



## Determination of some physical properties of native lentil seeds of Zabol as a function of moisture content

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### ABSTRACT

Taking into account the necessity of determination of physical properties to design of storage, handling, and processing systems for agricultural products, the object of this study was intended to determine some physical characteristics of native lentil seed of Zabol such as axial dimensions, surface area, geometric mean diameter, sphericity, filling angle of repose, bulk and true densities, true volume, porosity as well as coefficient of static friction against various surfaces. Analysis of data showed that all physical properties of the lentil seeds were significantly affected with the moisture content in the studied range (4.7% to 19.8% w.b.). The axial dimensions of lentil seeds namely length, width, thickness and also one thousand seed mass of lentil seeds respectively increased from 3.88 to 4.56 mm, 3.69 to 4.21 mm, 2.05 to 2.29 mm and 12.14 to 22.73 as the moisture content increased. The values of surface area (11.29-15.12 mm<sup>2</sup>) and geometric mean diameter (3.08 - 3.49 mm) of lentil seeds increased with increasing moisture content while the sphericity (79.61 to 76.69%) decreased. The filling angle of repose of the seeds increased significantly with an increase in moisture content. So, it changed from 26.57 at moisture content 4.7 to 29.74 at moisture content 19.8 (w.b. %). The values of bulk and true densities of lentil seeds decreased respectively from 546 to 476 kg/m<sup>3</sup> and 1390 to 1270 kg/m<sup>3</sup> as the moisture content increased. The true volume (6.15 – 6.71 mm<sup>3</sup>) and porosity (60.71 to 62.68 %) of lentil seeds increased linearly with increasing moisture content. The values of the coefficient of static friction increased as the moisture content of lentil seeds increased and also the values of this parameter with respect to galvanized iron (0.61-0.64) and fiberglass (0.60-0.64) were greater than that on the glass surface (0.53-0.62).

### Highlights

- Determining the physical properties of agricultural products is necessary to design of processing systems such as storage, handling etc.
- Some physical properties of native lentil seeds were determined.
- Physical properties of the lentil seeds were significantly affected with the moisture content.
- Mathematical models predicting the physical properties of the lentil seeds based on the moisture content were developed.

### 1. Introduction

lentil (*Lens culinaris*) is a small annual legume of the pea family (*Fabaceae*) which is widely cultivated throughout the world. Lentil seed, because of containing high amounts of proteins, cellulose, carbohydrate compounds and folic acid as well as being low in calories, low in fat and cholesterol free is known as a healthy food

(Szot et al., 2003). Native lentil seed of Zabol is one of varieties of lentil that is cultivated annually in different regions of Sistan and Baluchestan province. There has been an interest in cultivation of this agricultural product for several reasons, such as its resistance to drought stress, more appropriate price and more marketability compared to other lentil varieties (Ghasemi et al., 2022). It was estimated that cultivated area of that in Sistan and

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Baluchistan province is approximately 1,200 hectares. However, if enough water is available, it can be raised to 3,000 hectares (Jihad, 1399). Determination of physical properties of agricultural materials such as lentil seeds is necessary to design of storage, handling and processing systems (Kashaninejad et al., 2008). When these systems improperly designed, may reduce the quality of agricultural crop which consequently led reduction of waste (Seyedalibeyk Lavasani and Baradaran Motie, 2022). The data based on physical characteristics enable the engineers, food scientists and processors to develop the processes and equipment efficiently (Krishnakumar, 2019; Ghadge and Prasad, 2012). For instance, the axial dimensions of seeds are needed for selecting sieve separators and calculating grinding power during size reduction process (Rameshbabu, et al., 1996; White and Jayas, 2001). In determining the size of grain hoppers and storage facilities, bulk and true densities and also porosity can be useful. In addition, the rate at which heat and moisture are transferred in aeration and drying process can be altered by these parameters (Taheri et al., 2015). The angle of repose and coefficient of friction can be considered as crucial characteristics to design of seed containers and other storage structures (Taheri et al., 2015). Moreover, the magnitude of frictional force determines the amount of power required for the conveyor (Seyedalibeyk Lavasani and Baradaran Motie, 2022). Since, there is no physical study of native lentil seed of Zabol, the aim of this study

was to determine some handling and frictional properties of this agricultural crop as a function of moisture content.

