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PHYSICAL PROPERTIES OF SOME OIL PRODUCING CROPS

Matouk, A.M.; S.M. Abd El-latif and A. Tharwat
Dept. of Agricultural Engineering, Fac. of Agric., Mansoura Univ.

ABSTRACT

Physical properties such as principal dimensions and it's related characteristics, mass of 1000 seeds, projection area, bulk and true density and porosity for three different oil producing crops (sunflower, soybean and canola) were determined at five different levels of seeds moisture content. The obtained results showed that, the principal dimensions and it's related characteristics such as geometric and arithmetic mean diameter, actual and calculated volumes, shape index (K), surface area (As), surrounded surface area (Ass), coefficient of contact surface (C.C.), the aspect ratios, mass of 1000 seeds, seeds porosity and seeds projection area of sunflower seeds and kernels, soybean and canola seeds generally increased linearly with the increasing of seeds moisture content, on the other hand, the shape index (K), coefficient of contact surface and the aspect ratios of sunflower kernels decreased linearly with the increasing of seeds moisture content. But, sphericity of sunflower and soybean seeds and the bulk and true densities for all studied crops decreased with the increasing of seeds moisture content.

Mathematical relationships were also developed for the different studied crops to relate the obtained values of all physical properties with the change in seeds moisture content.

INTRODUCTION

Physical properties describe the unique, characteristic way a food material responds to physical treatments involving mechanical, thermal, electrical, optical, sonic, and electromagnetic processes.

A better understanding of the way food materials respond to physical and chemical treatments allows for optimum design of food equipment and processes to insure food quality and safety. (Wilhelm *et. al.*, 2004).

Deshpande *et. al.,* (1993) found that, for soybean, the average values of three principal dimensions (L, W, T) appeared to be linearly dependent on the moisture content. They also mentioned that, soybean grain expands more along its thickness in comparison to its other principal axes which may be due to the arrangements of the cells in the kernel and also to the increase in cavity between the two halves of the cotyledons.

Gupta and Das, (1997) determined the average length, width and thickness of sunflower seed and kernels. The results of the investigated varieties showed that, about 80% of the bulk seed had length varying between 8 and 10 mm whereas about 11 and 8% had length greater than 10 mm and less than 8 mm respectively. Also the length of the seed was found to be closely related to its thickness and width but less associated with its mass.

Also, Mwithiga and Sifuna, (2006) mentioned that, the dimensions of sorghum seed increased linearly by 2.8 % to 3.8 % when the moisture content was increased from 13.64% to 21.95 % (d.b.). The major dimension (length) had the smallest increase percentage with the increasing in moisture content.

Omobuwajo *et. al.,* (1999) showed that, the shape indices are required to give a comprehensive description of the shape of the seed. Where the sphericity is an expression of the shape of a solid relative to that of a sphere of same volume, the roundness is a measure of the sharpness of the so called corners of the seed, while the aspect ratio relates the width to the length of the seed and is indicative of tendency towards an oblong shape.

Sahoo and Srivastava, (2002) studied the shape of the seed, in terms of roundness and sphericity. Both roundness and sphericity were observed to decrease with the increasing of moisture content from 8.16 to 19.56% and, thereafter increased with the increasing of moisture content up to 20 %.

Matouk *et. al.,* (2004 a) revealed that, both shape index and coefficient of contact surface for rice, wheat, corn, and barely are decreased linearly with the increasing of grain moisture content.

Gupta and Das, (1997) found that the sunflower kernel had higher densities than that of seed. Also they found that, the seed bulk density decreased linearly with the increasing in moisture content while the true density was increased. On the other hand they found that, as the moisture content increased the corresponding densities for kernel are also increased.

Also, Çalışır *et .al.,* (2005) found that, the bulk density of rapeseed decreased from 612.1 to 585.1 kg/m^3 as the moisture content increased from 4.70 to 23.96 % (d.b.).

Deshpande *et. al.,* (1993) mentioned that, since the porosity depends on the bulk density as well as true or kernel densities, the magnitude of variation in porosity depends on these factors only. Also, they found that the porosity of soybeans grain decreases linearly with the increasing in moisture content.

The present study aims to determine some physical properties of sun flower, soybean and canola seeds as a function of the change in seeds moisture content. The measured properties included seeds dimensions and related characteristics, mass of 1000 seeds, seeds projection area, bulk and true density and porosity.

MATERIALS, MEASUREMENTS AND TEST PROCEDURES

1. Materials:

Samples of the investigated crops (Sunflower variety Giza 102, Soybean variety Giza 111 and Canola variety Serow 55) were obtained from the research station of Agricultural Research Center, (Gimmeza experimental station) to grantee the purity of the selected varieties. These varieties were selected based on its recent coverage area and the expected future expansion according to Ministry of Agriculture yearly bulletins (MALR, 2005 a,b). The samples were cleaned to remove impurities, immature kernels and foreign materials. The seeds of each variety were then stored in a burlap sacks inside a ventilated storage room.

2. Measurements and Test Procedures:

Physical properties of sunflower, soybean and canola varieties were measured and calculated at different levels of seeds moisture content. The measured properties included seed dimensions and related characteristics, mass of 1000 seeds, projection area, bulk and true density and porosity.

2.1. Seed's Principal Dimensions:

A digital caliper with accuracy of 0.01 mm, was used to measure the length (L), width (W) and thickness (T) for sunflower and soybean seeds and the diameter of canola seeds at different levels of seeds moisture content. The average length, width and thickness or the average diameter of 50 seeds were calculated for each variety.

