PHYSICAL AND MECHANICAL PROPERTIES OF BARLEY

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Abstract

The physical and mechanical properties such as bulk density, true density, angle of internal friction, porosity, static coefficient of friction are necessary for the design of transport, process and storage structures of the barley. The physical and mechanical properties were evaluated as a function of moisture content of grain varying from 10% to 14% (db). In this moisture range, as the bulk density decreased linearly from 647.34 to 623.00 kg/m^3, true density increased linearly from 984.00 to 1 013.67 kg/m^3. The porosity and angle of internal friction increased with the increase in the grain moisture content up to 38.50% and 22.50%, respectively, at 14% moisture content. The static coefficient of friction increased from 0.877 to 0.993, 0.773 to 0.920, 0.560 to 0.713 for concrete (BS 30), galvanized steel and wood surfaces respectively.

Key words: barley, physical properties, angle of internal friction, coefficient of friction

Nomenclature			
Q	amount of addition water (g)	v_w	volume of sample (m^3)
w_i	dry sample weight (g)	σ	normal stress (kpa)
m_i	initiative moisture content of sample (d.b. %)	N	load applied over sample (kg.f)
m_f	final moisture content of sample (d.b. %)	A	cellular area (cm^2)
ρ_b	bulk density (kg/m^3)	τ	stretch of cutting (kpa)
g_1	free weight of bulk density bucket (kg)	T	strength of cutting (kg.f)
g_2	weight of bulk density bucket with free barley grains (kg)	c	coefficient of cohesion
v	inner volume of bulk density bucket (m^3)	φ	angle of internal friction (degree)
ρ_t	true density (kg/m^3)	μ_S	static coefficient of friction
m_s	weight of liquid (kg)	f_s	strength of friction (N)
m_w	weight of air dry sample (kg)	w_n	normal strength (N)
v_s	volume of liquid (m^3)	ε	porosity (%)
m_c	moisture content (d.b. %)		

INTRODUCTION

Barley is among the major commodities for feeding mankind.The nutritive value of barley is of importance to humans and animals alike. Especially, barley is to be the main raw material the industries of malt and beer after from the industry revolution. Barley is 4th the most producing cereal after from wheat, rice and corn in the world (Kurt, 2002). The countries of the biggest producer and exporter are Russian, Canada, Ukraine and Australia. Also Turkey is one of the biggest producers of barley. The production in 2007 was 8.0 million tonnes in Turkey (Anonymous, 2008).

The physical and mechanical properties of barley depend on grain moisture content are important to design the storage structures and the selection of storage equipments. Designing such storage structures and selection of storage equipments without taking these into consideration may yield poor results. Therefore, the determination and consideration of properties such as bulk density, true density, angle of internal friction, static coefficient of friction of grain has an important role (Mohsenin, 1980; Molenda et al., 2002; Kashaninejad et al., 2006).

Because the granular products are biological originated, the effect of moisture content of grain is important on physical and mechanical properties of grain (Horabic and Molenda, 1988). The properties of different types of grains and seeds have been determined by other researchers; canola and wheat (Bargale et al., 1995); lentil (Çarman, 1996); sunflower (Gupta and Das, 1997); black pepper (Murthy and Bhattacharya, 1998); pigeon pea (Baryeh and Mangobe, 2002); cotton (Özarslan, 2002); millet (Baryeh, 2002); popcorn (Karababa, 2006); caper seeds (Dursun, Dursun, 2005); pistachio nut (Kashaninejad et al., 2006).

The objective of this study was to investigate the effect of moisture content on some physical and mechanical properties of barley typically cultivated in Turkey. The parameters measured at different moisture content (10–14% d.b) were bulk density, true density, angle of internal friction, static coefficient of friction of grain.