## 2. Materials and methods

### 2.1. Sample preparation

The lentil seeds used in the present study were obtained from a local mall in Zabol, a city in the eastern south of Iran. After cleaning, the initial moisture content of lentil seeds was determined by hot air oven drying method (ASAE S352.2, 1997). The samples with higher moisture content were prepared by adding distilled water which was calculated from the equation 1 (Kashaninejad et al., 2008).

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

Where,  $W_1$ ,  $W_2$ ,  $M_1$ , and  $M_2$  are sample weight (g), distilled water weight (g), final moisture content (w.b. %) and initial moisture content (w.b. %) respectively. At last, the sample was kept at 5C in a refrigerator for at least a week to ensure the uniform distribution of moisture throughout the product (Gupta and Das, 1997).

### 2.2. Dimensions, sphericity, one thousand seed mass

As defined in Figure 1, the three principal dimensions were determined randomly measuring the thickness (T), width (W) and length (L) of one hundred lentil seeds using an electronic digital caliper having a least count of 0.01 mm at each moisture level.

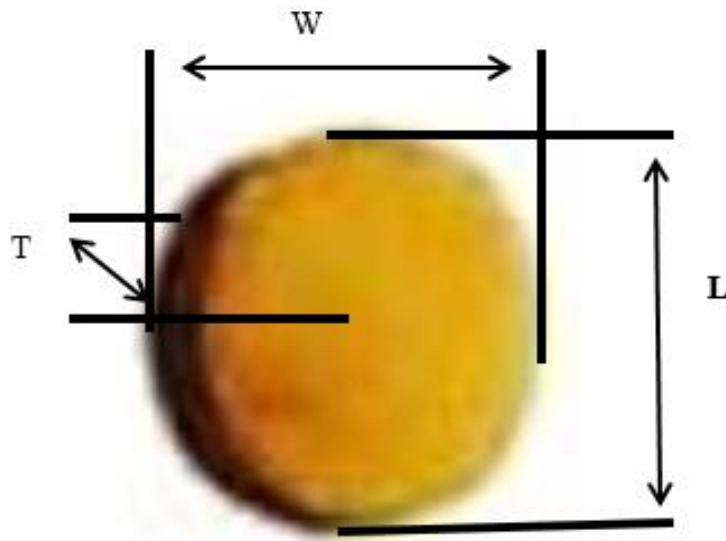


Figure 1. The three principal dimensions defined for lentil seed

To obtain the one thousand seed mass, 5 sub-samples each containing 1000 seeds were randomly selected from the bulk sample and then were weighed with digital balance with an accuracy of 0.001 g (Ghanbarian and Salek, 2014). Degree of sphericity ( $\phi$ ) was calculated from equation 2 (Mohsenin, 1980).

$$\phi = \frac{(LWT)^{1/3}}{L} \quad [2]$$

### 2.3. Geometric mean diameter and surface area

The equations 3 and 4 were used respectively for calculating geometric mean diameter ( $D_g$ ) and surface area (S) of seeds for each moisture level. (Mohsenin, 1980).

$$D_g = (LWT)^{1/3} \quad [3]$$

$$S = \pi D_g^2 \quad [4]$$

### 2.4. Bulk density, true density, porosity and true volume

The bulk density was calculated by mass and volume of the circular container with known quantity filled with lentils seeds (Kashaninejad et al., 2006). The true density

( $\rho_t$ ) was determined using an electronic balance reading to 0.001 g and a buret. This parameter is expressed as a ratio between the seed mass and the solid volume occupied by the sample (Baümler et al., 2006). True volume (V) of lentil seeds was determined using the liquid displacement method (Mohsenin, 1980). The porosity ( $\varepsilon$ ) of the bulk was obtained from equation 5. (Mohsenin, 1980):

$$\varepsilon = [(\rho_t - \rho_b)/\rho_t].100 \quad [5]$$

### 2.5. The filling angle of repose

The filling angle of repose ( $\theta_f$ ) is the angle with the horizontal line at which the material will stand when piled. The topless and bottomless cylinder of 10 cm diameter and 11 cm height was used to determine this parameter. The cylinder was placed at the center of a raised circular plate having a diameter of 35 cm and was filled with lentils. The cylinder was raised slowly until it formed a cone on a circular plate (Joshi et al., 1993; Mohammadi Moghadam et al., 2008). The height (H) of the cone and the diameter of sample distribution (D) was recorded. The filling angle of repose ( $\theta_f$ ) can be calculated from equation 6:

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right) \quad [6]$$

where H and D are expressed as mm.