2.1.1. Related Characteristics of Seed's Principal Dimensions:

a- Geometric mean diameter (Dg), arithmetic mean diameter (Da) and the calculated volume (V_{cal}):

Geometric mean diameter (D_g), arithmetic mean diameter (D_a) and the calculated volume of different studied crops were calculated using the following equation, respectively.

$$D_g = \left(L\,x W\,x T\right)^{1/3}\text{, mm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$D_a = \frac{L+W+T}{3}\text{, mm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$V_{cal.} = \frac{\pi}{6} L\,x W\,x T\text{ , mm}^3 \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

(Mohsenin, 1984 and El Raie *et. al.,* 1996).

b- Shape index of seeds (k):

Seeds shape index (k) was calculated using the measured values of the principal dimensions and used to describe shape of different seed varieties using the following equation **(Abd Alla, 1995)**:

$$k = L / \sqrt{(W.T)}\text{ , decimal} \ldots\ldots\ldots\ldots (4)$$

c- Sphericity (Φ):

The Sphericity percent of seeds was calculated from the following equation **(Mohsenin, 1984)**:

$$\phi = \frac{(WLT)^{1/3}}{L} x100\text{ , \%} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where $0 < \Phi \leq 100$ %

d- Coefficient of contact surface (C.C)

Coefficient of contact surface (C.C) was calculated for different studied crops according to **(Abd Alla, 1995)**:

$$C.C\% = \frac{A_f - A_t}{A_f} x100\text{ , \%} \ldots .(6)$$

Where:

A_f = area of flat surface = $(\pi/4)$ x Lx W, mm^2

A_t = area of transverse surface = $(\pi /4)$ x W x Th, mm^2

e- Surface area (A_s):

The surface area of seed was calculated using the following formula **(Deshpande *et. al.*, 1993)**:

$$A_s = \pi D_g^2 \text{ , mm}^2 \text{ ………………………….(7)}$$

f- Surrounded surface area (A_{ss}):

The surrounded surface area was calculated from the following equation **(El Raie et. al., 1996)**:

$$A_{ss} = \frac{\pi}{2}(L + D_g)\ (D_g) \text{ , mm}^2 \text{ ………………… (8)}$$

g- Aspect ratios (R_1, R_2 and R_3):

Three aspect ratios are developed based on the axial dimensions as follows:

$$R_1 = \frac{L}{W} \text{ , decimal …………………………. (9)}$$

$$R_2 = \frac{L}{Th} \text{ , decimal …………..……………. (10)}$$

$$R_3 = \frac{W}{Th} \text{ , decimal ……………..…………. (11)}$$

2.2. Real Volume and True Density:

Graduated flask and pipette (100 ml capacity and 0.1 ml accuracy) fixed with a tube holder used to determine the real volume and true density of seeds.

2.3. Seeds Porosity:

Porosity of the studied crops was measured using an apparatus developed by (Matouk *et. al.*, 2004b) according to that reviewed by (Mohsenin, 1984). The apparatus consists of two identical stainless-steel tanks sealed by compressed rubber covers. The first tank connected to an air compressor, pressure reducer and a control valve (1). The second tank filled with seeds sample and connected to control vale (2) and (3). A precise manometer fixed to the main pipe for detecting the air pressure during different stages of measurement. Fig. (1) shows the apparatus used for measuring seeds porosity.

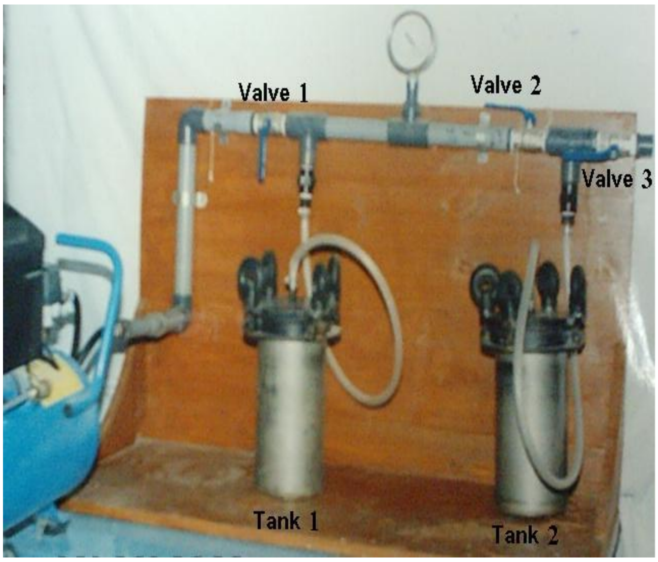

Figure (1): Apparatus used for measuring seeds porosity.

Detailed description of the measurement and test procedure are given by (Matouk *et. al.,* 2004b).

The porosity percentage obtained from the following equation:

$$\mathrm{Pr} = \frac{p_1 - p_3}{p_3} x 100 \text{ ....(12)}$$

where:

Pr: Seeds porosity, (%).

P_1: The absolute pressure in tank (1), (bar).

P_2: The absolute pressure in both tanks (1 and 2), (bar).

2.4. Mass of 1000 Seeds:

To determine the 1000 seeds mass, a sample of 0.5 kg was drawn from the bulk of each moisture content level and 10 sub-samples each of 1000 seeds were picked out. The mass of 1000 seeds of each sub-sample was determined by an electronic balance with accuracy of 0.01 gm, then the average of the sub-samples was calculated.