MATERİAL AND METHODS

Barley variety (Fahrettinbey) was obtained from Black Sea Agricultural Research Institute in Samsun. Broken, split, spoiled and deformed grains were discarded before the samples were prepared for the experiment. The equilibrium moisture content of the samples was determined, drying them at 80 ± 5^0C in drying-oven during 10 h. The postharvest equilibrium moisture content of barley was found to be 10% (d.b). The equilibrium moisture content under laboratory conditions was taken as the reference for the desired moisture contents in experimental samples. While drying was done to achieve conditions below the level of equilibrium moisture, the equation (1) developed by Balasubramanian (2001) was used for the conditions over the level of equilibrium moisture and then this amount was added to the moisture.

$$Q = \frac{w_i\left(m_f - m_i\right)}{100 - m_f} \qquad (1)$$

After desired amount of distillate water in samples was calculated and applied, the samples were filled into polyethylene bags individually and closed. The samples were kept in a curing room for 3 days to enable the moisture to distribute uniformly throughout the grains. After the grains reached equilibrium moisture, it were placed in a dessicator. Before each test, the required quantity of samples was taken out of dessicator and allowed to warm up to room temperature. All the physical and mechanical properties were determined at the moisture contents 10%, 12%, 14% (d.b).

To determine the bulk density of the experimental samples at different moisture levels, the method defined by Mohsenin (1980) and Singh and Goswami (1996) was used. Weight of a bulk density container of 1 000 ml volume and 108 mm height was used to determine bulk density. The bulk density container was filled up to 5 cm above the top. The barley samples were then allowed to settle into the container and the bulk density was calculated from the following equation:

$$\rho_b = \frac{g_{2-} g_1}{\nu} \qquad (2)$$

The liquid displacement method described by Aydın (2002) and Abalone et al. (2004) was used to determine the true density of barley samples. In this method, toluene (C_7H_8) was used in place of water because it is absorbed to a lesser extent by samples and its surface tension is low. To calculate true density, the air dried weight for samples was first determined. The samples were then submerged in toluene and the displacement volume was determined. In the second stage, the true density of samples was calculated by using equation 3 as follows:

$$\rho_t = \frac{m_s + m_w}{v_s + v_w} \qquad (3)$$

The porosity was computed from the values of bulk and true density using the relationship given by Mohsenin (1980) as follow:

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

To determine the angle of internal friction of grains at the different moisture content the direct shear method was used according to Zou and Brusewitz (2001), Molenda et al. (2002) and Mani et al. (2004). The velocity used during the experiment was 0.7 mm/min and the angle of internal friction of samples was calculated by using equations 5, 6 and 7 as follows;

$$\sigma = \frac{N}{A} \times 100 \qquad (5)$$

$$\tau = \frac{T}{A} \times 100 \qquad (6)$$

$$\tau = (c + \sigma \times \mathrm{tg}\,\phi)\,\tau \qquad (7)$$

The static coefficients of friction were determined with respect to three surfaces: wood, concrete (C30) and galvanized steel. These are common materials used for construction of storage and drying bins. The static coefficients of friction of the samples were determined according to the method of Beyhan et al. (1994). In this method; wood, concrete (C30) and galvanized steel surfaces were used as friction surfaces. During the experiment, the test surface was moved at a low velocity (2.4 cm/sec). The surfaces were driven by a 12V, adjustable direct current motor and strength of friction was measured by using a digital dynamometer. The static coefficients of friction of the samples were calculated by using equation 8 as follow;

$$\mu_s = \frac{f_s}{w_n} \qquad (8)$$

All the experiments were replicated three times, unless stated otherwise and the average values are reported. All the data obtained was statistically analysed for various parameters of study at different moisture contents using the SPSS 13 statistical programme. Duncan's multiple comparison was used to determine the difference existing at a 1% level of significance in barley variety.

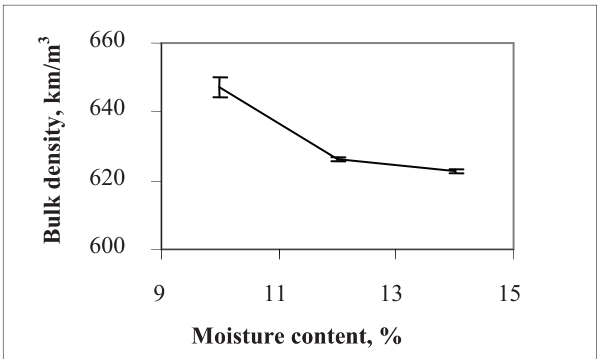
RESULTS AND DISCUSSION

Bulk density

The bulk density of the grain was observed to decrease from 647.34 to 623.00 kg/m^3 as the moisture content increased from 10% to 14% (Figure 1). The relationship between the bulk density and moisture content of grain can be expressed by following equation:

$$\rho_b = 705.21 - 6.08\,M_c \qquad (R^2 = 0.85)$$

Figure 1: Effect of moisture content on bulk density



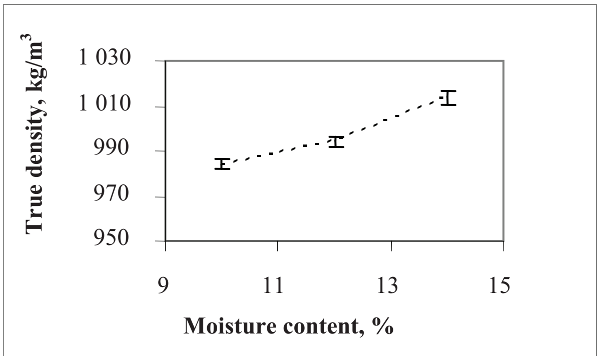
This was due to the higher rate of increase in volume than weight. The negative linear relationship was found by Çarman (1996) for lentil, Gupta and Das (1997) for sunflower, Özarslan (2002) for cotton, Karababa (2006) for popcorn. The effect of moisture content of grain on bulk density as a statistical was found with a significant level 1%.

True density

The variation of true density with moisture content for barley is shown in Figure 2. The true density of barley was found to increase from 984.00 kg/m^3 at a moisture content of 10% to 1 013.67 kg/m^3 at a moisture content of 14%.The variations in true density with moisture content of barley can be represented by following relationship:

$$\rho_t = 908.32 + 7.42\,M_c \qquad (R^2 = 0.97)$$

Figure 2: Effect of moisture content on true density

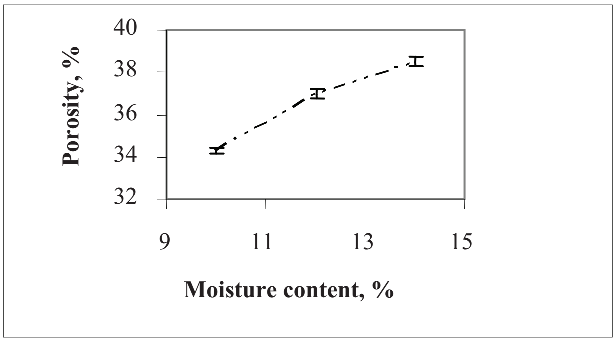


This increase indicates that there is a higher grain mass increase in comparison its volume increase as its moisture content increases. The positive linear relationship was observed by Gupta and Das (1997) for sunflower seeds, Baryeh (2002) for millet, Ogunjimi at al. (2002) for bean seed and Kingsly et al. (2005) for pomegranate seeds. It revealed that the true density linearly increased from 984.00 to 1 013.67 kg/m^3 with increase in moisture content and this change was significant at 1% level significance.

Porosity

Since the porosity depends on the bulk and true densities, variation in porosity depends on these factors only. The porosity was calculated from the bulk density and true density of grain. The porosity of grain increased with increase in moisture content as shown in Figure 3. Singh and Goswami (1996), Gupta et al. (1997), Coşkuner et al. (2005) and Yalçın (2006) found porosity to increase linearly with moisture content for cumin, sunflower seeds, flaxseed, cowpea seed respectively.

Figure 3: Effect of moisture content on porosity



A linear relationship between the porosity and moisture content of barley was obtained as:

$$\varepsilon_t = 23.89 + 1.06\,M_c \qquad (R^2 = 0.98)$$

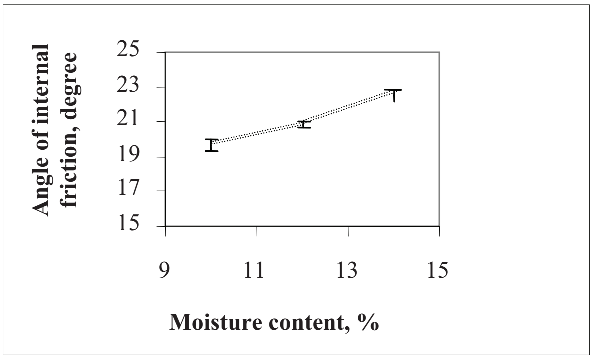
The statistical analysis of data concerning porosity showed that the interaction between porosity and moisture content is significant ($p < 0.01$).

