11	11.91
		(5.60)	(1.30)	(0.27)	(0.04)	(0.01)	(0.02)	(0.13)	(0.36)	(1.00)	(0.11)	(0.05)

Each value is a mean of three measurements. The standard deviation is given in parentheses.

Static Coefficient of Friction

The values of static coefficient of friction against various surfaces (galvanized steel, plexiglass, smoth and rough concrete) at different moisture levels for various types of chickpea samples are shown in Table 3. As the moisture content of the seeds increased, the static coefficients of friction increased significantly. Comparison of means indicated high significant difference ($P<0.0001$) between the mean values of coefficient of friction among various surfaces. The effect of moisture content on coefficient of friction for various types of chickpea samples against different surfaces are shown in Table 4. The same range values for the static coefficient of friction between chickpea and galvanized steel were reported by Konak et al. (2002).

Angle of Repose

The values of emptying and filling angles of repose for various types of chickpea samples at different moisture levels are shown in Table 3.

Both emptying and filling angles of repose increased in increase moisture content. The effect of moisture content on angles of repose of chickpea samples was expressed by polynomial and linear equations for filling and emptying angle of repose, respectively (Table 4). Comparison of mean difference revealed that desi chickpea had the highest angle of repose. This is due to the least sphericity of desi seeds which do not allow sliding easily on each other. Desi chickpea also has more rough and wrinkled surface than the kabuli types. Konak et al. (2002) reported 24.5 to 27.9^{o} for angle of repose of chickpea.

Table 4. Relationship between physical properties (Y) and moisture content (X) of chickpea samples.

	Large kabuli	Small kabuli	Desi
Particle density (kg/m^3)	Y=-0.22**X**^{2}+44.1**X**+1221.7 **(R^2=0.7839)**	Y=-0.99**X**^{2}+42.6**X**+1191.1 **(R^2=0.7573)**	Y=-1.43**X**^{2}+33.54**X**+1207.7 **(R^2=0.7756)**
Bulk density (kg/m^3)	Y=-1.33**X**^{2}+23.1**X**+707.71 **(R^2=0.9703)**	Y=-6.42**X**+881.24 **(R^2=0.98)**	Y=-1.16**X**^{2}+18.11**X**+712.25 **(R^2=0.9861)**
Porosity (%)	Y=0.23**X**+41.72 **(R^2=0.8285)**	Y=0.42**X**+38.03 **(R^2=0.9626)**	Y=0.63**X**+38.34 **(R^2=0.9712)**
Coefficient of friction(%)			
Galvanized steel	Y=0.02**X**^{2}+0.49**X**+2.79 **(R^2=0.8937)**	Y=0.02**X**^{2}+0.43**X**+2.55 **(R^2=0.8122)**	Y=0.02**X**^{2}+0.41**X**+2.41 **(R^2=0.9359)**
Plexiglass	Y=0.02**X**+0.11 **(R^2=0.9533)**	Y=0.02**X**+0.16 **(R^2=0.8324)**	Y=0.01**X**+0.25 **(R^2=0.8987)**
Smooth concrete	Y=0.02**X**+0.32 **(R^2=0.8301)**	Y=0.01**X**+0.33 **(R^2=0.976)**	Y=0.01**X**+0.46 **(R^2=0.8318)**
Rough concrete	Y=0.0202**X**+0.3087 **(R^2=0.951)**	Y=0.0092**X**+0.38 **(R^2=0.8129)**	Y=0.01**X**+0.46 **(R^2=0.8794)**
Angle of repose			
Emptying	Y=1.43**X**+13.99 **(R^2=0.9916)**	Y=0.7769**X**+18.504 **(R^2=0.9318)**	Y=0.67**X**+24.70 **(R^2=0.9062)**
Filling	Y=-0.24**X**^{2}+5.63**X** **(R^2=0.8843)**	Y=-0.53**X**^{2}+12.83**X**-44.03 **(R^2=0.9721)**	Y=-0.20**X**^{2}+5.71**X** **(R^2=0.9691)**
Projected area† (mm^3)	Y=0.66**X**+58.01 **(R^2=0.959)**	Y=1.41**X**+31.60 **(R^2=0.9669)**	Y=0.95**X**+28.70 **(R^2=0.9807)**
Terminal velocity (m/s)	Y=0.13**X**+12.15 **(R^2=0.9712)**	Y=0.09**X**+12.33 **(R^2=0.9864)**	Y=0.12**X**+10.26 **(R^2=0.9342)**