2.5. Bulk and True Densities of Seeds:

The bulk density was determined based on the volume occupied by seeds bulk as follows:

a- Bulk density at loose seeds fill:

Bulk density at loose fill condition was determined by filling a known container volume with the seeds from a height of 150 cm at constant rate (Matouk, *et. al.,* 2004 b) then the mass of seeds bulk was determined and the bulk density was calculated as follows:

$$B_d = \frac{M_b}{V_b}$$, kg/m^3 ……………….……………… (13)

Where:

B_d = bulk density of sample, (kg/m^3)
M_b = mass of bulk sample of seeds, (kg).
V_b = volume of bulk sample, (m^3)

b- True density:

The true density of each variety was determined using a toluene displacement method with a known mass of seeds. The following equation used for calculating the true density of each crop as follows:

$T_d = M / V_i$, kg/m^3 ………………….. (14)

Where:

T_d = true density of sample, (kg/m^3).
M = mass of sample, (kg).
V_i = displaced volume of toluene, (m^3).

RESULTS AND DISCUSSION

1. Seeds Principal Dimensions:

The effect of seeds moisture content on seeds principal dimensions are shown in Figures (2) through (4).

As shown in Figure (2), sunflower, variety Giza 102 recorded the highest seeds length which increased form 11.22 to 11.93 mm with the increasing of seeds moisture content from 7.35 to 23.7 % (w.b.). Also, the seeds width increased form 6.05 to 6.25 mm., while, the thickness increased from 4.09 to 4.19 mm at the same range of moisture content.

On the other hands, the sunflower kernels length increased from 8.84 to 9.06 mm with the increasing of moisture content from 6.33 to 22.57% (w.b.). Also, the width increased from 4.28 to 4.47 mm., while, the thickness increased from 2.42 to 2.61 mm at the same range of moisture content.

For soybean, variety Giza 111, Figure (3) shows that, seeds length, width and thickness increased from (7.5 to 7.98 mm), (6.74 to 7.02 mm) and (5.86 to 6.02 mm) with the increasing of seeds moisture content from 9.52 % to 24.644 % (w.b.).

However, due to the nature of canola seeds shape (round shape), the seeds diameter was considered for the experimental measurements. As shown in Figure (4), the diameter increased from 2.07 to 2.20 mm with the increasing of seeds moisture content from 7.11 to 25.722 % (w.b.).

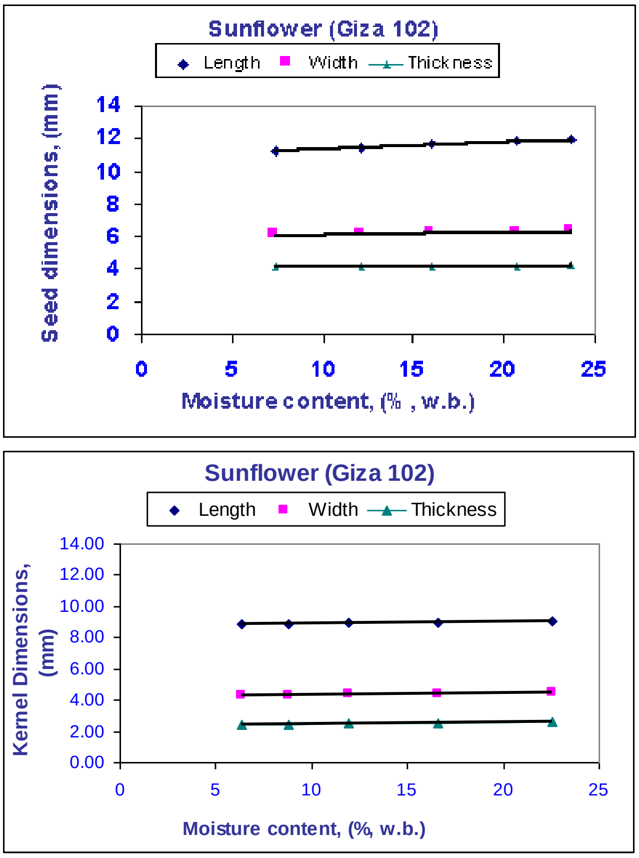

Figure (2): Effect of moisture content on sunflower seeds and kernels length, width and thickness.

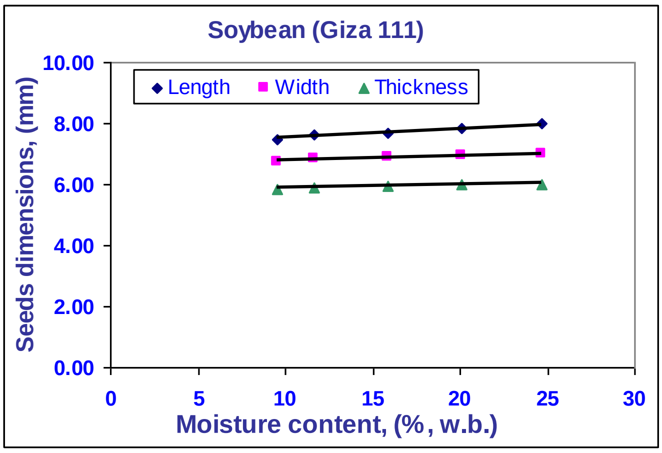

Figure (3): Effect of moisture content on soybean seeds length, width and thickness.

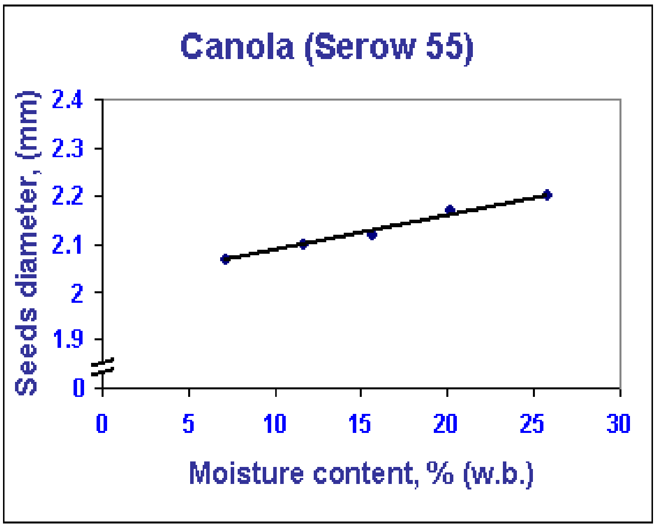

Figure (4): Effect of moisture content on canola seeds diameter.

