Moisture Dependent Physical Properties of Dragon's Head Seeds (*Lallemantia iberica*)

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ABSTRACT

Physical properties of Dragon's head seed, and other grains, are necessary for the design of equipment handling, transporting, processing and storing of the crop. A range of physical properties of Dragon's head (*Lallemantia iberica*) were determined as a function of moisture content. As the moisture content increased from 7.18 to 48.46 % (d.b.), the average length, width, thickness and the geometric mean diameter varied from 4.48 to 4.97 mm, 1.69 to 1.85 mm, 1.16 to 1.35 mm and 1.97 to 2.31 mm, respectively. In the same moisture range, studies on Dragon's head showed that, sphericity, surface area, thousand seed mass and true density increased from 41.73 to 46.50 %, 12.16 to 16.79 mm^2 and 9.75 to 11.17 g and 837.2 to 1047 kg/m^3, respectively. As the moisture content increased from 7.18 to 48.46 % (d.b.), bulk density decreased from 584.23 to 438.26 kg/m^3 whereas the angle of repose and porosity increased from 27.16 to 43.33º and 30.17 to 58.12 %, respectively. The static coefficient of friction of Dragon's head seeds increased linearly against surfaces of three structural materials, namely, glass (0.25–0.63), plywood (0.42-0.70), and galvanized iron (0.32–0.64) as the moisture content increased from 7.18 % to 48.46 % (d.b.).

Keywords: Dragon's head seed, physical properties, angle of repose, static coefficient of friction, bulk and true densities

Nomenclature

a	length, mm	s	surface area, mm^2
b	width, mm	Θ	angle of repose, deg
c	thickness, mm	μ	static coefficient of friction
D_g	geometric mean diameter, mm	D_a	arithmetic mean diameter, mm
M_c	moisture content, % d.b.	φ	sphericity, %
m_{1000}	thousand seed mass, g	ε	porosity, %
ρ_b	bulk density, kg/m^3	ρ_t	true density, kg/m^3
μ_{pw}	static coefficient of friction on plywood		
μ_{gi}	static coefficient of friction on galvanized iron		
μ_{gl}	static coefficient of friction on glass		

1. INTRODUCTION

Dragon's head (*Lallemantia iberica*) originates in the Caucasian region and may be locally naturalized in East and Central East Europe. Dragon's head is cultivated for its seeds from which oil is extracted. The seed contains up to 30 % of a drying oil. It is used for lighting, as a varnish, in paints and as a lubricant. The oil may also be used for oil-foods and as a tanning agent. It is considered as a linseed substitute in a number of applications including: wood preservative, ingredient of oil-based paints, furniture polishes, printing inks and soap making. It is also used in the manufacture of linoleum. The oilcake has been used to feed horses, ruminants and rabbits with no observed ill effects. A cow can be feed up to 2 kg per day. Researches on physical properties were reported for various crops, such as hemp seed (Sacilik et al**.,** 2003), fenugreek seeds (Altuntaş et al., 2005), lentil seeds (Amin et al., 2004), guna seeds (Aviara et al., 1999), millet (Baryeh, 2002), sunflower seeds (Baümler et al., 2006) and linseed (Selvi et al., 2006). Knowledge of the physical properties of Dragon's head is essential to facilitate and improve the design of equipment for handling, harvesting, processing, and storing of the seed. Various types of cleaning, grading and separation equipment may be designed on the basis of the physical properties of the seed. The purpose of this study was to determine some moisture-dependent physical properties of Dragon's head seed, namely, size, thousand seed mass, sphericity, surface area, bulk density, true density, porosity, angle of repose, and the static coefficient of friction in the moisture range from 7.18 to 48.46 % (d.b.).

2. MATERIALS AND METHODS

The Dragon's head seeds used in this study were obtained from the local market in Urmia, Iran. The samples were cleaned manually to get rid of all foreign matter, broken and immature seeds. The initial moisture content of seeds was determined as 7.18 % (d.b.), by oven drying at 105±1 ºC for 24 h (Selvi et al., 2006).

