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Effect of Moisture Content on Physical Properties of Barley Seeds

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ABSTRACT

In this article, the size, dimensions, volume, bulk and particle densities, empyting and filling angles of repose and friction coefficients against different surfaces were evaluated for two varieties of barley, Sahra and Valfajr, as a function of moisture content in the range of 10.12 to 42.17 (w.b.%). Most physical properties of barley varieties were significantly affected by moisture content variation. The length, width, thickness and unit mass of Sahra variety increased from 9.88 to 10.16 mm, 3.37 to 3.89 mm, 2.54 to 2.80 mm and 0.048 to 0.074 g, respectively, as the moisture content increased. The respective values for Valfajr varied from 8.37 to 8.87 mm, 3.03 to 3.21 mm, 2.21 to 2.37 mm and 0.037 to 0.043 g, respectively. In Sahra variety, sphericity, geometric mean diameter, bulk density, particle density and porosity increased from 44.59 to 47.40%; 4.38 to 4.79 mm; 568.10 to 613.68 kg m^{-3}; 1,099.65 to 1,245.72 kg m^{-3} and 48.34 to 50.74%, respectively. The coefficient of static friction increased linearly against all the tested surfaces as the moisture content increased. In Valfajr variety, sphericity increased from 45.79 to 45.89%; geometric mean diameter increased from 3.82 to 4.06 mm; bulk density increased from 579.68 to 608.58 kg m^{-3}; particle density varied from 1,410.82 to 1,230.61 kg m^{-3}; porosity varied from 58.91 to 50.55% and the coefficient of static friction increased linearly against all the tested surfaces as the moisture content increased. The angle of repose for emptying and filling increased linearly as well.

Keywords: Angle of repose, Barley, Density, Physical property, Porosity, Static coefficient of friction.

INTRODUCTION

Barley is the world's fourth most important cereal crop, after wheat, maize (corn), and rice (Dendy and Dobraszczyk, 2001). Barley probably came into cultivation about 10,000 years ago. Based on Food and Agriculture Organization (FAO) report, the world barley production in 2009 was 150.8 million tones. The average production of barley in Iran was 2.0 million tones in 2009.

Barley, which is of the genus *Hordeum*, is a cereal that belongs to the grass family *Poaceae*. It is a plant whose seed is processed to make malt, breakfast foods and animal feed. Barley is the most prominent crop in feeding livestock as well as it is a main ingredient in beer or other malted beverages. Although relatively small amounts of other cereals are malted, barley is the preferred species because of its particular chemical composition and the details of the changes that occur during germination. Because the husk protects the grain and the growing coleoptile during handling and malting, the compositions of barleys are very variable, even between batches of one cultivar. Barley is high in carbohydrates, with moderate amounts of protein, calcium and phosphorus. It also has small amounts of the B vitamins. High

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protein barley is best suited for animal feed or malt that will be used to make beer with a large adjunct content. Scientific evidence indicates that including barley in a healthy diet can help reduce the risk of coronary heart diseases by lowering LDL and total cholesterol levels (Briggs, 1997; Hoseney, 1994; MacGregor and Bhatty, 1993).

The design of storage, handling and processing systems for bulk materials such as barley requires data on bulk and handling properties namely, size dimensions, sphericity, bulk and particle densities, and friction coefficients of bulk materials on most commonly used structural surface materials. Theories used to predict the pressures and loads on storage structures require bulk density, angle of repose and friction coefficients against bin wall materials. Also the design of hoppers for processing machinery requires data on bulk density and angle of repose. Bulk density is used in design of drying and aeration systems because it affects the resistance to airflow of a stored bulk. Therefore the determination and consideration of these properties has an important role in the barley industry. Bulk and handling properties have been studied for various crops such as pigeon pea (Baryeh and Mangope, 2002), rapeseed (Çalışır *et al*., 2005), lentil (Scanlon, 2005), caper seed (Dursun and Dursun, 2005), fenugreek seed (Altuntas *et al*., 2005). green soybean (Sirisomboon *et al*., 2007), rice (Corrêa *et al*., 2007), pomegranate seeds (Kingsly *et al*., 2006), sorghum (Mwithiga and Sifuna, 2006) and barley grains (Tavakoli *et al*., 2009).

The objective of this study was to determine some physical properties of two varieties of barley, Sahra and Valfajr, as a function of moisture content in the range of 10.12 to 42.17% (w.b.). In this research, for two varieties of barley at 5 levels moisture content, dimensions, geometric mean diameter, sphericity, unit mass, kernel volume, particle density, bulk density, porosity, static coefficient of friction against various surfaces and filling and emptying angles of repose were investigated.

