

## Moisture Dependent Physical Properties of Canola Seeds

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### ABSTRACT

Physical properties of four common Iranian varieties of canola seeds (Hyola, Okapi, Orient and SLM) were evaluated as a function of their moisture contents. The average seed length and thousand seed mass varied linearly from 1.925 to 2.262 mm and from 3.06 to 4.84 g, respectively. The average diameter, geometric mean diameter, and sphericity varied non-linearly from 1.475 to 1.911 mm, 1.625 to 2.02 mm and from 0.82 to 0.93, respectively in a moisture content range of 5.27 to 23.69% wet basis (w.b.). Among the varieties, Hyola had the highest values for length, diameter, geometric mean diameter, sphericity and thousand seed mass at all moisture levels. Maximum and minimum values of bulk density were obtained for SLM (738.8 kg m<sup>-3</sup>) and Hyola (666.06 kg m<sup>-3</sup>). The filling and emptying angles of repose ranges were determined as 25.37-28.54° and 25.48-28.68°, respectively. At all moisture content levels, the static coefficient of friction was the greatest against rubber (0.372-0.460), followed by plywood (0.358-0.449), galvanized iron sheet (0.301-0.419) while fiberglass sheet (0.260-0.414) while the least for glass sheet (0.253-0.392). Among the four canola varieties, Orient and SLM showed respectively the least and the greatest static coefficients of friction at all moisture levels studied.

**Keywords:** Canola seed, Geometrical properties, Gravimetric properties, Frictional properties.

### INTRODUCTION

Canola is a member of a large family of plants called *crucifers*. It is one of the world's most important oilseed crops. Canola seed contains approximately 40% oil and the meal consists of 35 to 40% protein (Raymer, 2002; Shahidi, 1990).

Iran is one of the world's major importers of edible oil (more than 90% of its domestic use). The government is decided to produce the people's needed cooking oil as based on a futuristic strategic plan. Recent introduction of canola crop to Iran and a lack of adequate scientific information about the plant, including physical properties of canola seed would lead to weak equipment design and improper applications, resulting in a reduction of the process efficiency and subsequent increase in the product losses. Therefore, a consideration of a thorough knowledge of

physical properties plays an important role in designing the required equipment for the crop's planting, harvesting, transport, processing, as well as the storing. The designs would lead to inadequate applications, if carried out without taking these physical properties into consideration (Dursun and Dursun, 2005).

No detailed study concerning the physical properties of different common varieties of canola seeds have been reported. Hence, the present study was undertaken to (i) determine the important physical properties (principal dimensions, geometric mean diameter, one thousand seed mass, bulk density, porosity, filling and emptying angles of repose as well as the static coefficient of friction) for four common variety seeds of canola at their different moisture contents and (ii) to develop the mathematical models for a prediction of physical properties of

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each canola variety seed as a function of its moisture content.

## MATERIALS AND METHODS

Seeds of Hyola, SLM, Orient, and Okapi canola varieties were employed in the present study. The average initial moisture content of the seeds was found to vary between 5.27 and 6.61% (w.b.). The moisture content of the seeds was determined through an air convection oven drying the seeds at 103°C for 72 hours (Çalışır *et al.*, 2005). To raise the moisture content, a calculated predetermined quantity of distilled water was added to the samples which were then placed in sealed plastic bags and kept at 4°C in a refrigerator for at least a week to let the moisture distribute uniformly throughout the samples (Çalışır *et al.*, 2005). Before starting a test, the required quantity of seed was taken out of the refrigerator and allowed to warm up to room temperature. The quantity of distilled water added was calculated through the following equation (Tabatabaee-far, 2003):

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

Where,  $W_2$  is the mass of distilled water added in kg;  $W_1$  the initial sample mass in kg;  $M_1$ , the initial moisture content of sample in % w.b., and  $M_2$ , the desired moisture content of the sample in % w.b.. The physical properties were evaluated at three seed moisture levels of 5.27, 15.30 and 23.46% for Hyola; 6.40, 14.84 and 20.66% for SLM; 6.61, 13.60 and 21.85% for Okapi, and 5.33, 16.53 and 23.69% for Orient.

One thousand seed mass was determined through the standard method using a numerical seed counter, the seeds then being weighed by means of an electronic balance of 0.001 g accuracy. To determine the average size of a canola seed, 30 seeds were randomly picked and their two linear dimensions namely, length,  $L$  and diameter,  $D$  measured using a micrometer of an accuracy of 0.001 mm. The principal dimensions were measured at all the three moisture levels,

with 100 replications at each moisture level and for each variety.

Geometric mean diameter ( $D_g$ ) and sphericity values ( $\Phi$ ) were obtained, respectively using the following formulae (Mohsenin, 1970).

$$D_g = (LD^2)^{0.333} \quad (2)$$

$$\Phi = \frac{(LD^2)^{0.333}}{L} \quad (3)$$

For an evaluation of bulk density, a container of known mass and volume was filled with canola seeds to the top. Seeds were poured to the container in excess and with a constant rate from a height of about 150 mm (Singh and Goswami, 1996). Dropping the seeds from a height of 150 mm produces a tapping effect in the container to reproduce the settling effect during storage (Amin *et al.*, 2004). After filling the container, excess seeds were removed by passing a flat stick across the top surface using 2 zigzag motions. The seeds were not allowed to get compacted in any way. The container was weighed, using a digital balance with a reading accuracy of 0.01 g. Bulk density was calculated as the ratio of mass of seeds in the container to container's volume. Bulk density was assessed at all the three moisture levels, with 10 replications at each level and for each variety.