The change in principal dimensions of sunflower seeds and kernel, soybean and canola seeds as a function of moisture content, could be described by the following empirical relationship:

$$L, W, T, D = a + b\ (MC.) \quad \ldots\ldots\ldots\ldots (15)$$

Where:

L, W, T and D=length, width, thickness and diameter, (mm).

MC. = Moisture content, % (w.b.).

a and b = Constants.

The values of the constants (a and b) are presented in Table (1).

Table (1): Values of constants (a and b) of equations (15):

Crop		Dimension	a	b	R^2
Sunflower	Seeds	Length, L, mm	10.897	0.0449	0.977
		Width W, mm	5.9551	0.0122	0.996
		thickness T, mm	4.0412	0.0062	0.986
	kernels	Length, L, mm	8.769	0.0128	0.986
		Width W, mm	4.2149	0.0114	0.995
		thickness T, mm	2.3626	0.0114	0.974
Soybean seeds		Length, L, mm	7.2321	0.0301	0.991
		Width W, mm	6.6055	0.0170	0.965
		thickness T, mm	5.7805	0.0101	0.961
Canola seeds		Diameter, D, mm	2.0164	0.0072	0.986

1.1. Related characteristics of seeds principal dimensions:

A- Geometric and arithmetic mean diameter (D_g and D_a):

The effect of moisture content on both geometric (D_g) and arithmetic (D_a) mean diameter are shown in Figure (5).

The geometric mean diameter for sunflower seeds and kernels increased from 6.52 to 6.79 mm and from 4.51 to 4.73 mm with the increasing of moisture content from 7.53 to 23.7 % (w.b.) and from 6.33 to 22.57 % (w.b.), respectively. Also, the arithmetic mean diameter increased from 7.12 to 7.46 mm and from 5.18 to 5.38 mm with the increasing of moisture content from (6.51 to 6.79 %) and from (4.51 to 4.73 %)for seeds and kernels respectively.

However, both geometric and arithmetic mean diameters of soybean seeds increased from 6.67 to 6.96 mm and from 6.70 to 7.01 mm respectively, as the moisture content increased from 9.52 to 24.644 % (w.b.).

The relationship between geometric and arithmetic mean diameter and the moisture content of sunflower seeds and kernels and soybean seeds could be expressed as follows:

$$D_g, D_a = c + d\ (MC) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Where:

D_g = The geometric mean diameter, mm.
D_a = The arithmetic mean diameter, mm.
MC = Moisture content, % (w.b.).
c and d = Constants.

The values of the constants (c and d) were presented in Table (2).

Table (2): Values of constants (c and d) of equations (16):

Crop		Mean diameter, mm.	c	d	R^2
Sunflower	Seeds	D_g	6.4016	0.0163	0.989
		D_a	6.9645	0.0211	0.986
	kernels	D_g	4.4371	0.0132	0.986
		D_a	5.1155	0.0119	0.989
Soybean seeds		D_g	6.5128	0.0183	0.982
		D_a	6.5349	0.0191	0.983

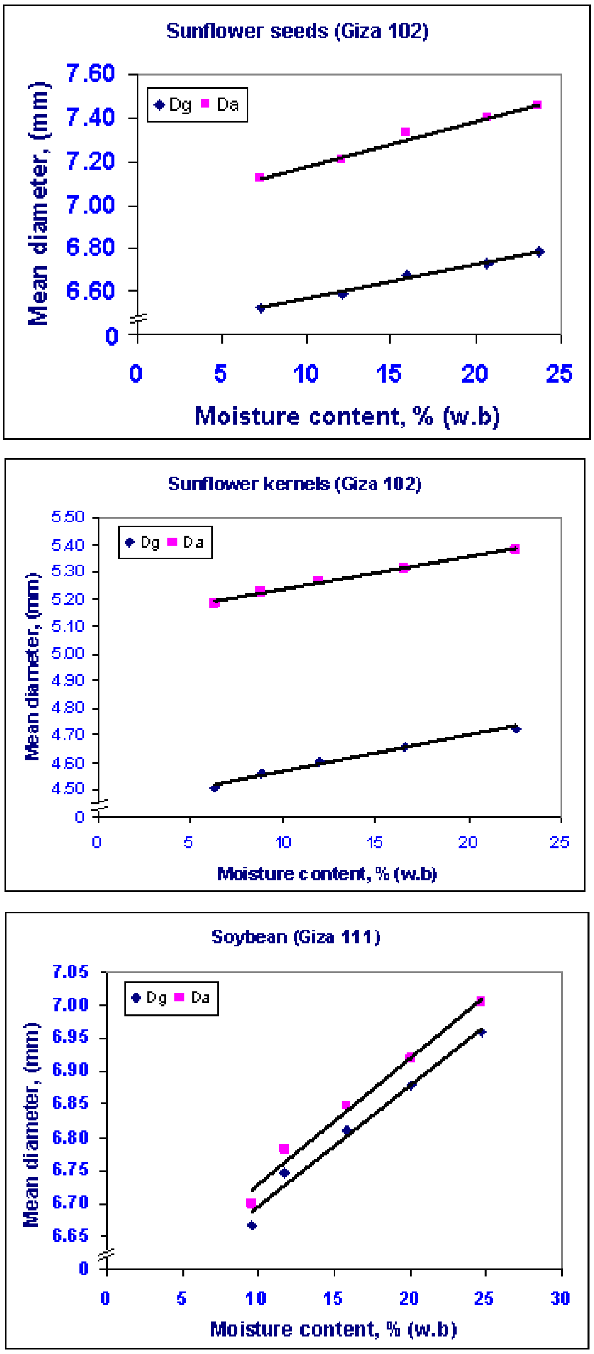

Figure (5): The effect of moisture content on geometric and arithmetic mean diameter of sunflower seeds and kernels and soybean seeds.