MATERIALS AND METHODS

Sample Preparation

In this study, two most important varieties of barley, Sahra and Valfajr, were used. Sahara variety was obtained from Seed and Plant Breeding Institute of Jahad-Agricultural Organization, Gonbad and Valfajr was obtained from a farm in Mashhad, Iran. The samples were manually cleaned to remove foreign matter, dust, dirt, broken and immature grains.

The initial moisture content of the samples was determined by oven drying at 103 ±2ºC for 5 hours (AOAC, 2005). The samples at desired moisture levels were prepared by adding calculated amounts of distilled water, thorough mixing and then sealing in separate polyethylene buckets. The quantity of distilled water was calculated from the following equation:

$$W_2 = W_1 \times \left[\frac{M_1 - M_2}{100 - M_1} \right] \quad (1)$$

The samples were kept in a refrigerator at 5ºC for 7 days to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantities of sample were allowed to warm up to room temperature (Tabatabaeefar, 2003). All the physical properties of grains were measured at moisture levels of 10.12, 15.82, 24.13, 33.78 and 42.17 (wet basis: w.b. %) for Sahara and 9.92, 17.44, 20.74, 32.3 and 41.57 (w.b. %) for Valfajr variety with five replications at each level.

Dimensions, Sphericity and Unit Mass

In order to determine dimensions, sphericity and unit mass, one hundred barley kernels were randomly selected and for each, the three principal dimensions, namely minor diameter (thickness), intermediate diameter (width) and major diameter (length), were measured using an electronic digital caliper (GUANGLU) having a least count of 0.01 mm at each moisture level.

To obtain the unit mass, each seed was weighed on a precision electronic balance (Sartorius, TE313S, Canada) reading to 0.001 g. Geometric mean diameter and degree of sphericity of barley were calculated at each moisture level by Equations (2) and (3) (Mohsenin, 1980):

$$D = (LWT)^{1/3} \quad (2)$$

$$\phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad (3)$$

Volume, Bulk Density, Particle Density and Porosity

Bulk density was calculated from the mass and volume of the circular container with known volume that was filled with the barley samples. After filling the circular container, excess seeds were removed by passing a stick across the top surface using five zigzag motions. The samples were not compacted in any way (Kashaninejad *et al*., 2006).

The particle density is defined as the ratio of the mass of the grain to the particle volume occupied by the sample. The particle density, was determined using an electronic balance reading to 0.001 g and a pycnometer (Baümler *et al*., 2006). Barley kernel volume was determined using the liquid displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by seeds to a less extent and because of its low surface tension it can fill even shallow deeps in a seed (Mohsenin, 1980).

The porosity (ε) of the bulk is the ratio of spaces in the bulk to its bulk volume and was determined by the following equation (Mohsenin, 1980):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (4)$$

Coefficient of Static Friction

Coefficient of static friction for barley kernels was determined against surfaces of galvanized iron, plywood, concrete, fiberglass and rubber at different moisture contents. A wooden box of 100 mm length, 100 mm width and 40 mm height without base and lid was filled with the sample and placed on an adjustable tilting plate, faced with the test surface. The sample container was raised slightly (5–10 mm) so as not to touch the surface. The inclination of the test surface was increased gradually with a screw device until the box just started to slide down and the angle of tilt (α) was read from a graduated scale. For each replication, the sample in the container was emptied and refilled with a new sample (Joshi *et al*., 1993). The coefficient of static friction was calculated from the following relationship:

$$\mu = tg\alpha \quad (5)$$

Angle of Repose

In general, the angle of repose is called the angle of repose for emptying (θ_e) in situations where the material is being emptied from a bin (Mohsenin, 1980). In order to obtain this angle, the samples were filled in a 15×15×15 cm hand made wooden box with a sliding side door. The angle of repose was then calculated from a measurement of the depths of the free surfaces (h_1 and h_2) of the seeds at two known horizontal distances (x_1 and x_2) from one end of the box and then the emptying angle of repose, θ_e was obtained using the following equation (Fraser *et al.,* 1978).

$$\theta_e = \tan^{-1}\left(\frac{h_2 - h1}{x_2 - x_1}\right) \quad (6)$$

To obtain the angle of repose for filling (θ_f), samples were poured from 15 cm height on a wooden horizontal surface. The height of kernels pile above the floor (H) and the diameter of the heap (D) were measured and used to determine the angle of response for

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filling with the following relationship (Kaleemullah and Gunasekar, 2002):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right) \quad (7)$$

Data Analysis

All experiments were replicated five times, unless stated otherwise, and the average values are reported. Mean, maximum, minimum and standard deviation of dimensions and unit mass of barley grains were determined using Microsoft Excel (2003) software program. The effect of moisture content on different physical properties of barley kernels was determined using the analysis of variance (ANOVA) method and significant differences of means were compared using the Duncan's test at 1% significance level using SAS software (2001) program. The best relationships between moisture content and physical properties of barley kernels were determined using linear and non linear (NLIN procedure) regression analysis of SAS software (2001) program. The best model was chosen as the one with the highest coefficient of determination and the least residual mean square and the mean relative percent error.