A specially constructed topless box (20×20×20 cm) having a removable panel was used to determine the emptying angle of repose of the seeds as a function of moisture content. The box was filled with seeds, and then the front panel quickly removed to allow the seeds to flow to their natural slope. 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,  $\theta_e$  was obtained using the following equation (Fraser *et al.*, 1978).

$$\theta_e = \tan^{-1} \left( \frac{h_2 - h_1}{x_2 - x_1} \right) \quad (4)$$

The filling angle of repose is the angle made with the horizontal at which the material will stand when piled. This was deter-

mined by using a topless and bottomless cylinder of 15 cm diameter and 25 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 35 cm and then filled with canola seeds. The cylinder was raised slowly until it formed a seed cone on the circular plate. The height of the cone was measured and the filling angle of repose,  $\theta_f$  calculated using the following equation (Kaleemullah and Gunasekar, 2002).

$$\theta_f = \tan^{-1} \left( \frac{2H}{D} \right) \quad (5)$$

where, H and D are the height and diameter of the cone in mm, respectively.

Coefficient of static friction of seeds was measured for five structural surfaces, namely glass, fiberglass, rubber, plywood, and galvanized iron sheets. A topless and bottomless fiberglass box of 15 cm length, 10 cm width, and 4 cm height was placed on an adjustable inclined plane, faced with the test surface, and filled with the sample. The box was raised slightly (5-10 mm), so as not to be in touch with the surface. The structural surface with the box resting on it was inclined gradually with a screw device until the box just started to slide down over the surface and then the angle of tilt,  $\alpha$  was read from a graduated scale. The static coefficient of friction,  $\mu_s$  was then calculated from the following equation (Nimkar and Chatopadhyay, 2001):

$$\mu_s = \tan \alpha \quad (6)$$

All the experiments reported were replicated at least five times, unless stated otherwise. Statistical analysis of data for various parameters of the study at different moisture contents were not relevant among canola varieties, since adjusting for the same moisture content for each variety was not technically possible. Error bars in all figures represent the standard errors of the replication's means.

## RESULTS AND DISCUSSION

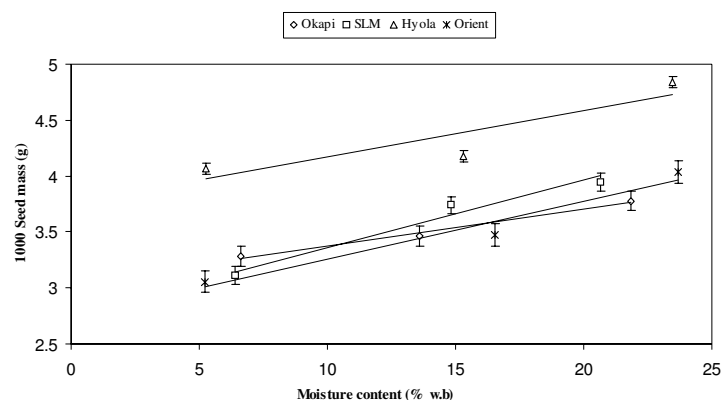
### One Thousand Seed Mass

The effect of moisture content and canola variety on one thousand seed mass is shown in Figure 1. As seen, an increasing trend is observed for 1,000 seed mass with an increase in moisture content in all varieties. It is also observed that Hyola and Orient bear the highest and the lowest 1000 seed mass (4.84 and 3.06 g, respectively) at the studied moisture range of 5.27-23.69% (w.b.).

The regression relationship obtained between one thousand seed mass and moisture content for different varieties at the studied moisture content ranges is presented in Table 1. It can be seen that there are positive linear relationships of one thousand seed mass with moisture content for each variety. Similar results have been found by Deshpande and Ojha (1993) and also Singh and Goswami (1996) for soybean and cumin seeds, respectively. Çalışır *et al.* (2005) also found a positive linear relationship between 1000 seed mass of rapeseeds and their moisture content.

### Dimensional Properties

The size distribution curves for the mean values of the canola seed dimensions at initial moisture content showed a trend towards a normal distribution (Figure 2). It can be seen that about 90% of SLM and Orient seeds had lengths between 1.6 and 2 mm and 86% diameters ranging from 1.4 to 1.8 mm. Nearly 86% of the lengths in Hyola and Okapi seeds lies within 1.8 and 2.2 mm, while about 86% of the diameters in of Hyola seed and 83% of Okapi seed's diameter were between 1.8 and 2 mm and from 1.6 to 1.8 mm, respectively.