### 2.6. Frictional characteristics

The coefficient of static friction for lentil seeds was determined on surfaces of glass, fiberglass, and galvanized iron at different moisture content. A galvanized iron box of 150 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 surface with the cylinder resting on it was inclined gradually, until the cylinder just started to slide down. (Kashaninejad et al., 2006). Equation 7 was used to calculate the coefficient of static friction.

$$\mu = \tan(\alpha) \quad [7]$$

Where  $\mu$  is coefficient of static friction and  $\tan(\alpha)$  is tangent of angle of inclination.

### 2.7. Data analysis

The data were subjected to analysis of variance (ANOVA), and significant differences between means were determined by Duncan's multiple range tests at the 5% significance level. Analysis of data was performed using SAS 9.2 software and regression analyses were performed using Excel software. All these experiments were replicated five times, unless stated otherwise (Ahmadi and Siaharsar, 2011).

## 3. Results and discussion

### 3.1. Dimensions and one thousand seed mass

Analysis of data (Table 1) shows that there are significant differences among the dimensions and one thousand seed mass of lentil seeds depending on moisture content. The results also indicated that the mentioned parameters have increased linearly with increase in moisture content (Figure 2). The length, width, thickness and one thousand seed mass of lentil seeds ranged from 3.88–4.56 mm, 3.69–4.21 mm, 2.05–2.22 mm and 12.14–22.73 g respectively as the moisture content increased from 4.77 to 19.8 (d.b.%).

Szot et al. (2003) expressed the length, thickness and one thousand seed mass of Tina lentil seed (a polish lentil variety) ranged from 5.60–5.93 mm 2.47–2.57 mm and 46.52–58.48 g respectively and of Laird lentil seed (a Canadian lentil variety) ranged from 6.15–6.63, 2.47–2.80 mm and 64.27–72.73 g respectively with increasing the moisture content. In another study, the length and thickness of lentil seeds of Qazvin were measured 6.36 mm and 2.78 mm respectively by Sharifi et al. (2019). thus, it can be found that the lentil seeds of Zabol have smaller dimension and one thousand seed mass in comparison with the mentioned varieties.

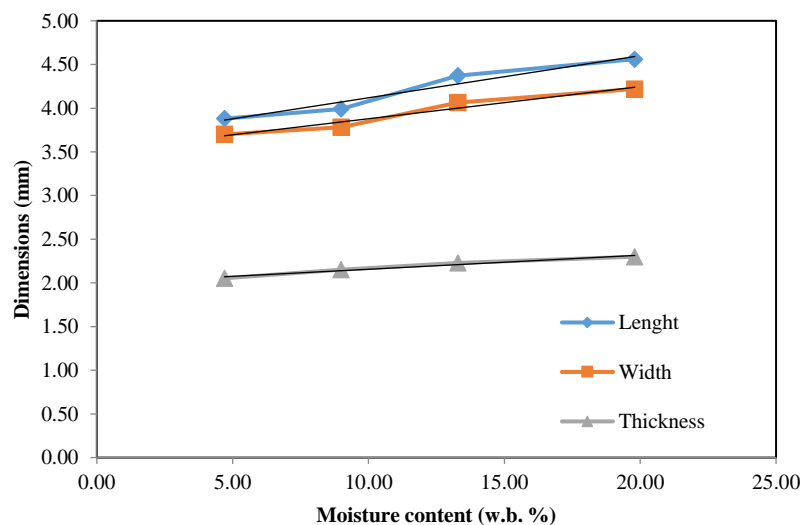


Figure 2. Variation in dimensions of lentil seeds with increasing moisture content

**Table 1. Dimensions and one thousand seed mass of the lentil seeds.**

Moisture content (w.b %)	Length (mm)	Width (mm)	Thickness (mm)	One thousand seed mass (g)
4.7	3.88±0.2d	3.69±0.2d	2.05±0.14d	12.14±0.07d
9	3.99±0.17c	3.78±0.14c	2.15±0.17c	19.13±0.0c
13.3	4.37±0.2b	4.06±0.2b	2.22±0.2b	19.81±0.03b
19.8	4.56±0.2a	4.21±0.2a	2.29±0.19a	22.73±0.0a

Means ±SD (standard deviation) within a column with the same lowercase letters are not significantly different at  $P < 0.05$ .