The Dragon's head seeds at the different moisture levels were prepared by adding calculated quantity of water mixing thoroughly and then sealing in separate polyethylene bags. The Dragon's head seeds were kept at 5 ºC in a refrigerator for a week to allow the moisture to distribute uniformly throughout the sample. Before each test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to room temperature. All the physical properties of the seeds were determined at moisture contents of 7.18 %, 15.22 %, 23.95 %, 33.55 %, and 48.46 % (d.b.). To determine the length, width and thickness of seeds at each moisture content, samples of 50 seeds were randomly selected. Baryeh (2002) have measured these dimensions for millet grains in similar manner to determine of size and shape properties. Materials were measured by a Mitutoyo micrometer caliper with an accuracy of 0.01 mm. The geometric mean diameter (D_g), arithmetic mean diameter (D_a) and sphericity (φ) of Dragon's head seeds were calculated using the following equations (Mohsenin, 1970):

$$D_g = (abc)^{1/3} \qquad (1)$$

$$D_a = \left(\frac{a+b+c}{3}\right) \qquad (2)$$

$$\phi = \frac{(abc)^{1/3}}{a} \tag{3}$$

where *a* is the length, *b* is the width and *c* is the thickness in mm.
The surface area of seeds was found by analogy with a sphere of the same geometric mean diameter, using the following equation cited by Sacilik et al. (2003), Tunde-Akintunde and Akintunde (2004) and Altuntaş et al. (2005):

$$s = \pi D_g \tag{4}$$

where s is the surface area in mm^2.

Unit mass of seeds and thousand seed mass were measured by a digital electronic balance with the accuracy of 0.001 g. To evaluate the thousand seed mass, 50 seeds were randomly selected from the bulk sample and averaged.

The true density of a seed is defined as a ratio of the mass of a sample of a seed to solid volume occupied by the sample. It was determined by the toluene displacement method (Mohsenin 1986) for sample of seeds. The bulk density is the ratio of the mass of a sample of a seed to its total volume. This was determined by filling a Aluminum's container of 10 cm height and 5 cm diameter with seed from a constant height, striking the top level and then weighing the constants (Deshpande et al., 1993; Gupta and Das, 1997; Konak et al., 2002; Paksoy and Aydin, 2004).

The porosity was calculated from bulk and true densities using the relationship given by Mohsenin (1970), as follows**:**

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)100 \tag{5}$$

where ε is the porosity in %; ρ_b is the bulk density in kg/m^3; and ρ_t is the true density in kg/m^3.

The static coefficient of friction was determined against different surfaces: plywood, glass, and galvanized iron. A hollow metal cylinder (fig. 1) of diameter 75 mm and 50 mm depth, opened at both ends, was filled with the seeds at the desired moisture content and placed on an adjustable tilting surface such that the metal cylinder did not touch the surface. Then the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006).

Figure 1. Apparatus to determine coefficient of static friction

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus consisting of a plywood box of 140×160×35 mm and two plates: fixed and adjustable (fig. 2). The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the seeds to flow and assume a natural slope (Tabatabeefar, 2003).

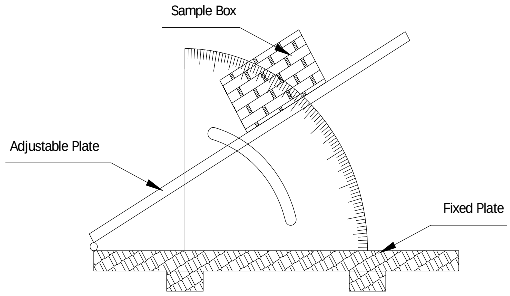

Figure 2. Apparatus to determine angle of repose

3. RESULTS AND DISCUSSION

3.1 Seed Size

Means and standard errors of the axial dimensions of Dragon’s head seeds at different moisture contents are given in table 1. From this table, it can be seen that as the moisture content of seeds increased from 7.18 % to 48.46 % (d.b.), the average length, width and thickness of seeds increased from 4.48 to 4.97 mm, 1.69 to 1.85 mm, 1.16 to 1.35 mm, respectively. ANOVA results showed that the differences between moisture levels were statistically significant ($P<0.01$) for the three axes. These results were similar to those reported by Selvi et al. (2006) for linseed. The dimensional increase along the three axes was 10.94 %, 9.47 %, 16.38 % with an increase in moisture content from 7.18 to 48.46 % (d.b.).