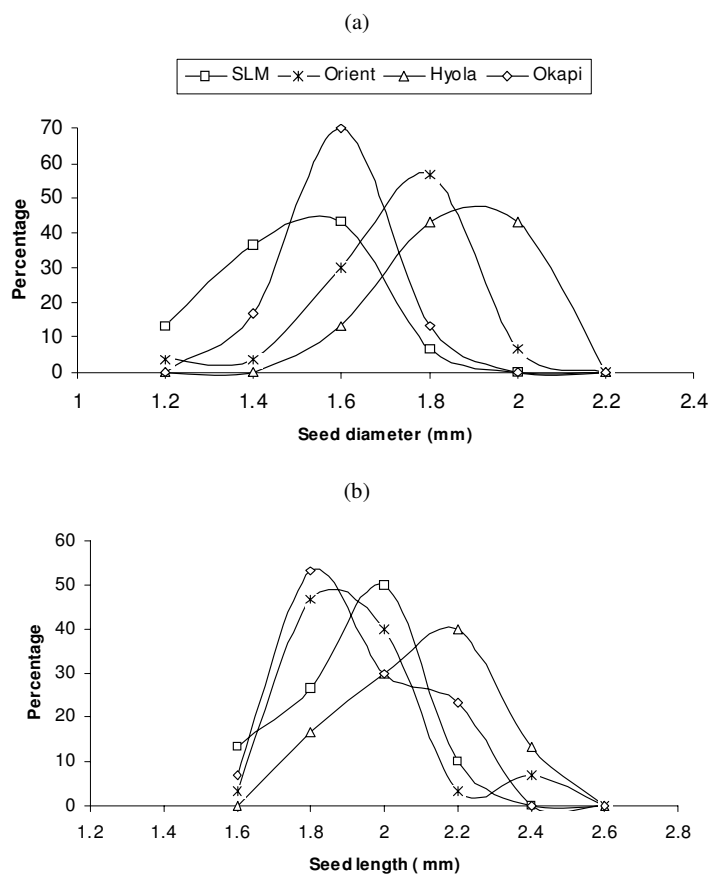
**Figure 1.** Variation of one thousand seed mass as against seed moisture content.

**Table 1.** The relationship between one thousand seed mass ( $M_{1000}$ , g) and moisture content ( $M_c$ ) for four canola varieties.

Variety	$M_c$ (w.b.%)	Equation	$R^2$
Hyola	5.27-23.46%	$M_{1000}=3.7594+0.0411M_c$	0.8105
SLM	6.40-20.66%	$M_{1000}=2.7615+0.0600M_c$	0.9696
Okapi	6.61-21.85%	$M_{1000}=3.0436+0.0330M_c$	0.9875
Orient	5.33-23.69%	$M_{1000}=2.7384+0.0517M_c$	0.9521

The variation of diameter, length, geometric mean diameter, and sphericity of canola seeds as a function of moisture content are presented in Figure 3 (a, b, c, and d). All these parameters for different canola varieties decreased at the second moisture content level while being increased at the third level of moisture content, except for length that was increased with increasing seed moisture content. Probably, this is due to the effect of diameter decreasing with moisture content being more effective on the sphericity, and geometric mean diameter rather than the increasing effect of length. Mean values of length, diameter, geometric mean diameter, and sphericity ranged from 1.925 to 2.262 mm, 1.475 to 1.911 mm, 1.625 to 2.020 mm, and 0.82 to 0.93, respectively. Among the varieties, Hyola possessed the highest values of length, diameter, geometric mean diame-

ter, and sphericity at all moisture levels. Baryeh and Mangope (2002) found similar results for pigeon pea and reported all the dimensions decreased with seed moisture content up to 18.5% while being increased at 25% moisture content. They suggested that there are some voids in the seed which when being filled with water make the voids contract due to surface tension effects resulting in reduction in dimension. When the voids are filled, further water absorption by the seeds results in swelling, making the dimensions more. Regression equations obtained for dimensions, geometric mean diameter and sphericity of canola seed as a function of moisture content are presented in Table 2. It can be observed that there are non-linear relationships in all the cases, except for the length in SLM, Okapi and Orient varieties.



**Figure 2.** Dimensions frequency distribution curves of canola seed varieties at their initial moisture content (% w.b.): (a) Seed diameter and (b) Seed length.

Çalışır *et al.* (2005) reported that length, diameter and geometric mean diameter of rapeseeds increased together with an increase in moisture content, but sphericity decreased as moisture content increased. Deshpande and Ojha (1993) found that the principal dimensions of soybean increase linearly with increasing seed moisture content, while Hsu *et al.* (1991) showed that principal dimensions of pistachios increase nonlinearly with an increase in the level of moisture content.