The equations 8-11 represent the significant ( $p < 0.05$ ) linear relationships between the dimensions as well as one thousand seed mass and moisture content for the lentil seeds.

$$L = 0.0482M_c + 3.6373 \quad (R^2=0.94) \quad [8]$$

$$W = 0.0368M_c + 3.5112 \quad (R^2=0.95) \quad [9]$$

$$T = 0.0162M_c + 1.9942 \quad (R^2=0.96) \quad [10]$$

$$M = 0.636M_c + 11.016 \quad (R^2=0.83) \quad [11]$$

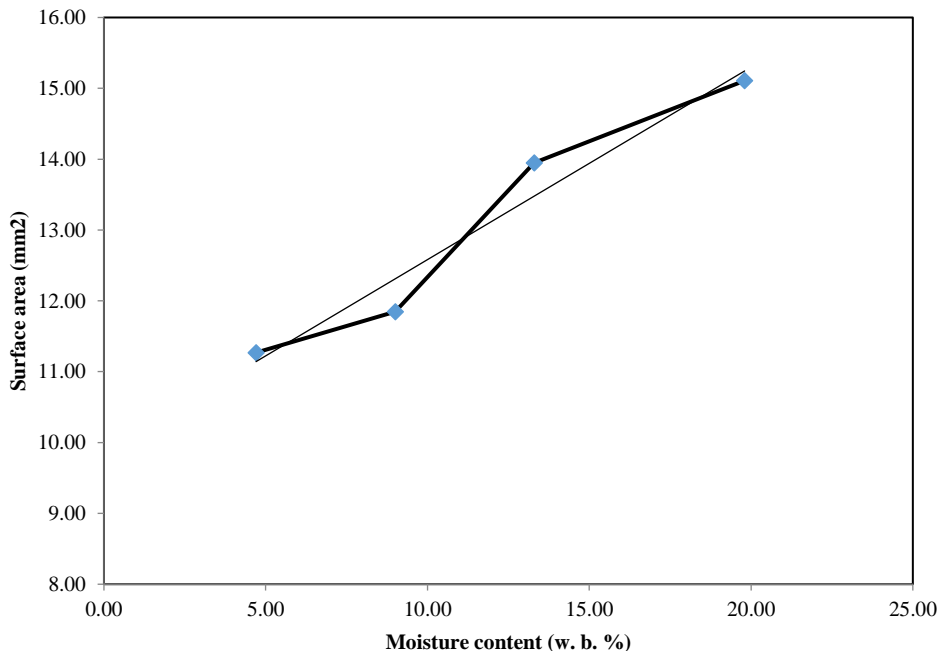
Similar trends have been reported for groundnuts gram; guna seeds and green gram (Baryeh, 2001; Aviara, 1999; Nimkar and Chattopadhyay, 2001)

As illustrated in Figure 3, the surface area of lentil seeds increased linearly with increasing moisture content changing significantly from 11.29 to 15.12 mm<sup>2</sup> as moisture content increased (Table 2). Kashaninejad et al. (2008) reported a similar result working with different varieties of soybean. However, Hsu et al. (1991) found the reverse trend for the pistachio. The surface area of lentil seeds of Qazvin has been reported 40.01 mm<sup>2</sup> (Sharifi et al., 2019).