RESULTS AND DISCUSSION

Dimensions and Unit Mass

Table 1 shows the dimensions and unit mass of the two barley varieties at different moisture contents in the range of 10.12 to 42.17 (w.b. %). Significant differences were observed among measured parameters with increase in moisture content. Increase in moisture content caused an increase in barley kernel size. Dimensions (length, width and thickness) of both varieties increased linearly with moisture content. The reason for this increase was probably to the presence some tiny air voids on the kernels. Similar results were found for soybean (Deshpande *et al*., 1993), sorghum (Mwithiga and Sifuna, 2006), barley grains (Tavakoli *et al*., 2009), canola seeds (Razavi *et al*., 2009) and lentil seeds (Carman, 1996). As observed in Table 1, the values for length, width, thickness and unit mass of the Sahra variety are higher than those of Valfajr variety. Frequency distribution of kernel dimensions for Sahra variety at the moisture content of 10.12 (w.b. %) is given in Figure 1. 90% of barley kernels have a length from 8.80 to 11.20 mm, 89% have a width from 3.10 to 3.70 mm and 90% have a thickness ranging from 2.30 to 3.00 mm at a

Table 1. Dimensional properties and unit mass of barley kernel varieties.

Variety	Moisture content (w.b.%)	Length (mm)	Width (mm)	Thickness (mm)	Mass (g)
Sahra	10.12	9.88±0.90 [a]	3.37±0.22 [d]	2.54±0.25 [b]	0.048±0.008 [cd]
	15.85	9.91±0.97 [a]	3.52±0.21 [c]	2.61±0.24 [b]	0.052±0.009 [c]
	24.14	9.95±0.77 [a]	3.58±0.23 [c]	2.62±0.27 [b]	0.065±0.058 [b]
	33.78	10.15±0.77 [a]	3.75±0.25 [b]	2.77±0.26 [a]	0.067±0.011 [ab]
	42.17	10.16±0.94 [a]	3.89±0.28 [a]	2.80±0.27 [a]	0.074±0.013 [a]
Valfajr	9.92	8.37±0.36 [c]	3.03±0.25 [g]	2.21±0.23 [d]	0.037±0.007 [e]
	17.44	8.59±0.62 [cb]	3.11±0.26 [fg]	2.28±0.19 [cd]	0.040±0.029 [de]
	25.90	8.68±0.50 [b]	3.13±0.35 [fe]	2.32±0.20 [cd]	0.041±0.006 [de]
	32.30	8.82±0.58 [b]	3.16±0.20 [fe]	2.37±0.47 [c]	0.042±0.007 [de]
	41.57	8.87±0.54 [b]	3.21±0.23 [e]	2.37±0.25 [c]	0.043±0.033 [cde]

Superscript letters indicate that means with the same letter designation in a column are not significantly different at P= 0.01.

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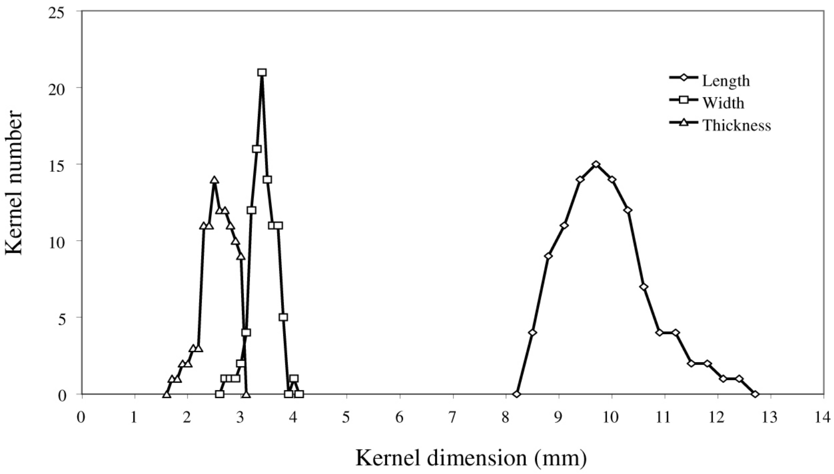