### Bulk Density

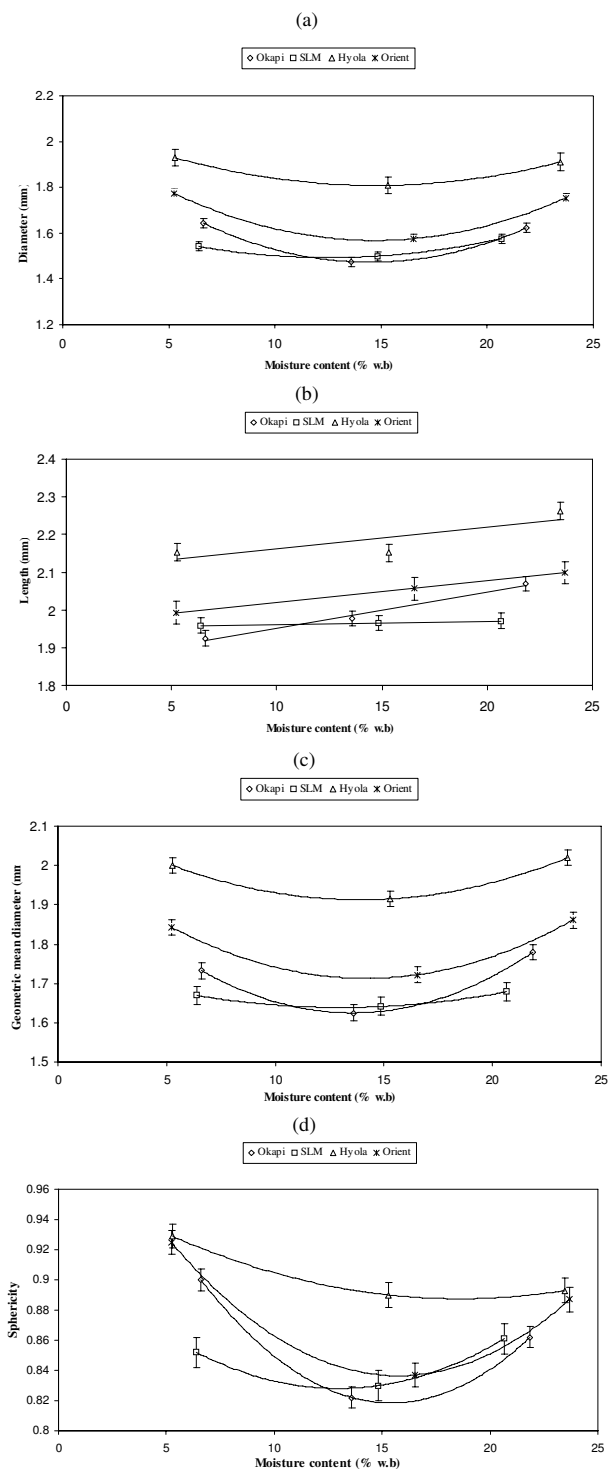
Bulk densities of Hyola, SLM, Okapi and Orient seeds as against varied moisture contents are shown in Figure 4. Among four canola varieties, Hyola, SLM and Orient

showed approximately a similar decreasing trend in bulk density in the range of moisture contents evaluated. Furthermore, the results showed that bulk density of each variety decreased 1.5-3.5% from the first moisture level to the second and 3.5-5% from the second to the third. Hyola showed obvious differences in bulk density in comparison with the other three varieties with this variety possessing the least bulk density at all moisture levels. Maximum and minimum values of bulk density were obtained for SLM ( $738.8 \text{ kg m}^{-3}$  at 6.61% w.b.) and Hyola ( $666.06 \text{ kg m}^{-3}$  at 20.66% w.b.) respectively.



The relationship between bulk density and moisture content obtained for each canola

variety is presented in Table 3. It is observed that there is a negative linear correlation be-



**Figure 3.** Variation of dimensional properties of four canola varieties with moisture content: (a) Diameter; (b) Length, (c) Geometric mean diameter and (d) Sphericity.

tween bulk density and moisture content for all canola varieties studied. Çalışır *et al.* (2005) reported that the bulk density of rapeseed within a moisture range of 4.7-28.96% (d.b.) decreased linearly from 612.1 to 585.1 kg m<sup>-3</sup>. This was probably due to the higher rate of increase in seed volume in comparison to mass and due to structural properties of the canola seed. A negative relationship between bulk density and moisture content was also reported by Baumler *et al.* (2006) for safflower seeds, Carman (1996) for lentil seeds, Coskun *et al.* (2005) for sweet corn seeds, Desphande *et al.* (1993) for soybeans, Dursun and Dursun (2006) for caper seeds, and Mwithiga and Sifuna (2005) for sorghum seeds. While Masoumi *et al.* (2006) reported positive relationship between bulk density and moisture content.

### Filling and Emptying Angles of Repose

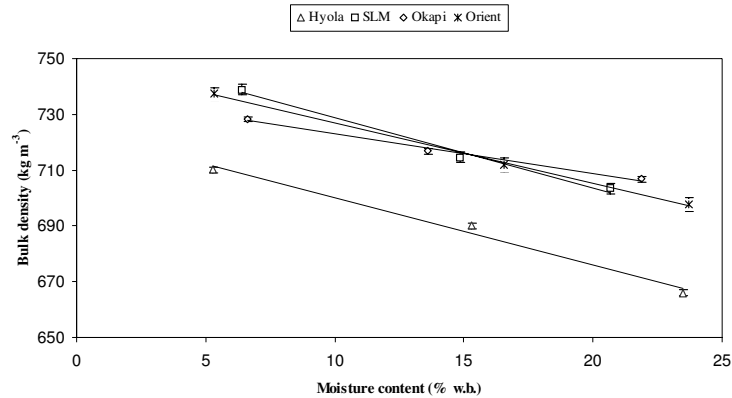
The experimental results for the filling and emptying angles of repose for canola seeds at various moisture levels are shown in Figures 5 and 6, respectively. The highest value of emptying angle of repose obtained for SLM variety was equal to 28.68 degrees at 20.66 (% w.b.). The emptying angle of repose for all canola varieties showed increasing trend with increase in moisture content except for Hyola (Figure 5). This was expected as cohesiveness would increase with an increase in moisture content for many food products, particulate foods such as moist grain, seed, and powders. In the initial stage, an increase in moisture content hardly affected these indices but a marked increase was observed when the moisture content exceeded 13.6 up to 16.53%. An increase in

**Table 2.** Regression equations obtained for dimensions, geometric mean diameter and sphericity of canola seeds as a function of moisture content.