Equation 12 indicate a linear relationship between moisture content and surface area of lentil seeds.

$$S = 0.2717M_c + 9.864 \quad (R^2=0.95) \quad [12]$$

### 3.2. Surface area



**Figure 3. Variation in surface area of lentil seeds with increasing moisture content**

### 3.3. Geometric mean diameter and sphericity

The Figures 4 and 5 indicate that the geometric mean diameters and sphericity of lentil seeds respectively increased and decreased with increasing moisture content. According to Table 2, the values of the geometric mean diameter increased significantly from 3.08 to 3.49 while, the sphericity decreased from 79.61 to 76.69% as moisture content increased. The reduction of lentil seed sphericity indicates that the seeds are inclined towards a rounded shape. However, they are able to slip on flat surfaces as well. Therefore, such a tendency to either roll or slide should be considered in the design of hoppers for milling (Ghadge and Prasad, 2012). Sharifi et al. (2019) reported

geometric mean diameter and sphericity value of lentil seeds of Qazvin 3.61 mm and 56 % respectively.

The regression relationship and coefficient of determination between sphericity and moisture content and also for geometric mean diameter and moisture content of lentil seeds are presented by equations 13 and 14. The similar results were reported for soybean seed and millet (McCabe, et al., 1986; Baryeh, 2002).

$$D = 0.0292M_c + 2.965 \quad (R^2=0.90) \quad [13]$$

$$\phi = -0.203M_c + 81.148 \quad (R^2=0.84) \quad [14]$$

### 3.4. The filling angle of repose:

As it can be seen in Table 2, the filling angle of repose of lentil seeds increased significantly from 26.57 at

moisture content 4.7 (w.b. %) to 29.74 at moisture content 19.8 (w.b. %). The increase can be explained by the presence of a higher amount of water on the surface of the seeds at higher moisture content resulting in increasing stickiness of the seeds which consequently facilitates sliding of them on each other (Kashaninejad et al., 2008).

Similar result reported by Kashaninejad et al. (2008) for different varieties soybean. The equation 15 revealed positive linear relationship between filling angle of repose of lentil seeds and moisture content and its coefficient of determination ( $R^2$ ).

$$\theta = 0.2234M_c + 25.06 \quad (R^2=0.91) \quad [15]$$

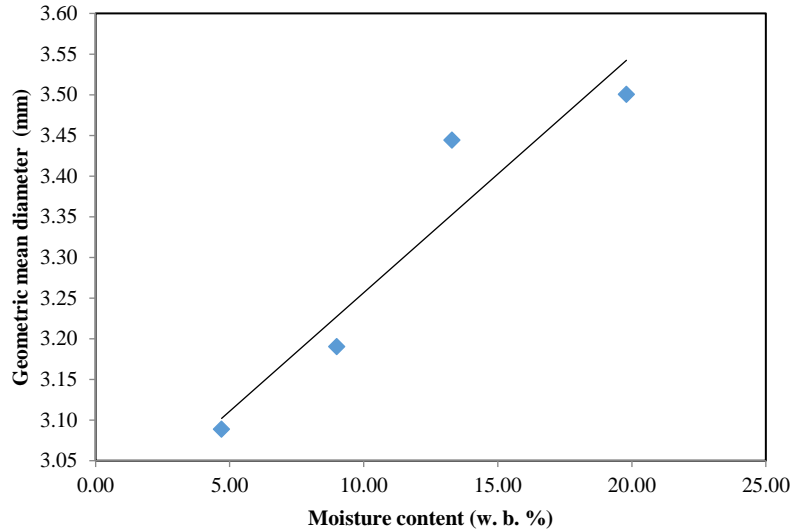


Figure 4. Variation in geometric mean diameter of lentil seeds with increasing moisture content