Table 1. Means and standard errors of the axial dimensions of Dragon’s head

M_c, %	a, mm	b, mm	c, mm	D_a, mm	D_g, mm
7.18	4.48 ±0.032	1.69 ±0.0116	1.164 ±0.022	2.453	1.968
15.22	4.53 ±0.035	1.71 ±0.014	1.175 ±0.020	2.456	2.055
23.95	4.77 ±0.030	1.73 ±0.024	1.177 ±0.020	2.543	2.080
33.55	4.83 ±0.035	1.73 ±0.016	1.191 ±0.020	2.576	2.137
48.46	4.97 ±0.036	1.85 ±0.018	1.346 ±0.018	2.722	2.310

The average diameters calculated by the arithmetic mean and geometric mean are also presented in table 1. The average diameters increased with increasing moisture content. The arithmetic and geometric mean diameter ranged from 2.45 to 2.72 mm and 1.97 to 2.31 mm as the moisture content increased from 7.18 to 48.46 %. The Dragon’s head seed expanded more in thickness in comparison with its other two principal axes. Such behavior was observed by Sacilik et al. (2003) for hemp seed.

3.2 Sphericity

The sphericity of Dragon's head seed increased from 41.73 to 46.5 % while the moisture content increased from 7.18 to 48.46 % d.b. (fig. 3). A similar trend has been reported by Baümler et al. (2006) for safflower seeds, Selvi et al. (2006) for linseed and Altuntaş et al. (2007) for faba bean grain.

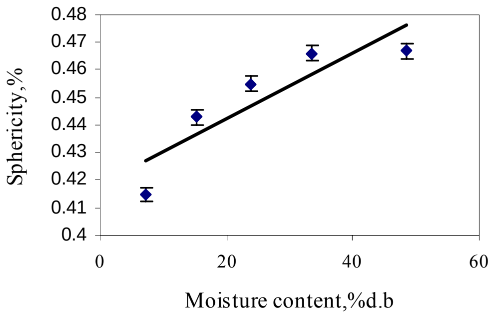

Figure 3. Effect of moisture content on sphericity of Dragon's head seed

3.3 Thousand Seed Mass

The thousand seed mass of Dragon's head seed (m_{1000}, g) increased from 9.75 to 11.17 g as the moisture content increased from 7.18 to 48.46 % d.b. (fig. 4). This relationship can be represented by the following equation (R^2=0.99):

$$m_{1000} = 9.31 + 0.06M_c \quad (6)$$

Similar trends have been reported by Aviara et al. (1999) for guna seeds, Selvi et al. (2006) for linseed, Baryeh (2002) for millet, and Coşkuner (2007) for flaxseed**,** respectively.

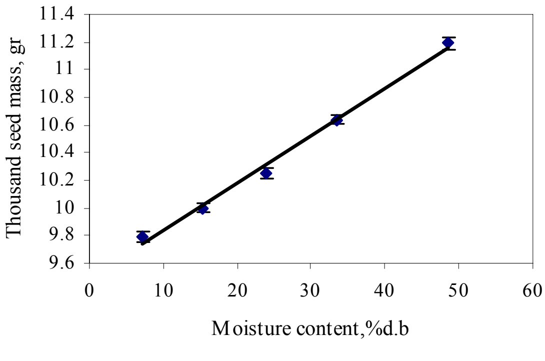

Figure 4. Effect of moisture content on 1000 seed mass of Dragon's head

3.4 Surface Area

The surface area of seeds (fig. 5) increased linearly while the moisture content increased from 7.18 to 48.46 % (d.b.). Variation of moisture content with surface area can be expressed by the following equation (R^2=0.94):

$$s = 10.9 + 0.16M_c \quad (7)$$

Similar trends have been reported by Baryeh (2002) for millet and by Selvi et al. (2006) for linseed.

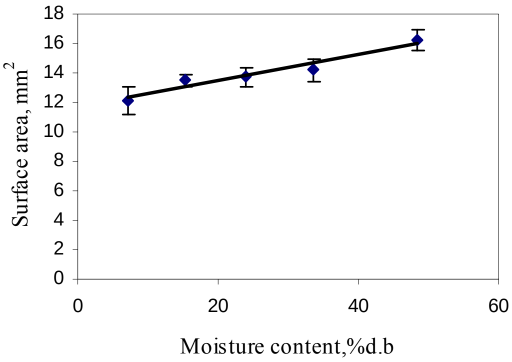

Figure 5. Surface area variations with moisture content

3.5 Bulk Density

The bulk density of Dragon's head seeds at different moisture contents varied from 584.23 to 438.26 kg/m^3. The result showed decrease in bulk density with an increase in moisture content from 7.18 to 48.46 % (d.b.). Variation of bulk density with moisture content was linear as shown in figure 6, and can be expressed as follows (R^2=0.89):

$$\rho_b = 609.5 - 5.57M_c \quad (8)$$

Similar results were found by Özarslan (2002) for cotton, Coşkun et al. (2006) for sweet corn and Selvi et al. (2006) for linseed, respectively.