Figure 1. Frequency distribution curves for barley kernel (Sahra variety) dimensions at 10.12% moisture content (w.b. %).

moisture content of 10.12 (w.b. %). The relationship between length, width, thickness, unit mass and moisture content of barley kernels for Sahra variety were given by the following equations:

L= 2.95; W= 3.93, T= 212.07 M (8)

$$L= 0.0098\ M_C + 9.7643,\ (R^2 = 0.917) \quad (9)$$

$$W= 0.0153\ M_C + 3.2393,\ (R^2 = 0.981) \quad (10)$$

$$T= 0.0083\ M_C + 2.4589,\ (R^2 = 0.939) \quad (11)$$

$$M= 0.0008\ M_C + 0.0408,\ (R^2 = 0.950) \quad (12)$$

Figure 2 shows the frequency distribution of kernel dimensions for Valfajr variety at the moisture content of 9.92 (w.b. %). 86% of barley kernels have a length from 7.80 to 8.70 mm, 96% have a width from 2.70 to 3.40 mm and 90% have a thickness from 2.00 to 2.70 mm at a moisture content of 9.92 (w.b. %).

The relationship between length, width, thickness, unit mass and moisture content can be represented by the following regression equations for Valfajr variety:

L= 2.78; W= 3.83, T= 232.726 M (13)

$$L= 0.0155\ M_C + 8.2701,\ (R^2 = 0.937) \quad (14)$$

$$W= 0.0052\ M_C + 2.9952,\ (R^2 = 0.951) \quad (15)$$

$$T= 0.0052\ M_C + 2.1727,\ (R^2 = 0.906) \quad (16)$$

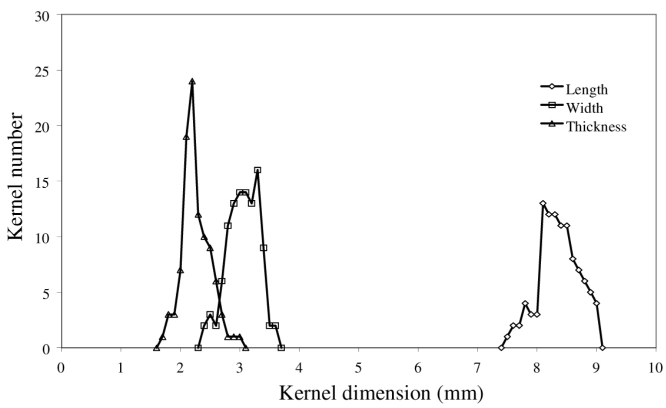

Figure 2. Frequency distribution curves for barley kernel (Valfajr variety) dimensions at 9.92% moisture content (w.b. %).

Table 2. Barley kernel varieties dimensions ratio at initial moisture content (w.b. %).

Variety	Particulars	Mean value	Standard deviation	Minimum value	Maximum value
Sahra (10.12% w.b.)	*L/W*	2.95[b]	0.36	2.42	4.19
	L/T	3.93[b]	0.58	2.97	6.01
	L/M	212.07[a]	47.91	123.48	378.15
Valfajr (9.92% w.b.)	*L/W*	2.78[b]	0.26	2.31	3.68
	L/T	3.83[b]	0.44	2.55	5.04
	L/M	232.73[a]	46.83	157.84	386.82

$$M = 0.0002\, M_C + 0.0357,\ (R^2 = 0.967) \quad (17)$$

Table 2 shows the relationship between barley kernels. The results show that all ratios are significant at 1% level but L/M ratio is more significant than L/W and L/T ratios for barley kernels (seen as higher correlation coefficients). It indicates that the mass shows more association with the length of kernels than width and thickness. Similar relationships were reported for lentil seeds (Carman, 1996), sunflower seeds (Gupta and Das, 1997) and pumpkin seeds (Joshi *et al*., 1993).