Angle of internal friction

The results obtained for angle of internal friction with increase in grain moisture content are shown in Figure 4. The angle of internal friction increased from 19.67^0 to 22.50^0 as grain moisture content increased from 10% to 14% d. b. As the moisture content increased, the angle of internal friction was found to increase linearly. This change was significant at 1% level significance. Similar results have been observed by Ogunjimi et al. (2002) for locust bean seed, Aydın et al. (2002) for Turkish mahaleb, Amin et al. (2004) for lentil grains, Altuntaş et al. (2005) for fenugreek seeds and Kingsly et al. (2005) for pomegranate seeds. The angle of internal friction and the moisture content can be correlated as below:

$$\phi_b = 12.51 + 0.71\,M_c \qquad (R^2 = 0.99)$$

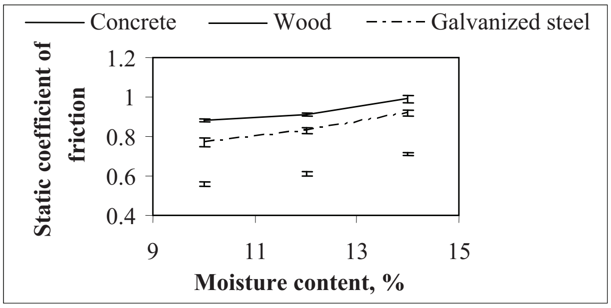
Figure 4: Effect of moisture content on angle of internal friction



Static coefficient of friction

The static coefficient of friction of barley against various structural materials, namely, galvanized steel, wood, concrete (BS 30) are presented graphically in Figure 5.

Figure 5: Effect of moisture content on static coefficient of friction



It was found that for barley the static coefficient of friction increased with increase in the corresponding moisture contents of 10–14% d.b. The values of static coefficient of friction were found in the range of 0.560–0.993 against the various surfaces with increase in the moisture content of grain. It was observed that static coefficient of friction increased linearly with the increase of the moisture content of grain for every three friction surface. Concrete (BS 30) has the highest coefficient of friction, followed by galvanized steel and wood. The variations can be expressed as follows:

$$\mu_{concrete} = 0.597 + 0.028 M_c \qquad (R^2 = 0.94)$$

$$\mu_{galvanized\ steel} = 0.390 + 0.038 M_c \qquad (R^2 = 0.99)$$

$$\mu_{wood} = 0.177 + 0.038 M_c \qquad (R^2 = 0.96)$$

Similar results on effect of grain moisture on static coefficient of friction have been reported for lentil seeds (Çarman, 1996), for sunflower seeds (Gupta and Das, 1997), for millet (Baryeh, 2002), for caper seeds (Dursun et al., 2005) and for popcorn (Karababa, 2006). In respect to the statistical effect of the moisture content of grain on static coefficient of friction is significant ($p < 0.01$).

CONCLUSIONS

The postharvest equilibrium moisture content of barley was found to be 10% (d.b).

The bulk density decreased linearly from 647.34 to 623.00 kg/m^3 with increase in moisture content.

True density is higher than bulk density at all grain moisture contents studied. True density increased linearly from 984.00 to 1 013.67 kg/m^3 with increase in moisture content.

The porosity increased linearly from 34.27% to 38.50% with increase in moisture content.

The angle of internal friction increased from 19.67^0 to 22.50^0 with increase in moisture content. The positive linear relationship between angle of internal friction and moisture content was determined.

The static coefficient of friction increased with increasing moisture content from 10% to 14% d.b. for all surfaces. The static coefficients of friction were highest for concrete, followed by galvanized steel and wood.

The physical and mechanical properties of grain were expressed in the linear regression equations as a function of moisture content. High correlation coefficients were found at 1% level of significance.

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