B- Seeds volume:

For sunflower seeds, sunflower kernels, soybean seeds and canola seeds, Figure (6) shows that, the actual volume increased from 150.06 to 177.781 mm^3, from 49.208 to 58.462 mm^3, from 148.338 to 171.388 mm^3 and from 3.17 to 3.68 mm^3 with the increasing of moisture content from 7.35 to 23.7 % (w.b.), from 6.33 to 22.57 % (w.b.) from 9.52 to 24.644 % (w.b.) and from 7.11 to 25.72 % (w.b.), respectively. On the same time, the actual volume (V_{Dg}) increased from 145.369 to 163.586 mm^3, from 155.102 to 176.502 mm^3 and from 3.25 to 3.46 mm^3, respectively. While, the calculated volume (V_{Da}) increased from 188.99 to 217.058 mm^3, and from 157.48 to 180.031 mm^3 for sunflower seeds, sunflower kernels and soybean, respectively.

The results obviously show that, the calculated values of the geometric mean diameter gave closer values with the measured values. This means that, it could be conveniently used for the theoretical determination of seeds volume.

The relationship between the actual and the calculated volume of all studied crops was found to be as follow:

1- For sunflower:

$$V_a = 1.0634\ (V_{Dg}),\ (R^2 = 0.906)\ldots\ldots\ldots\ldots\ (17)$$

2- For soybean:

$$V_a = 0.9508\ (V_{Dg}),\ (R^2 = 0.930)\ldots\ldots\ldots\ldots\ldots(18)$$

3- For canola:

$$V_a = 0.9784\ (V_{Dg}),\ (R^2 = 0.978)\ldots\ldots\ldots\ldots\ldots(19)$$

C- Shape index (k) and Sphericity (Φ):

As shown in Table (3), for sunflower seeds the shape index increased from 2.26 to 2.33 while, the sphericity decreased from 58.14 to 56.88 % with the increasing of moisture content from 7.35 to 23.7 % (w.b.).

Similar trend was also obtained for both shape index and sphericity of soybean seeds, where the shape index increased from 1.19 to 1.23 while, the sphericity decreased from 88.88 to 87.21 % with the increasing of moisture content from 9.52 to 24.644 % (w.b.).

Moreover, the shape index and sphericity of sunflower kernels detected an opposite trend of variation with the moisture content, where the shape index decreased from 2.75 to 2.65 and the sphericity increased from 50.99 to 52.18 % with the increasing of moisture content from 6.33 to 22.57 % (w.b.).

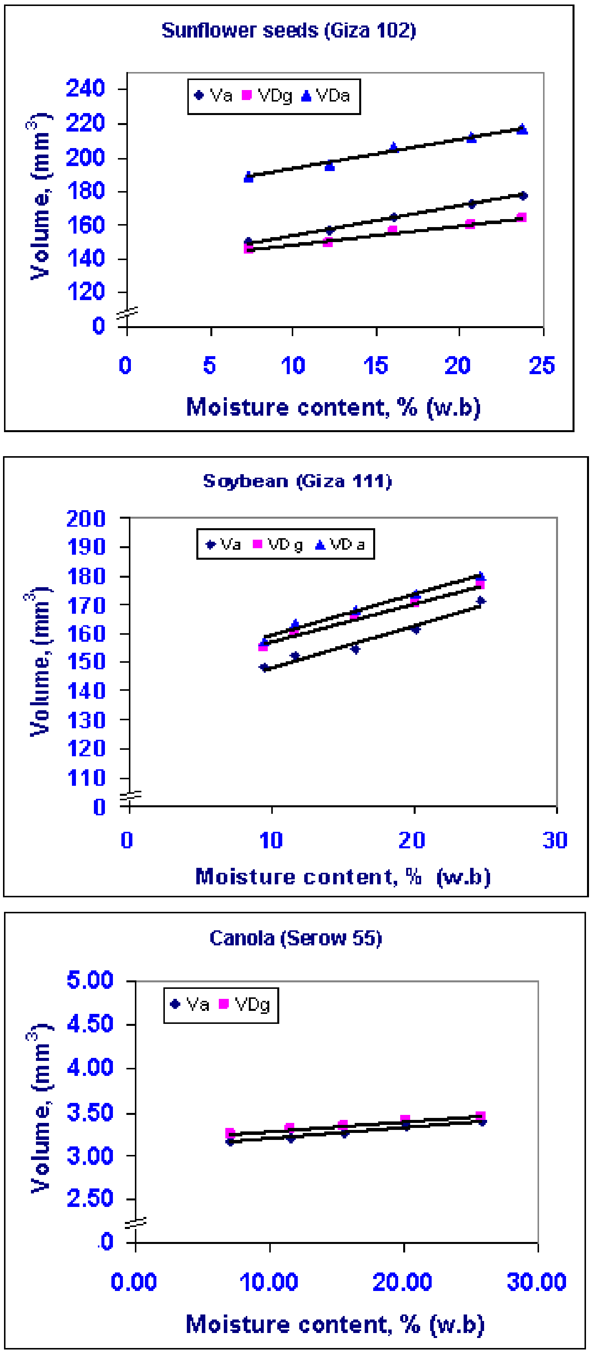

Figure (6): Change in the actual and the calculated volumes of different studied crops as a function of moisture content.