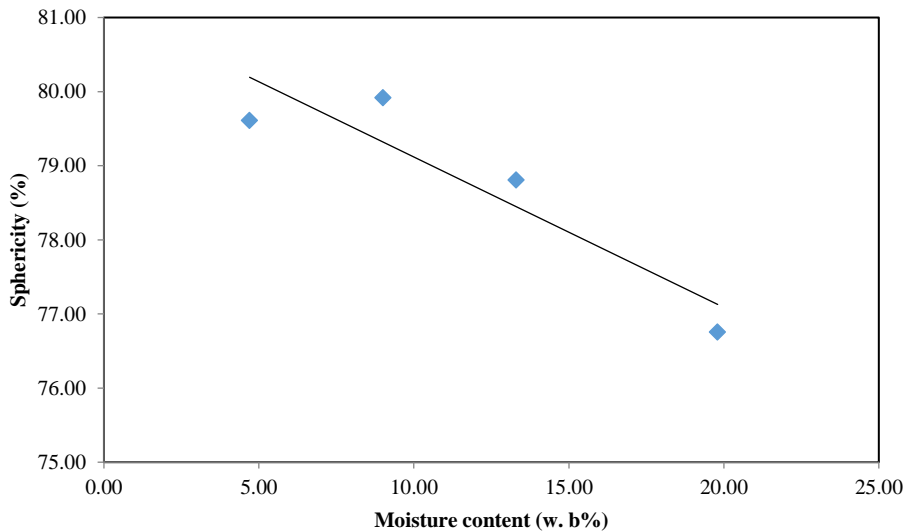


Figure 5. Variation in sphericity of lentil seeds with increasing moisture content

Table 2. Geometric mean diameter, sphericity, surface area and the filling angle of repose of the lentil seeds

Moisture content (w.b. %)	Geometric mean diameters (mm)	Sphericity (%)	Surface area (mm) <sup>2</sup>	The filling angle of repose:
4.7	3.08±0.14c	79.61±0.14a	11.29±1.1d	26.57±0.0c
9	3.18±0.13b	79.89±2.4ab	11.86±0.86c	26.57±0.0c
13.3	3.44±0.2a	78.83±2.8b	13.99±1.6b	27.85±0.0b
19.8	3.49±0.17a	76.69±3.4c	15.12±1.2a	29.74±0.0a

Means ±SD (standard deviation) within a column with the same lowercase letters are not significantly different at  $P < 0.05$ .

### 3.5. Bulk density:

As shown in Table 3, the values of bulk density of lentil seeds decreased significantly from 546 to 476 kg/m<sup>3</sup> as the moisture content increased indicating a linear trend between this parameter and moisture content (Figure 6).

Similarly, Szot et al. (2003) have reported the bulk density of tina lentil seeds (a polish lentil variety) and laird lentil seeds (a Canadian lentil variety) decreased from 783-747 kg/m<sup>3</sup> and 793-731 kg/m<sup>3</sup> respectively with increasing moisture content. Also, Sharifi et al. (2019) have reported bulk density 586 kg/m<sup>3</sup> for lentil seeds of Qazvin. These

results obviously show that the lentil seeds of Zabol possesses lower bulk density in comparison with the mentioned varieties. The decrease in bulk density indicates that the lentil seeds have lower weight increase compared to volume increase with increasing their moisture content. Equation 16 represents the relationship between the bulk density of lentil seeds and the moisture content and its coefficient of determination ( $R^2$ ).

$$\rho_b = -5.039M_c + 574.5 \quad (R^2=0.94) \quad [16]$$

The same findings were reported for cocoa beans, chick pea seeds (Plange and Baryeh, 2003; Konak et al., 2002).

### 3.6. True volume and true density

The results presented in Table 3 revealed that the true volume and true density of lentil seeds respectively increased and decreased linearly (Figure 6, for true density)

as the moisture content increased. The values of the true volume changed from 6.15 to 6.71 mm<sup>3</sup> and values of true density from 1390 to 1270 kg/m<sup>3</sup> with increasing moisture content. Similarly, a decrease in the true density has been observed for cotton seeds and chickpeas as the moisture content increased (Ozarlan, 2002; Konak et al., 2002). While, being an opposite trend for cumin seeds (Singh and Goswami, 1996), equations 17 and 18 represent the relationship between moisture content and true volume and true density. There is a similarity between the true volumes of the present paper and the findings reported in previous studies working with lupin, pigeon pea (Ogut, 1998; Shepherd and Bhardwaj, 1986).