Varieties	M <sub>c</sub> (w.b.%)	Nut equation	R <sup>2</sup>
Hyola	5.27-23.46	L=0.0058M <sub>c</sub> +2.1044	0.6897
		D=0.0014M <sub>c</sub> <sup>2</sup> -0.0398M <sub>c</sub> +2.1025	0.9998
		D <sub>g</sub> =0.0012M <sub>c</sub> <sup>2</sup> -0.0326M <sub>c</sub> +2.1393	0.9999
		Φ=0.0002M <sub>c</sub> <sup>2</sup> -0.0087M <sub>c</sub> +0.9684	0.9998
SLM	6.40-20.66	L=0.0008M <sub>c</sub> +1.9534	0.9889
		D=0.0013M <sub>c</sub> <sup>2</sup> -0.0315M <sub>c</sub> +1.6914	0.9998
		D <sub>g</sub> =0.0007M <sub>c</sub> <sup>2</sup> -0.018M <sub>c</sub> +1.7558	0.9999
		Φ=0.0006M <sub>c</sub> <sup>2</sup> -0.0144M <sub>c</sub> +0.9215	0.9998
Okapi	6.61-21.85	L=0.0096M <sub>c</sub> +1.8565	0.9870
		D=0.0028M <sub>c</sub> <sup>2</sup> -0.08M <sub>c</sub> +2.0522	0.9998
		D <sub>g</sub> =0.0022M <sub>c</sub> <sup>2</sup> -0.0604M <sub>c</sub> +2.0336	0.9998
		Φ=0.0011M <sub>c</sub> <sup>2</sup> -0.0324M <sub>c</sub> +1.0682	0.9997
Orient	5.33-23.69	L=0.0057M <sub>c</sub> +1.9628	0.9999
		D=0.0023M <sub>c</sub> <sup>2</sup> -0.0675M <sub>c</sub> +2.0641	0.9998
		D <sub>g</sub> =0.0016M <sub>c</sub> <sup>2</sup> -0.0462M <sub>c</sub> +2.0401	0.9998
		Φ=0.0008M <sub>c</sub> <sup>2</sup> -0.0252M <sub>c</sub> +1.0349	0.9999

**Table 3.** Relationship between bulk density and moisture content for different varieties of canola at the studied moisture content ranges.

Varieties	M <sub>c</sub> (w.b.%)	Equation	R <sup>2</sup>
Hyola	5.27-23.46	ρ <sub>b</sub> =724.03-2.4048M <sub>c</sub>	0.9878
SLM	6.40-20.66	ρ <sub>b</sub> =753.96-2.5112M <sub>c</sub>	0.9885
Okapi	6.61-21.85	ρ <sub>b</sub> =736.90-1.4026M <sub>c</sub>	0.9924
Orient	5.33-23.69	ρ <sub>b</sub> =748.41-2.1601M <sub>c</sub>	0.9985



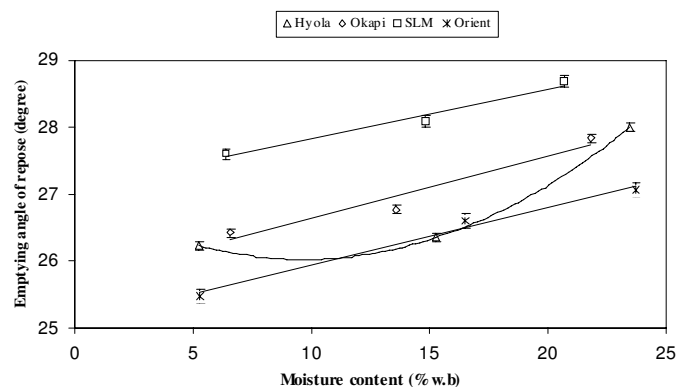
**Figure 4.** Bulk density of canola seeds at various moisture contents.

emptying angle of repose with increasing moisture content was also reported for different other seeds (Altuntas *et al.*, 2005; Dutta *et al.*, 1988; Murthy and Bhattacharya, 1998; Oyelade *et al.*, 2005; Sacilik *et al.*, 2003; Tunde-Akintunde and Akintunde, 2004; Visvanathan *et al.*, 1990).

The filling angle of repose decreased as seed moisture content increased in Orient and Hyola varieties (Figure 6). This might have been due to the seed surface properties. The forces of solid friction at the seed/material interface were generally decreased with increase in grain moisture content. The filling angles of repose observed here showed a maximum decrease obtained

in Orient variety, equal to 25.37 degrees at 23.69% (w.b.) seed moisture content. Ozguven *et al.* (2005) reported similar results for pine seeds.

The variation in filling and emptying angles of repose for canola seeds, as a function of moisture content, can be shown as equations given in Table 4. It can be seen that there were linear relationships for all cases studied except for emptying angle of repose in Hyola and filling angle of repose for Okapi, in which a non-linear relationship was observed.