† major projected area

Projected Area of Seed

The projected area of various chickpea samples at different moisture levels varied from 66.9 mm^2 for large kabuli to 35.4 mm^2 for desi (Table 3). The linear relationships of projected area with moisture content for all chickpea samples were highly significant ($P<0.001$) (Table 4). Konak et al. (2002) also observed the linear increased in projected area with increase in moisture content of the seeds.

Terminal Velocity

Table 3 shows the values of terminal velocity at different moisture levels for various chickpea samples which were randomly selected from the medium size of bulk samples.

The relationship between terminal velocity and moisture content for various chickpea samples were expressed by linear equations (Table 4). A similar model with different coefficients was reported by Konak et al. (2002) for chickpea (cv. 'Kocbasi').

Cohesion

As Fig.4 shows, the values of cohesion at initial moisture content of the sample were obtained from the intercept of the extrapolated shear stress at zero normal stress in shear box test. The values of cohesion for large kabuli, small kabuli (chico) and desi chickpeas were 1.55, 1.17 and 2.85 (KPa) respectively. Comparison of means indicated a high significant difference ($P<0.01$) between the mean values of cohesion of large kabuli and desi. No significant difference ($P<0.05$) was observed between the mean values of cohesion of small kabuli and large kabuli as well as that of small kabuli and desi.

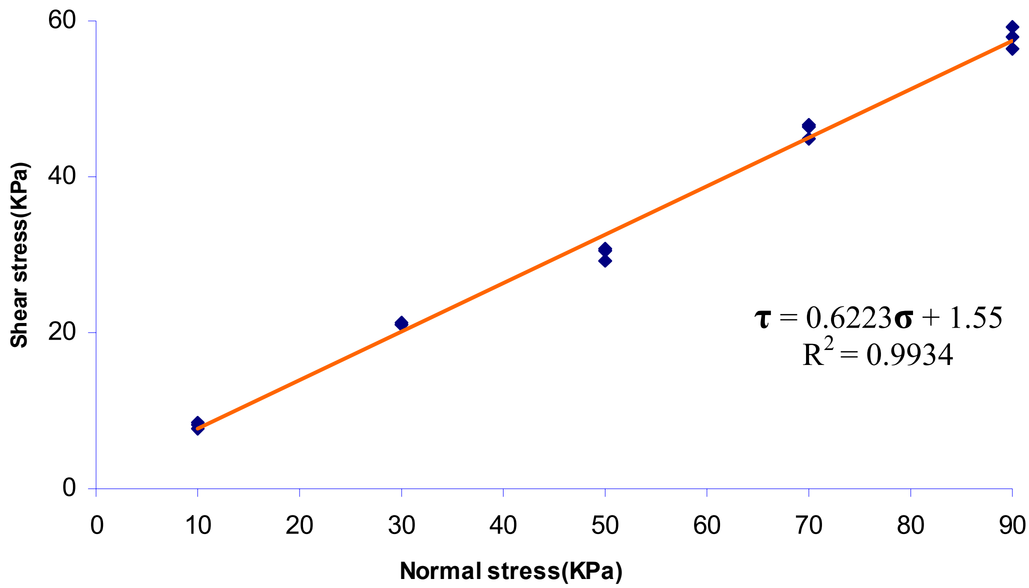

Figure 4. Relationship between shear stress and normal stress for large kabuli chickpea.

CONCLUSIONS

1. The moisture content of large kabuli, small kabuli (chico) and desi chickpeas affected the different physical properties measured. All physical properties except bulk density of various types of chickpea samples increased with increase moisture content. Also the particle densities of large kabuli and small kabuli decreasd with increase moisture content in this study.
2. The various types of chickpeas (large kabuli, small kabuli and desi) had different effect on physical properties.
3. The mean values of coefficient of static friction of chickpea samples at various surfaces had high significant difference ($P< 0.01$).
4. The relationships between physical properties of various chickpeas and moisture content were established by linear and second degree polynomial models.

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