Geometric Mean Diameter and Sphericity

The sphericity and geometric mean diameters of both varieties increased with increasing moisture content. Analysis of data shows significant differences among sphericity and geometric mean diameter with increase in moisture content. The sphericity of barley kernels increased from 44.59 to 47.40% and 45.73 to 45.89% for Sahra and Valfajr varieties, respectively, when the moisture content increased. It was observed that sphericity of Sahra variety is more affected by moisture content than Valfajr variety. Geometric mean diameter of barley kernel was higher than those reported for sorghum seed (Mwithiga and Sifuna, 2006), caper seed (Dursun and Dursun, 2005), flaxseed (Coşkuner and Karababa, 2007) and was found to be close to okra seeds (Çalışır *et al*., 2005). However, it was considerably lower than those reported for popcorn kernels (Karababa, 2006). Sphericity of barley kernel was much lower than those reported for flaxseed (Coşkuner and Karababa, 2007), popcorn kernels (Karababa, 2006), caper seed (Dursun and Dursun, 2005), okra seeds (Çalışır *et al*., 2005) and was found to be close to barley grains (Tavakoli *et al*., 2009). The relationship between sphericity and moisture content as well as geometric mean diameter and moisture content was found to be the following for Sahra and Valfajr varieties, respectively:

$$\phi_s = 0.0811\, M_C + 43.951,\ (R^2 = 0.958) \quad (18)$$

$$\phi_v = 0.0054\, M_C + 45.658,\ (R^2 = 0.928) \quad (19)$$

$$D_s = 0.0127\, M_C + 4.262,\ (R^2 = 0.971) \quad (20)$$

$$D_v = 0.0076\, M_C + 3.776,\ (R^2 = 0.941) \quad (21)$$

Bulk Density

The experimental results of the bulk density for barley kernels at different moisture levels are presented in Figure 3. The bulk density of Sahra and Valfajr varieties increased from 568.1 to 613.7 and from 579.7 to 608.6 kg m^{-3}, respectively as the moisture content increased from 10.12 to 42.17%. The increase in bulk density of both barley varieties with increase in moisture content indicates that the increase in mass owing to moisture gain in the sample is more than the accompanying volumetric expansion of the bulk. The same trend has also been reported for pomegranate seeds (Kingsly *et al*., 2006).

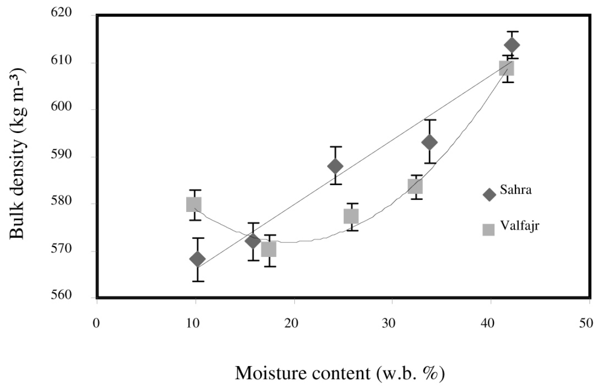

Figure 3. Effect of moisture content on bulk density of barley kernel.

The following equations were obtained to show the relationship between moisture content and bulk density of Sahra and Valfajr varieties, respectively:

$\rho_{bs} = 1.3726\, M_c + 552.37$, ($R^2 = 0.957$) (22)

$\rho_{bv} = 0.076\, M_c^2 - 2.9707\, M_c + 600.89$, ($R^2 = 0.988$) (23)

Particle Density and Kernel Volume

Figure 4 shows kernel volume changes of barley grains at different moisture contents. The kernel volume of both varieties of barley was observed to increase linearly from 0.043 to 0.057 and 0.024 to 0.032 cm^3 for Sahra and Valfajr, respectively when the moisture content increased from 10.12 to 42.17% (w.b.). The kernel volume of Sahra variety was higher than that of Valfajr variety at all moisture contents. The following equations were obtained to show the relationship between moisture content and kernel volume of Sahra and Valfajr varieties, respectively:

$V_s = 0.0004 M_c + 0.0385$, ($R^2 = 0.906$) (24)

$V_v = 0.0002 M_c + 0.0217$, ($R^2 = 0.913$) (25)

The variation of particle density with moisture content for both varieties of barley grains is shown in Figure 5. Particle density of barley at different moisture levels varied from 1,099.7 to 1,245.7 and 1,410.8 to 1,230.6 kg m^{-3} for Sahra and Valfajr, respectively. The relationship existing between moisture content and particle density (ρ_t) appears to be non-linear for Sahra but linear for Valfajr which can be represented by the following equations:

$\rho_{ts} = -0.257 M_c^2 + 17.497 M_c + 955.9$, ($R^2 = 0.948$) (26)

$\rho_{tv} = -5.251 M_c + 1456.1$, ($R^2 = 0.969$) (27)

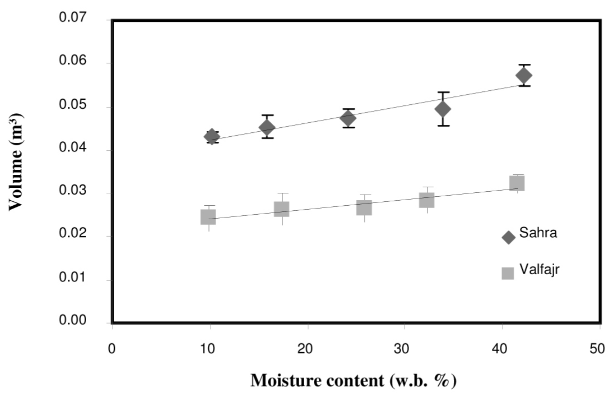

Figure 4. Effect of moisture content on volume of barley kernel.