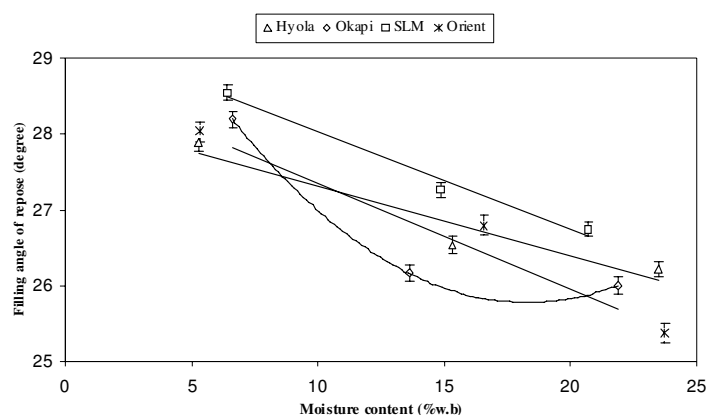


**Figure 5.** Effect of moisture content on emptying angle of repose of canola seeds.



**Table 4.** Relationship between filling angle of repose ( $\theta_f$ ), emptying angle of repose ( $\theta_e$ ) and moisture content obtained for different varieties of canola as a function of moisture content.

Varieties	$M_c$ (w.b.%)	Equation	$R^2$
Hyola	5.27-23.46	$\theta_f = -0.0929M_c + 28.24$ $\theta_e = 0.0105M_c^2 - 0.2032M_c + 27.01$	0.9194 0.9999
SLM	6.40-20.66	$\theta_f = -0.1281M_c + 29.302$ $\theta_e = 0.0744M_c + 27.081$	0.9823 0.9715
Okapi	6.61-21.85	$\theta_f = 0.0177M_c^2 - 0.6465M_c + 31.68$ $\theta_e = 0.0936M_c + 25.695$	0.9997 0.9457
Orient	5.33-23.69	$\theta_f = -0.1421M_c + 28.889$ $\theta_e = 0.0873M_c + 25.055$	0.9732 0.9879

**Figure 6.** Effect of moisture content on filling angle of repose of canola seeds.

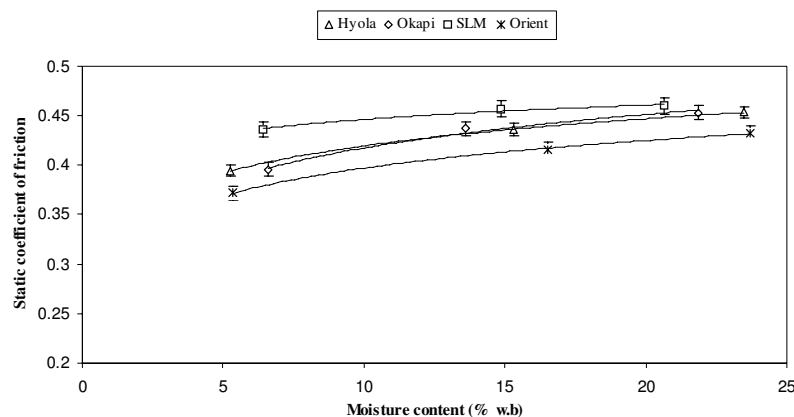
### Coefficient of Static Friction

The static coefficients of friction for Hyola, SLM, Okapi and Orient seeds at different moisture contents on five different structural surfaces (rubber, plywood, galvanised iron, fiberglass, and glass) are shown in Figures 7 to 11. It can be seen that the static coefficient of friction on all surfaces increased with increase in moisture content. This could be due to increased adhesion between the seed and the surface at higher moisture values.

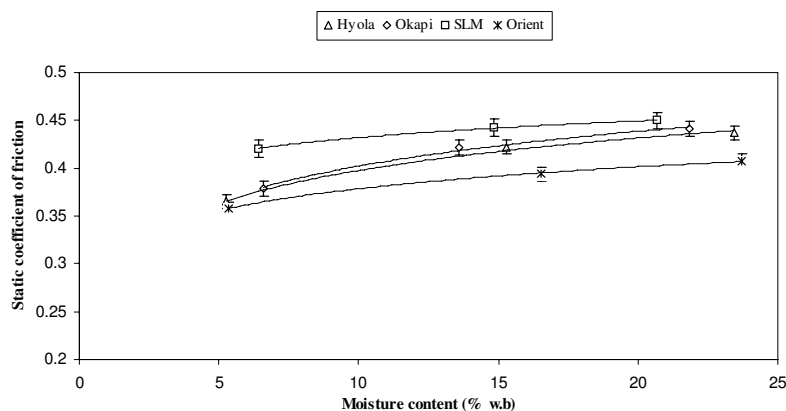
At all moisture levels, the static coefficient of friction was greatest against rubber (0.372-0.460), followed by plywood (0.358-0.450), galvanised iron sheet (0.301-0.419)

and fiberglass (0.260-0.414) while the least for glass sheet (0.253-0.392). This may be due to smoother and more polished surface of glass in comparison with other test surfaces. Among canola varieties, Orient was observed to undergo the least static coefficients of friction in the series, whereas, SLM exerted the greatest static coefficients of friction at all moisture levels studied.

The relationship between static coefficients of friction and moisture contents for each canola variety is presented in Table 5. It can be observed that there exists a logarithmic relationship in all cases. Çalışır *et al.* (2005) reported the static coefficient of friction of rapeseeds on iron sheet, galvanized sheet and plywood. On all these three surfaces, the static coefficient of friction increased with increase in moisture content



**Figure 7.** The static coefficient of friction of canola seeds on rubber surface as a function of moisture content and variety.