Table (3): The values of shape index and sphericity of sunflower and soybean seeds at different levels of moisture content:

Crop		Moisture content, % (w.b.)	Shape index (k)	Sphericity (Φ), %
Sunflower	seeds	7.35	2.26	58.14
		12.11	2.28	57.77
		15.997	2.32	57.13
		20.7	2.33	56.94
		23.7	2.33	56.88
	kernels	6.33	2.75	50.99
		8.81	2.72	51.27
		11.93	2.70	51.57
		16.61	2.67	51.93
		22.57	2.65	52.18
Soybean		9.52	1.19	88.88
		11.693	1.20	88.66
		15.831	1.20	88.33
		20.053	1.21	87.96
		24.644	1.23	87.21

D- Coefficient of contact surface (C.C.):

As shown in Table (4), the coefficient of contact surface (C.C.) is generally increased with the increasing of seeds moisture content except for sunflower kernels.

On the same time, sunflower kernels recorded the highest values of coefficient of contact surface, which decreased from 72.62 to 71.20% with the increasing of seeds moisture content from 6.33 to 22.57 %. While, soybean seeds recorded the lowest values which increased from 21.87 to 24.56 % with the increasing of seeds moisture content from 9.52 to 24.644 %.

E- Surface area (A_s):

As shown in Table (4), soybean seeds recorded the highest values of surface area, which increased from 139.60 to 152.17 mm^2 with the increasing of seeds moisture content from 9.52 to 24.644 % followed by sunflower seeds which increased from 133.70 to 144.65 mm^2 with the increasing of moisture content from 7.35 to 23.7 % and sunflower kernels which increased from 63.82 to 70.20 mm^2 with the increasing of moisture content from 6.33 to 22.57 %. On the same time, canola seeds recorded the lowest values of surface area which increased from 13.46 to 15.21 mm^2 with the increasing of seeds moisture content from 7.11 to 25.72 %.

F- Surrounded surface area (A_{ss}):

The surrounded surface area is generally increased with the increasing of seeds moisture content.

As shown in table (4), sunflower seeds recorded the highest values of surrounded surface area, which increased from 181.83 to 199.48 mm^2 with the increasing of seeds moisture content from 7.35 to 23.7 % followed by soybean seeds which increased from 148.34 to 163.32 mm^2 with the increasing of moisture content from 9.52 to 24.644 % and sunflower kernels which increased from 94.50 to 102.38 mm^2 as the moisture content increased from 6.33 to 22.57 %. On the same time, canola seeds recorded the lowest values of surrounded surface area which increased from 13.46 to 15.21 mm^2 with the increasing of seeds moisture content from 7.11 to 25.72 %, respectively.

G- The aspect ratios (R_1, R_2 and R_3):

As shown in Table (4), the aspect ratios generally increased with the increasing of seeds moisture content except for sunflower kernels.

The obtained data showed that, sunflower kernels recorded the highest values of all ratios R_1, R_2 and R_3, followed by sunflower seeds, while soybean recorded the lowest values.

Table (4): The related characteristics of sunflower seeds and kernels, soybean and canola seeds at different levels of moisture content levels:

Crop		M.C., % (w.b.)	(C.C.), %	A_s, mm^2.	A_{ss}, mm^2.	R_1 (L/W)	R_2 (L/T)	R_3 (W/T)
Sunflower	seeds	7.35	63.55	133.70	181.83	1.855	2.743	1.479
		12.11	63.94	136.25	186.06	1.871	2.773	1.482
		15.997	64.57	140.14	192.71	1.900	2.822	1.485
		20.7	64.81	142.55	196.45	1.906	2.842	1.491
		23.7	64.86	144.65	199.48	1.910	2.846	1.490
	Kernels	6.33	72.62	63.82	94.50	2.065	3.653	1.769
		8.81	72.26	65.26	96.28	2.058	3.605	1.751
		11.93	71.88	66.66	97.97	2.051	3.556	1.734
		16.61	71.48	68.20	99.76	2.037	3.506	1.721
		22.57	71.20	70.20	102.38	2.027	3.473	1.713
Soybean seeds		9.52	21.87	139.60	148.34	1.113	1.280	1.150
		11.693	22.34	143.03	152.17	1.114	1.288	1.156
		15.831	22.83	145.70	155.33	1.120	1.296	1.157
		20.053	23.40	148.64	158.82	1.126	1.306	1.160
		24.644	24.56	152.17	163.32	1.137	1.326	1.166
Canola		7.11	---------	13.46	13.46	--------	--------	---------
		11.60	---------	13.85	13.85	--------	--------	---------
		15.60	---------	14.12	14.12	--------	--------	---------
		20.12	---------	14.79	14.79	--------	--------	---------
		25.72	---------	15.21	15.21	-------	--------	---------

2. Mass of 1000 seeds:

As shown in fig. (7), the mass of 1000 seeds increased linearly with the increasing of seeds moisture content.

For sunflower seeds, variety Giza 102 the mass of 1000 seeds, increased from 68.391 to 76.124 g with the increasing of seeds moisture content from 7.35 to 23.7 % (w.b.), respectively.

Also, for soybean crop, variety Giza (111) the mass of 1000 seeds, increased from 181.27 to 203.19 g with the increasing of seeds moisture content form 9.52 to 24.644 % (w.b.).