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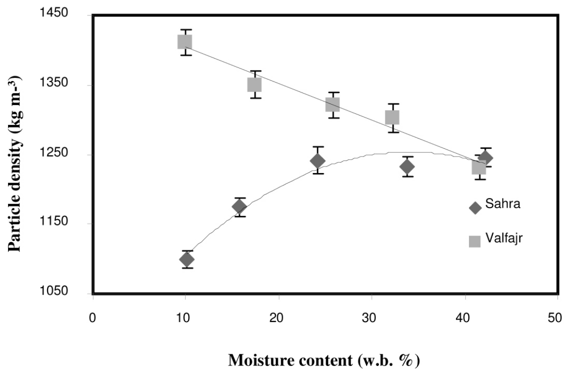

Figure 5. Effect of moisture content on particle density of barley kernel.

An increase in particle density with an increase in moisture content was reported for cumin seeds (Singh and Goswami, 1996), sunflower (Gupta and Das, 1997), pigeon pea (Baryeh and Mangope, 2002). However, Deshpande *et al*. (1993), Ozarslan (2002), Tavakoli *et al*. (2009) and Konak *et al*. (2002) have found that the particle density of soybean, cotton seed, barley grains and chickpea, respectively decreases as the moisture content increases.

Porosity

Since porosity depends on the bulk as well as particle densities, the magnitude of variation in porosity depends on these factors only. The values of porosity were calculated using the data on bulk and particle densities of the barley kernels and the results are presented in Figure 6. For Sahra variety, porosity varied from 48.34 to 50.74% while it varied from 58.91 to 50.55% for Valfajr variety, as the moisture content changed from 10.12 to 42.17 (w.b. %). A similar trend was reported for soybean (Deshpande *et al*., 1993) and pumpkin seed (Joshi *et al*., 1993), but different to that reported for sunflower seed (Gupta and Das, 1997), lentil seed (Carman, 1996), barley grains (Tavakoli *et al*., 2009) and pigeon pea (Baryeh and Mangope, 2002). The relationship existing between moisture content and porosity appears to be non-linear for Sahra variety and linear for Valfajr variety as seen in the following regression equations:

$$\varepsilon_s = -0.0121M_c^2 + 0.6863M_c + 42.971,\ (R^2 = 0.930) \quad (28)$$

$$\varepsilon_v = -0.2496M_c + 62.086,\ (R^2 = 0.914) \quad (29)$$

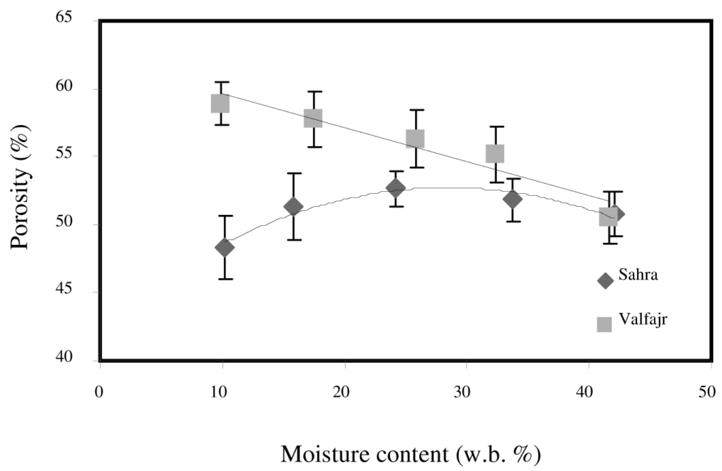

Figure 6. Effect of moisture content on porosity of barley kernels.