**Figure 8.** The static coefficient of friction of canola seeds on plywood surface as a function of moisture content and variety.

and at all moisture levels, plywood showing the highest static coefficient of friction, followed respectively by iron and galvanized sheets. Many researchers studied the static coefficient of friction of agricultural products on different surfaces and reported positive linear relationships between coefficient of friction and moisture content (Altuntas *et al.* 2005; Carman 1996; Dursun and Dursun 2006; Mwithiga and Sifuna 2005; Paksoy and Aydin 2004; and Singh and Goswami 1995).

## CONCLUSIONS

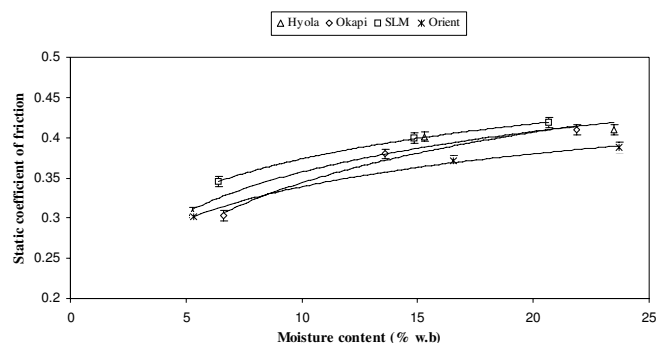
The following conclusions are drawn from this investigation into moisture dependent physical properties of four common varieties of canola seed.

1. The physical properties of canola seed varied from variety to variety and these variations were functions of the seed moisture content.

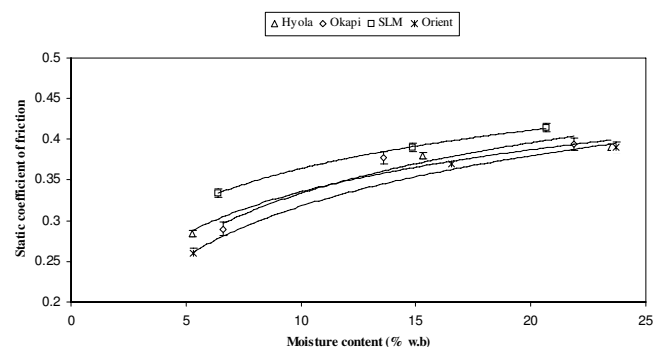
**Table 5.** Relationship between static coefficient of friction on five structural surfaces and moisture content obtained for different varieties of canola as a function of moisture content.

Varieties	M <sub>c</sub> (w.b.%)	Frictional surfaces	Equation	R <sup>2</sup>
Hoyla	5.27-23.46	Glass	$\mu_{sg}=0.0686\text{Ln}(M_c)+0.1436$	0.9649
		Fiberglass	$\mu_{sf}=0.0744\text{Ln}(M_c)+0.1642$	0.9600
		Galvanized iron	$\mu_{si}=0.7260\text{Ln}(M_c)+0.1901$	0.9581
		Plywood	$\mu_{sp}=0.6491\text{Ln}(M_c)+0.2846$	0.9932
		Rubber	$\mu_{sr}=0.0396\text{Ln}(M_c)+0.3286$	0.9999
SLM	6.40-20.66	Glass	$\mu_{sg}=0.0788\text{Ln}(M_c)+0.1062$	0.9941
		Fiberglass	$\mu_{sf}=0.6790\text{Ln}(M_c)+0.2076$	0.9996
		Galvanized iron	$\mu_{si}=0.0622\text{Ln}(M_c)+0.2008$	0.9994
		Plywood	$\mu_{sp}=0.0170\text{Ln}(M_c)+0.3745$	0.9990
		Rubber	$\mu_{sr}=0.0208\text{Ln}(M_c)+0.3984$	0.9735
Okapi	6.61-21.85	Glass	$\mu_{sg}=0.0850\text{Ln}(M_c)+0.1114$	0.9868
		Fiberglass	$\mu_{sf}=0.0898\text{Ln}(M_c)+0.1269$	0.9361
		Galvanized iron	$\mu_{si}=0.0907\text{Ln}(M_c)+0.1351$	0.9840
		Plywood	$\mu_{sp}=0.5250\text{Ln}(M_c)+0.2813$	0.9896
		Rubber	$\mu_{sr}=0.0490\text{Ln}(M_c)+0.3047$	0.9826
Orient	5.33-23.69	Glass	$\mu_{sg}=0.0806\text{Ln}(M_c)+0.1193$	0.9910
		Fiberglass	$\mu_{sf}=0.0894\text{Ln}(M_c)+0.1119$	0.9927
		Galvanized iron	$\mu_{si}=0.0589\text{Ln}(M_c)+0.2034$	0.9976
		Plywood	$\mu_{sp}=0.0331\text{Ln}(M_c)+0.3023$	0.9983
		Rubber	$\mu_{sr}=0.0403\text{Ln}(M_c)+0.3042$	0.9986