While, the mass of 1000 seeds for canola seeds increased from 3.401 to 3.712 g with the increasing of seeds moisture content from 7.11 to 25.722 %.

3. Seeds projection area:

Projection areas of seeds generally increased with the increasing of moisture content.

As shown in Fig. (8), seeds projection area of sunflower increased from 53.79 to 58.90 mm^2 with the increasing of seeds moisture content from 7.35 % to 23.7%. While, the kernels projection area increased from 31.68 to 34.51 mm^2 with the increasing of kernels moisture content from 6.33 to 22.57%, respectively.

Meanwhile, for soybean seeds, the projection area increased from 41.73 to 44.79 mm^2 with the increasing of seeds moisture content from 9.52 to 24.644%.

While, the projection area of canola seeds was also increased from 3.42 to 3.79 mm^2 with the increasing of seeds moisture content from 7.11 % to 25.722 %, respectively.

A simple regression analysis was also carried out to relate the change in the projection area with moisture content of all studied crops. The nature of dependence could be expressed by the following equation:

$$A_P = k + l\,(MC) \quad \text{..............................(20)}$$

Where:

A_p= seed projection area, mm^2

k and l = Constants.

The values of constants (k and l) are presented in Table (5) as follows:

Table (5): Values of constants (k and l) of equation (20):

Crop		k	l	R^2
sunflower	**seeds**	51.02	0.3192	0.969
	kernels	30.528	0.1807	0.984
Soybean seeds		40.142	0.1932	0.970
Canola seeds		3.290	0.0198	0.995

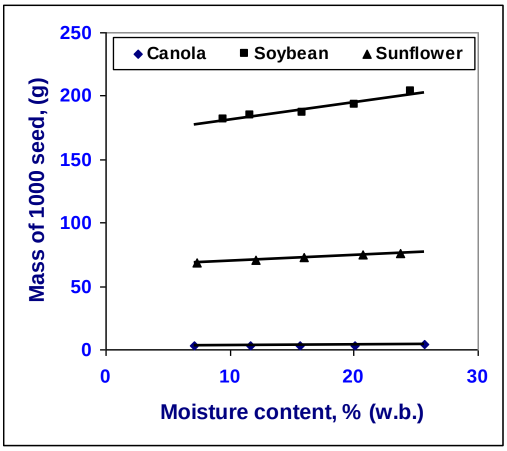

Figure (7): Effect of moisture content on mass of 1000 seeds for different studied crops.

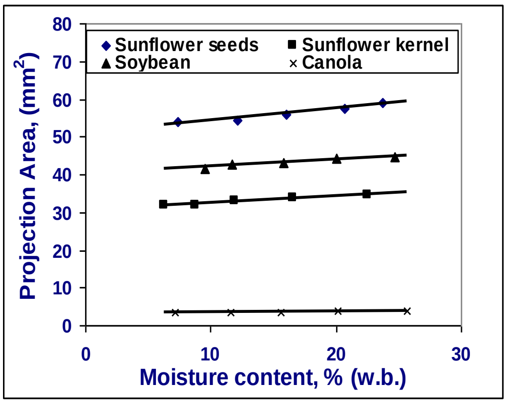

Figure (8): Effect of moisture content on projection area of different studied crops.

4. Bulk density of seeds:

The effect of seeds moisture content on bulk density indicated that, the values of bulk density decreased with the increasing of seeds moisture content for all studied crops. As shown in Fig. (9), the bulk density of sunflower seeds decreased from 436.044 to 358.524 kg/m3 with the increasing of seeds moisture content from 7.35 to 23.7 %, respectively.

However, for soybean seeds, the seeds bulk density decreased from 757.654 to 691.006 kg/m3 with the increasing of moisture content from 9.52 to 24.644 %.

Also, the bulk density decreased from 644.163 to 596.378 kg/m3 with the increasing of moisture content from 7.11 % to 25.722 % for canola seeds.

On the same time, the related bulk density of sunflower kernels at moisture content of 6.33 %, crushed soybean at moisture content of 9.52 % and crushed canola at moisture content of 7.11 % were 529.096, 591.033 and 445.476 kg/m^3, respectively.

To asses the relationship between the changes in seeds bulk density with seeds moisture content, the following relationship was obtained:

$$B_d = m\,(MC.)^{n} \quad \ldots\ldots (21)$$

Where:

B_d = Seeds bulk density, kg/m^3

m and n = Constants.

The values of the constants (m and n) were recorded in Table (9).

Table (9): Values of the constants (m and n) for the equation (21):

Crop	m	n	R^2
sunflower	610.71	-0.0167	0.996
soybean	929.8	-0.0917	0.9778
canola	732.12	-0.0614	0.945

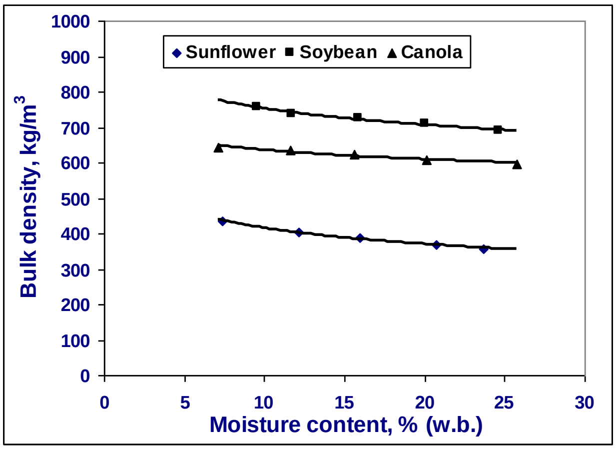

Figure (9): Effect of moisture content on bulk density for different studied crops.