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Static Coefficient of Friction

At all moisture contents, the static coefficient of friction was the highest for both varieties on rubber and the least for galvanized iron. It was observed that the static coefficient of friction for barley kernels increased linearly with the increase in moisture content on all surfaces. The relationships between these coefficients against various surfaces and moisture contents of barley kernel varieties are shown in the following regression equations:

Plywood

$\mu_s = 0.0024\, M_c + 0.272$, ($R^2 = 0.926$) (30)

$\mu_v = 0.0021\, M_c + 0.2941$, ($R^2 = 0.939$) (31)

Concrete

$\mu_s = 0.0015\, M_c + 0.3401$, ($R^2 = 0.930$) (32)

$\mu_v = 0.002\, M_c + 0.3344$, ($R^2 = 0.951$) (33)

Fiberglass

$\mu_s = 0.0018\, M_c + 0.2802$, ($R^2 = 0.982$) (34)

$\mu_v = 0.0011 M_c + 0.3025$, ($R^2 = 0.923$) (35)

Galvanized iron

$\mu_s = 0.0027 M_c + 0.2113$, ($R^2 = 0.928$) (36)

$\mu_v = 0.0005\, M_c + 0.2995$, ($R^2 = 0.977$) (37)

Rubber

$\mu_s = 0.0014\, M_c + 0.3452$, ($R^2 = 0.916$) (38)

$\mu_v = 0.0015\, M_c + 0.3675$, ($R^2 = 0.926$) (39)

It was observed that the moisture content had a more significant effect than the surface material on the static coefficient of friction. This is owing to the increased adhesion between the kernel and surface material at higher moisture values.

The reason for the increased friction coefficient at higher moisture content may be the water present in the kernels offering a cohesive force on the surface of contact. As the moisture content of kernels increases, the surface of the samples becomes more sticky. Water tends to adhere to surfaces and the water on the moist seed surface would be attracted to the surface across which the sample is being moved. Other researchers found that as the moisture content increased, the static coefficient of friction also increased (Joshi *et al*., 1993; Carman, 1996; Gupta and Das, 1997; Ogut, 1998, Razavi *et al*., 2009).

Angle of Repose

The experimental results for the angle of repose for barley kernels at various moisture levels are shown in Figure 7. It was observed that the angles of repose for filling and emptying increased linearly with increase in moisture content for both varieties of barley grain.

Angle of repose for filling increased from 23.07 to 30.02° and 25.50 to 33.26° for Sahra and Valfajr varieties and angle of repose for emptying increased from 30.06 to 40.08° and 34.60 to 42.51° for Sahra and Valfajr varieties, respectively in the moisture range of 10.12-42.17 (w.b.%). The angle of repose for barley kernel was close to values reported for flaxseed (Coşkuner and Karababa, 2007), popcorn kernels (Karababa, 2006), caper seed (Dursun and Dursun, 2005) and moth gram (Nimkar *et al*., 2005) but higher than faba bean grains (Altuntaş and Yıldız, 2007), and sorghum

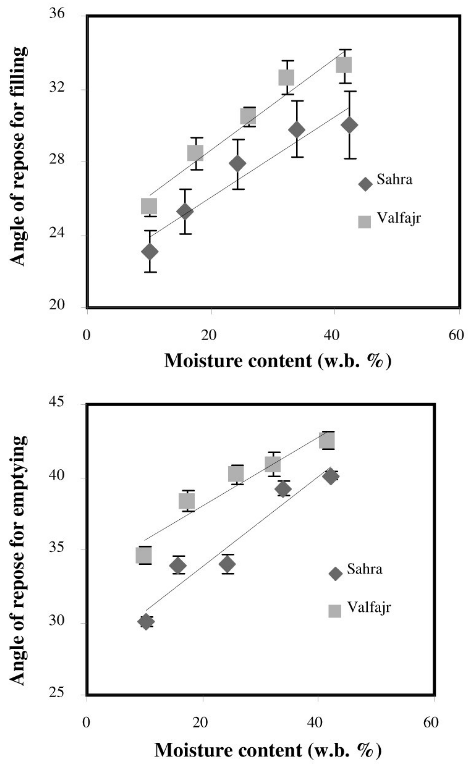

Figure 7. Effect of moisture content on angle of repose of barley kernels.

seeds (Mwithiga and Sifuna, 2006). The relationship existing between moisture content and angle of repose appears to be linear and can be formulated as following:

Variety Sahra

$\theta_f = 0.221\, M_c + 21.629, (R^2 = 0.922)$ (40)

$\theta_e = 0.3063\, M_c + 27.75, (R^2 = 0.924)$ (41)

Variety Valfajr

$\theta_f = 0.2496\, M_c + 23.707, (R^2 = 0.948)$ (42)

$\theta_e = 0.2346\, M_c + 33.328, (R^2 = 0.923)$ (43)

CONCLUSIONS

Several physical properties of two varieties of barley kernels were investigated in moisture contents ranging from 10.12 to 42.17 (w.b.%). The results indicated that the modifications of moisture content of barley kernels caused a variation with linear regression in its dimensions, volume, unit mass, sphericity, static coefficient of friction, angle of repose for filling and emptying for both varieties. Particle density and porosity for Sahra variety decreased with a non-linear regression but for Valfajr variety with a linear regression. The bulk density of Sahra and Valfajr increased with a linear and non linear regresion, respectively.