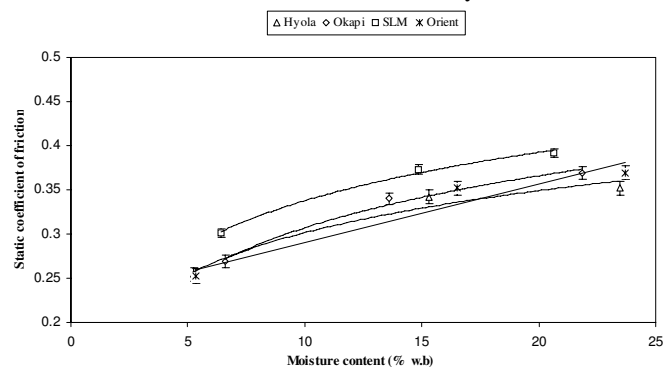
2. With increase in moisture content, the length, and thousand seed mass of canola seeds increased linearly in all varieties, except for Hoyla in which the change was non-linear. Bulk density decreased linearly for each and every variety. The average length, one thousand seed mass, and bulk density of the canola seed ranged from 1.925 to 2.262 mm, 3.06 to 4.84 g and 666.06 to 738.8 kg m<sup>-3</sup> as the moisture content increased from 5.27 to 23.69 % w.b., respectively.
3. The diameter, geometric mean diameter and sphericity changed non-linearly with increasing moisture content in all canola varieties. Diameter and geometric mean diameter of the seeds varied from 1.475 to 1.911 mm and 1.625 to 2.02 mm within the moisture content range studied. Furthermore, canola seeds were of a near spherical shape as reflected by their high sphericity values (close to 1.0).
4. An increase in the seed moisture content led to linear increases in the emptying angle of repose in all varieties, except for Hoyla. Linear decreasing of the filling angle of repose was the result of an increase in seed moisture content for all varieties, except for Hoyla and Okapi. The maximum emptying angle of repose was obtained for SLM (28.68°), while minimum filling angle of repose recorded for Orient (25.48°). The static coefficients of friction on various surfaces increased non-linearly with increase in seed moisture content. The highest static coefficient of friction was observed on rubber (0.460) and for variety SLM



**Figure 9.** The static coefficient of friction of canola seeds on galvanized iron sheet surface as a function of moisture content and variety.



**Figure 10.** The static coefficient of friction of canola seeds on fiberglass surface as a function of moisture content and variety.



**Figure 11.** The static coefficient of friction of canola seeds on glass surface as a function of moisture content and variety.

while the least on glass sheet (0.253) and for Orient variety.

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## Nomenclature

D	Diameter, mm
$D_g$	Geometric mean diameter, mm
L	Length, mm
$M_c$	Moisture content, (% w.b.)
$M_1$	Initial moisture content, (% w.b.)
$M_2$	Desired moisture content, (% w.b.)
$M_{1000}$	One thousand seed mass, g
$R^2$	Coefficient of determination
$W_1$	Initial sample mass, kg
$W_2$	Mass of distilled water added, kg
$\alpha$	Angle of tilt, degree
$\theta_f$	Filling angle of repose, degree
$\theta_e$	Emptying angle of repose, degree
$\mu_s$	Static coefficient of friction
$\rho_b$	Bulk density, kg m <sup>-3</sup>
$\Phi$	Sphericity, decimal

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### خواص فیزیکی وابسته به رطوبت دانه کلزا

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#### چکیده

خواص فیزیکی چهار وارپته رایج ایرانی دانه کانولا (هایولا، اکابی، اورپنت، اس ال ام) به عنوان تابعی از رطوبت مورد ارزیابی قرار گرفت. میانگین طول و وزن هزار دانه به صورت خطی به ترتیب از ۱/۹۲۵ تا ۲/۲۶۲ میلی متر و ۳/۰۶ تا ۴/۸۴ گرم تغییر کرد. میانگین قطر، قطر هندسی، کروییت در محدوده رطوبتی ۵/۲۷ تا ۲۳/۶۵ درصد (وزن مرطوب) به طور غیرخطی به ترتیب از ۱/۴۷۵ تا ۱/۹۱۱ میلی متر، ۱/۶۲۵ تا ۲/۰۲ میلی متر و ۰/۸۲ تا ۰/۹۳ تغییر کرد. در میان وارپته ها و در تمامی سطوح رطوبتی، هایولا بالاترین میزان طول، قطر، قطر هندسی، کروییت و وزن هزار دانه را در تمامی سطوح رطوبتی دارا بود. بیشترین و کمترین میزان دانسیته توده برای اس ال ام ( $738/8 \text{ kg m}^{-3}$ ) و هایولا ( $666/06 \text{ kg m}^{-3}$ ) به دست آمد. زاویه ریپوز پر کردن و تخلیه به ترتیب در محدوده ۲۵/۳۷ تا ۲۸/۵۴ و ۲۵/۴۸ تا ۲۸/۶۸ درجه تغییر کرد. در تمامی سطوح رطوبتی، بالاترین مقدار ضریب اصطکاک ایستایی مربوط به لاستیک (۰/۳۷۲ تا ۰/۴۶۰) و بعد از آن به ترتیب مربوط به تخته سه لا (۰/۳۵۸ تا ۰/۴۴۹)، آهن گالوانیزه (۰/۳۰۱ تا ۰/۴۱۹)، فایبرگلاس (۰/۲۶۰ تا ۰/۴۱۴) و کمترین ضریب اصطکاک ایستایی مربوط به شیشه (۰/۲۵۳ تا ۰/۳۹۲) بود. در تمام سطوح رطوبتی، اورپنت و اس ال ام به ترتیب کمترین و بیشترین مقدار ضریب اصطکاک ایستایی را به خود اختصاص دادند.