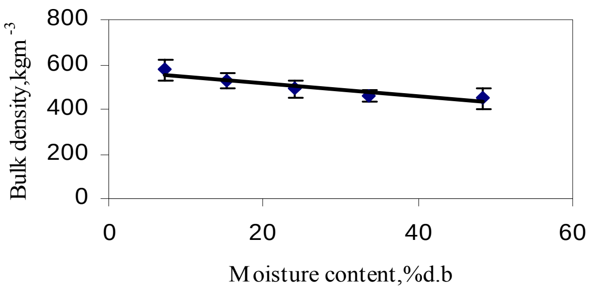

Figure 6. Relationship of moisture content and bulk density of Dragon's head seed

3.6 True Density

The true density varied from 837.2 to 1047 kg/m^3 when the moisture level increased from 7.18 % to 48.46 % d.b. (fig. 7). Seed true density and moisture content can be correlated as follows (R^2=0.86):

$$\rho_t = 806.7 + 8.28M_c \quad (9)$$

The increase in true density of seeds with increase in moisture content showed that the increase in weight in the sample is greater than volume increase of seed. This is in agreement with the findings of Baryeh (2002), Coşkun et al. (2006), Selvi et al. (2006), and Altuntaş et al. (2007) for millet, sweet corn, linseed and faba bean, respectively.

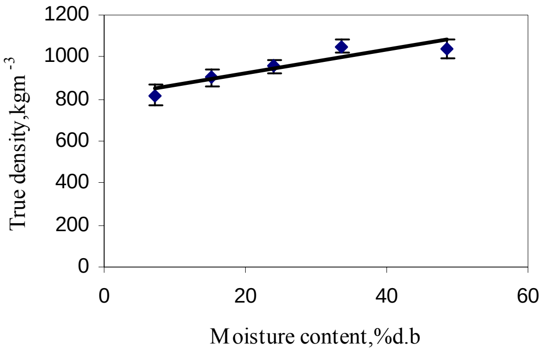

Figure 7. Moisture content dependence of true density of Dragon’s head seed

3.7 Porosity

Porosity was calculated from Eq. 5 by using the data on bulk and true densities of the Dragon’s head seed. Variations of porosity depending on moisture content are shown in fig. 8. The porosity values of Dragon’s head at moisture contents between 7.18 % and 48.46 % varied between 30.17 % and 58.12 %. The relationship between porosity value and moisture content was found to be as follows (R^2=0.91):

$$\varepsilon = 26.37 + 1.10M_c \tag{10}$$

Selvi et al. (2006) and Coşkuner et al. (2007) showed that the porosity value increased with increasing moisture content for linseed and flaxseed, respectively.

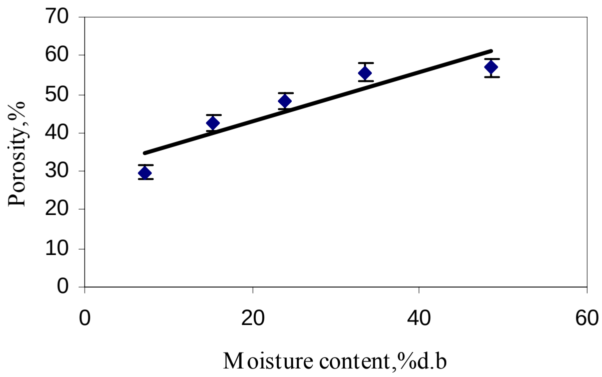

Figure 8. Effect of moisture content on porosity of Dragon’s head seed

3.8 Angle of Repose

The variations of angle of repose Θ (in degree) with respect to moisture content are plotted in fig . 9. It increased linearly from 27.16º to 43.33º with an increase in moisture content from 7.18 % to 48.46 % (d.b.). The relationship between moisture content and angle of repose can be represented by the following equation (R^2=0. 85):

$$\Theta = 23.8 + 0.53M_c \tag{11}$$

A linear increase in angle of repose with increasing seed moisture content has also been noted by Gupta and Das (1997), Amin et al. (2004), and Selvi et al. (2006) for sunflower seed, lentil seed and linseed**,** respectively.