This study reveals that there is a clear difference in the physical properties of Sahra and Valfajr varieties of barley grain. These properties are very useful in the design of equipment used for processing, transportation and storing. Taking the advantage of the difference in the properties of the grain will assist in the design of versatile machines to handle the processing of the two varieties.

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Nomenclature

D	Geometric mean diameter, (mm)
H	Height of seed, (mm)
L	Length of seed, (mm)
M	Mass of seed, (g)
M_1	Final moisture content, (w.b.%)
M_2	Initial moisture content, (w.b.%)
M_C	Moisture content, (w.b.%)
R^2	Coefficient of determination
T	Thickness of seed, (mm)
V	Volume of seed, (cm^3)
W	Width of seed, (mm)
W_1	Sample weight, (g)
W_2	Distilled water weight, (g)

Greek symbols

ε	Porosity, (%)
μ	Coefficient of static friction
ρ_b	Bulk density, (kg m^{-3})
ρ_t	Particle density, (kg m^{-3})
ϕ	Sphericity, (%)
θ_e	Angle of repose for emptying
θ_f	Angle of repose for filling

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تاثیر رطوبت بر خواص فیزیکی دانه جو

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چکیده

در این مقاله، اندازه، ابعاد، حجم، دانسیته حجمی و دانه‌ای، زاویه ریپوز تخلیه و پرکردن و ضریب اصطکاک ایستایی روی سطوح مختلف برای دو رقم جو صحرا و والفجر در محدوده رطوبتی ۴۲/۱۷- ۱۰/۱۲ (درصد در مبنای مرطوب) مورد بررسی قرار گرفت. اکثر خواص فیزیکی ارقام جو به‌صورت معنی‌داری تحت تاثیر رطوبت تغییر کردند. طول، عرض، ضخامت و جرم واحد رقم صحرا با افزایش رطوبت به ترتیب از ۹/۸۸ به ۱۰/۱۶ میلی‌متر، ۳/۳۷ به ۳/۸۹ میلی‌متر، ۲/۵۴ به ۲/۸۰ میلی‌متر و ۰/۰۴۸ به ۰/۰۷۴ گرم افزایش یافت. تغییرات این کمیت‌ها در رقم والفجر به ترتیب از ۸/۳۷ تا ۸/۸۷ میلی‌متر، ۳/۰۳ تا ۳/۲۱ میلی‌متر، ۲/۲۱ تا ۲/۳۷ میلی‌متر و ۰/۰۳۷ تا ۰/۰۴۳ گرم بود. در رقم صحرا، کرویت، قطر میانگین هندسی، دانسیته حجمی، دانسیته دانه‌ای و تخلخل به ترتیب از ۴۴/۵۹ به ۴۷/۴۰ درصد، ۴/۳۸ به ۴/۷۹ میلی‌متر، ۵۶۸/۱۰ به ۶۱۳/۶۸ کیلوگرم بر مترمکعب، ۱۰۹۹/۶۵ به ۱۲۴۵/۷۲ کیلوگرم بر مترمکعب و ۴۸/۳۴ به ۵۰/۷۴ درصد افزایش یافتند. ضریب استاتیک ایستایی بر تمامی سطوح مورد آزمایش با افزایش رطوبت، افزایش یافت. در رقم والفجر، کرویت از ۴۵/۷۹ به ۴۵/۸۹ درصد، قطر میانگین هندسی از ۳/۸۲ به ۴/۰۶ میلی‌متر و دانسیته حجمی از ۵۷۹/۶۸ به ۶۰۸/۵۸ کیلوگرم بر مترمکعب، افزایش یافت. دانسیته دانه‌ای از ۱۴۱۰/۸۲ تا ۱۲۳۰/۶۱ کیلوگرم بر مترمکعب تغییر کرد، تخلخل از ۵۸/۹۱ تا ۵۰/۵۵ درصد تغییر کرد و ضریب اصطکاک ایستایی بر تمامی سطوح مورد آزمایش با افزایش رطوبت به صورت خطی افزایش یافت. زاویه ریپوز تخلیه و پرکردن نیز به صورت خطی افزایش یافت.

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