$$V = 0.0435M_c + 5.91 \quad (R^2=0.95) \quad [17]$$

$$\rho_t = -8.010M_c + 1437.9 \quad (R^2=0.96) \quad [18]$$

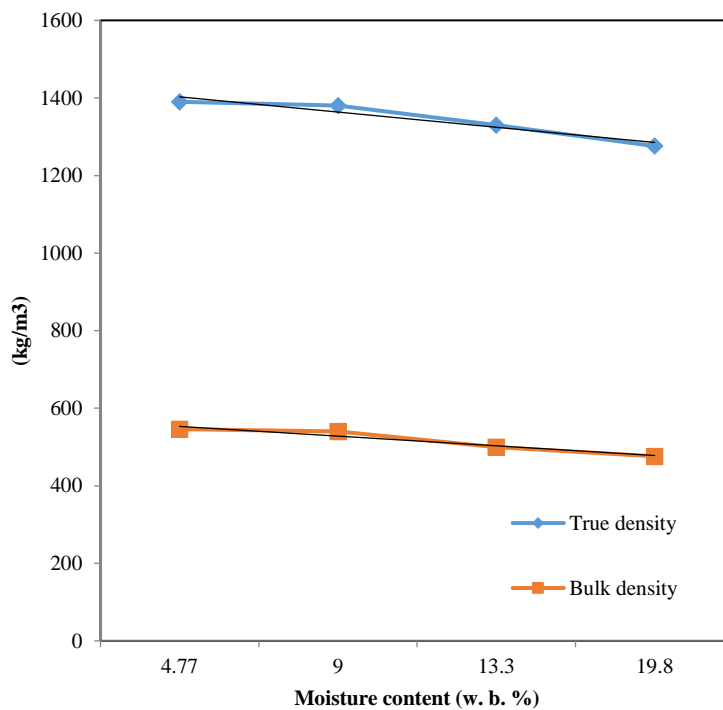


Figure 6. Variation in true and bulk densities of lentil seeds with increasing moisture content

### 3.7. Porosity:

According to Table 3, the porosity of lentil seeds of Zabol increased significantly from 60.71 to 62.68 % with increasing moisture content. Szot et al. (2003) stated the porosity of Tina and Laird lentil seeds ranged from 45.7-47.8 % and 50.3-50.2% respectively with increasing the moisture content. Also, similar trends were reported in lentil seeds (Scanlon et al., 2005) and grape seeds (Ahmadi and Siahisar, 2011). However, a reverse trend was found for pistachio nut by Kashaninejad et al. (2006). The variation in porosity with moisture content followed a linear relationship for lentil seeds (Figure 7), which can be represented by equation 19.

$$\varepsilon = 0.1451M_c + 59.95 \quad (R^2=0.88) \quad [19]$$

### 3.8. Coefficient of static friction:

As the results of Table 4 show the values of the coefficient of static friction of lentil seeds on galvanized iron (0.61-0.64) and fiberglass (0.60-0.64) were greater than that on glass surface (0.53-0.62). In addition, it was found that the coefficient of static friction increased linearly with an increase in moisture content for all the surfaces tested (Figure 8). Increase in static friction coefficient at higher moisture contents have been attributed to an increment in the cohesive force of wet seeds with the structural surface arising from the more stickiness of the seeds as moisture content increases. (Kashaninejad et al., 2008). These findings were confirmed by other researchers (Joshi et al., 1993; Gezer et al., 2002; Carman, 1996). The

linear relations between moisture content and the coefficient of static friction obtained for lentil seeds, can be expressed by equations 20, 21, and 22.

$$\mu_{Glass} = 0.0059M_c + 0.5111 \quad (R^2=0.93) \quad [20]$$

$$\mu_{fiberglass} = 0.0029M_c + 0.5815 \quad (R^2=0.92) \quad [21]$$

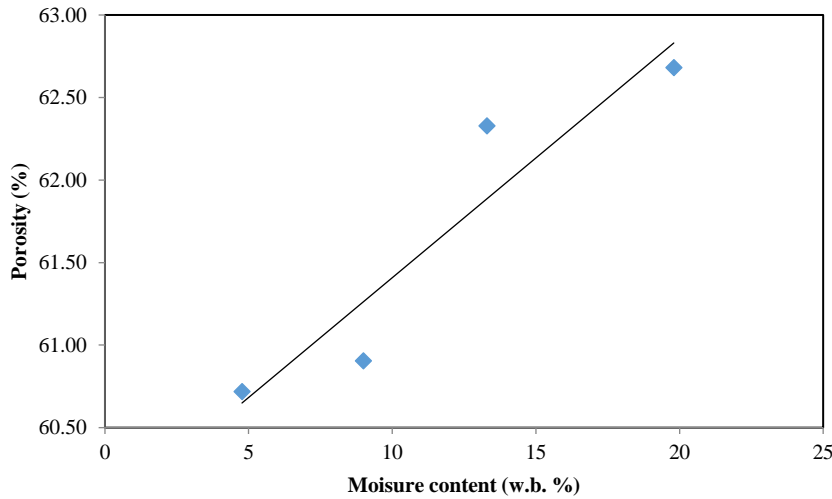
$$\mu_{galvanized\ iron} = 0.0013M_c + 0.6098 \quad (R^2=0.70) \quad [22]$$

These linear behaviors are in agreement with the results for soybean varieties, and grape seeds (Kashaninejad et al., 2008; Ahmadi and Siasar 2011).