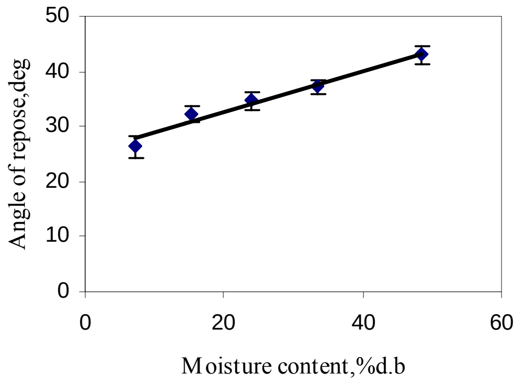

Figure 9. Changes in angle of repose with increasing moisture content of Dragon's head seed

3.9 Static Coefficient of Friction

The static coefficient of friction for Dragon's head seed determined against three different structural surfaces are given in fig. 10. It was observed that the static coefficient of friction increased with increase in moisture content for all the surfaces. This could be due to increased adhesion between the seed and the surface at higher moisture values. Similar results have been reported by other researchers (Çarman, 1996; Suthar and Das, 1996; Nimkar and Chattopadhyay, 2001; Konak et al. 2002). At all moisture contents, the static coefficient of friction was greatest against plywood (0.42–0.70), followed by galvanized iron (0.32–0.64) and glass (0.25–0.63). This result indicates smaller coefficient of friction values on smoother and more polished surfaces. The relationships between moisture content and static coefficients of friction on all test surfaces can be represented by the following equations:

$$\mu_{pw} = 0.36 + 0.0103M_c \quad (12)$$

$$\mu_{gi} = 0.27 + 0.0115M_c \quad (13)$$

$$\mu_{gl} = 0.20 + 0.0103M_c \quad (14)$$

where μ_{pw}, μ_{gi} and μ_{gl} refer to coefficients of friction on plywood, galvanized iron and glass, respectively. The values of the coefficients of determination (R^2) for μ_{pw}, μ_{gi} and μ_{gl} were 0.97, 0.96 and 0.91, respectively.

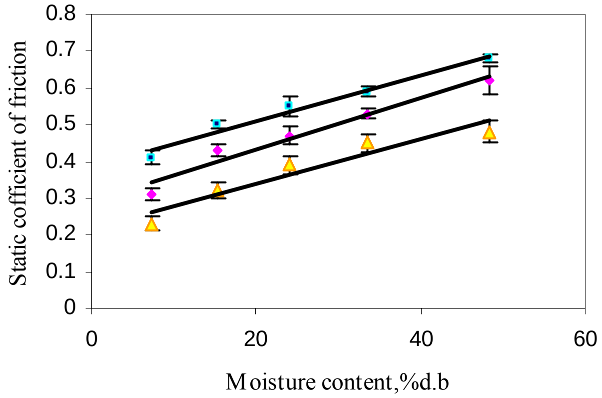

Figure 10. Effect of moisture content on static coefficient of friction:
(Δ) glass; (◊) galvanized iron (□) plywood galvanized iron

4. CONCLUSIONS

The investigation of the physical properties of Dragon's head seed as a function of moisture content revealed the followings:

(1) The major axis, medium axis and minor axis of seed increased from 4.47 to 4.97 mm, 1.69 to 1.85 mm and 1.16 to 1.35 mm as the moisture content increased from 7.18 to 48.46 % (d.b.)

(2) The arithmetic and geometric mean diameters increased from 2.45 to 2.72 mm and 1.97 to 2.31 mm in the moisture content ranged from 7.18 to 48.46 % d.b., respectively.

(3) As the moisture content increased from 7.18 to 48.46 % d.b., the sphericity, surface area, and thousand seed mass varied from 41.7 to 46.5 %, 12.16 to 16.79 mm^2 and 9.75 to 11.17 g, respectively.

(4) Bulk density decreased from 584.23 to 438.26 kg/m^3 whereas true density increased from 837.2 to 1047.0 kg/m^3 in the specified moisture range.

(5) The angle of repose and porosity increased linearly from 27.16 to 43.33° and 30.17 to 58.11 % as moisture content increased from 7.18 to 48.46 % (d.b.), respectively.

(6) The static coefficient of friction increased linearly with increasing moisture content from 7.18 to 48.46 % d.b. for all surfaces. The static coefficient of friction varied from 0.32 to 0.64, 0.42 to 0.70 and 0.25 to 0.52 for galvanized iron, plywood and glass, respectively.

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