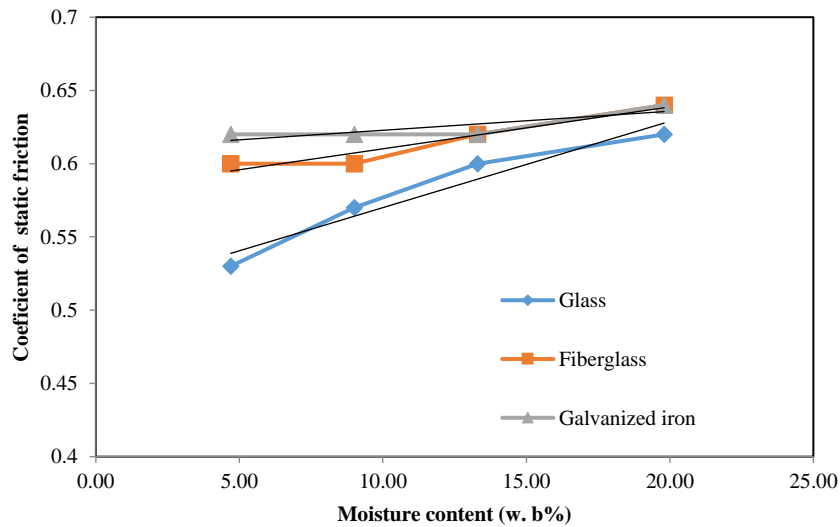
**Table 3. True volume, true density, bulk density and porosity of the lentil seeds**

Moisture content (w.b %)	Kernel volume (mm <sup>3</sup> )	True density (Kg/m <sup>3</sup> )	Bulk density (Kg/m <sup>3</sup> )	Porosity (%)
4.7	6.15±0.006d	1.39±0.01a	0.546±0.004a	60.71±0.22b
9	6.22±0.02c	1.38±0.004b	0.540±0.0b	60.90±0.11b
13.3	6.54±0.0b	1.33±0.001b	0.500±0.0c	62.32±0.07a
19.8	6.76±0.01a	1.27±0.002d	0.476±0.005d	62.68±0.45a

Means ±SD (standard deviation) within a column with the same lowercase letters are not significantly different at P < 0.05.



**Figure 7. Variation in porosity of lentil seeds with increasing moisture content**



**Figure 8. The coefficient of static friction of lentil seeds on different structural surfaces depending on moisture content**

**Table 4. The coefficient of static friction of the lentil seeds on different structural surfaces at different moisture contents**

Moisture content (w.b %)	Glass	Fiberglass	Galvanized iron
4.7	0.53±0.01d	0.60±0.01c	0.61±0.01b
9	0.57±0.0c	0.60±0.0c	0.62±0.0b
13.3	0.60±0.0b	0.62±0.0b	0.62±0.0b
19.8	0.62±0a	0.64±0.0a	0.64±0.0a

Means ±SD (standard deviation) within a column with the same lowercase letters are not significantly different at P < 0.05.

#### 4. Conclusions

The results showed that the physical properties of native lentil seeds of Zabol were significantly dependent on their moisture content. According to the obtained results dimensions, one thousand seed mass, surface area, geometric mean diameter, true volume, porosity, the falling angle of repose, and the static coefficient of friction of lentil seeds increased linearly with increasing moisture content. While, sphericity, bulk, and true densities decreased. Considering the necessity of these parameters to design equipment and machinery for transporting, sorting, handling, processing, drying, and storage of agricultural products, Therefore, the obtained findings represent some physical properties needed for designing storage, handling, and processing systems of native lentil seeds which is accounted a valuable crop in Sistan region of Iran.

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