5. True density of seeds:

Figure (10) shows that, for sunflower seeds, the true density decreased from 716.191 to 668.36 kg/m3 with the increasing of seeds moisture content from 7.35 to 23.7%.

While, the true density of soybean seeds was decreased from 1222.003 to 1185.557 kg/m3 with the increasing of seeds moisture content from 9.52 to 24.644% and from 1071.986 to 1009.414 kg/m^3 with the increasing of seed moisture content from 7.11 to 25.722% for canola seeds.

The true density of sunflower kernels at moisture content of 6.33 %, crushed soybean with moisture content of 9.52 % and crushed canola with moisture content of 7.11 % were 1069.556, 1324.45 and 1062.303 kg/m^3, respectively.

The changes in true density with the change in seeds moisture content for all studied crops, was related as follow:

$$D_t = a' + b' (MC) \quad \text{……………………………(22)}$$

Where:

D_t = Seeds true density, kg/m^3.
a' and b' = constants.

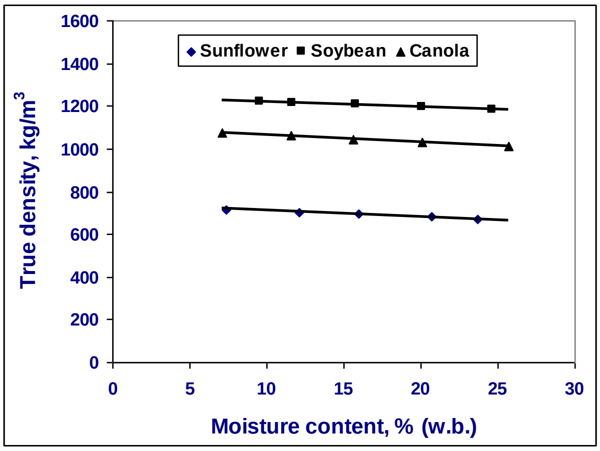

Figure (10): Effect of moisture content on true density of different studied crops.

The regression constants (a' and b') were tabulated in Table (10).

Table (10): Regression parameters of equation (22) relating the change in seeds moisture contents with the true density.

Crop	Moisture content, % (w.b.)	Regression parameters		
		a	b	R^2
Sunflower seeds	7.35 - 23.700	738.45	-2.9238	0.997
Soybean seeds	9.52 - 24.644	1242.9	-2.2994	0.979
Canola seeds	7.11 - 25.722	1009.3	-3.4756	0.993

The observed reduction in both bulk and true density of different studied crops with the increasing in seeds moisture content was mainly due to the higher rate of increase in seeds volume than seeds mass. The same trend was noticed by (Deshpande *et. al*., 1993, Gupta and Das, 1997, Aviara et. al., 1999 and Matouk *et. al*., 2004b).

6. Seeds porosity:

As shown in Figure (11), seeds porosity increased from 41.16% to 46.52 % with the increasing of seeds moisture content from 7.35 to 23.7% for sunflower seeds, from 40.498 % to 44.51 % with the increasing of moisture content from 9.52 to 24.644% for soybean seeds and from 42.22% to 47.39

% with the increasing of seeds moisture content from 7.11 to 25.722% for canola seeds.

Also, a simple linear regression analyses was applied to relate the change in seeds porosity with the change in moisture content for all studied crops. The obtained regression equation was in the form of:

$$P_o = c' + d' (MC) \quad \text{.................................(23)}$$

Where:

P_o = Seeds porosity, %.

c' and d' = Constants.

The regression constants (c' and d') were tabulated in Table (11).

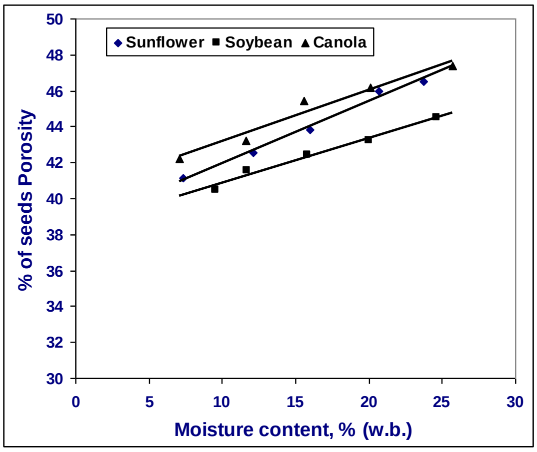

Figure (11): Effect of moisture content on porosity of different studied crops.

Table (11): Regression parameters of equation (23) relating the change in seeds moisture contents with the seeds porosity.

Crop	Moisture content, % (w.b.)	Regression parameters		
		c'	d'	R^2
Sunflower seeds	7.35 - 23.7	38.506	0.344	0.9905
Soybean seeds	9.52 - 24.644	38.409	0.2469	0.9805
Canola seeds	7.11 - 25.722	40.292	0.2867	0.9634

CONCLUSION

1- The principal dimensions of sunflower seeds and kernels, soybean and canola seeds increased linearly with the increasing of moisture content.

2- The related characteristics such as geometric and arithmetic mean diameter, actual and calculated volumes, shape index (K), surface area (A_s), surrounded surface area (A_{ss}) and the aspect ratios generally increased linearly with the increasing of seeds moisture content for all studied crops except the shape index and the aspect ratios of sunflower kernels which decreased linearly with the increasing of seeds moisture content.

3- Coefficient of contact surface (C.C.) increased with the increasing of seeds moisture content However, for sunflower kernels, the coefficient of contact surface was decreased with the increasing of moisture content.
4- Sphericity of sunflower and soybean seeds decreased with the increasing of seeds moisture content. However, an opposite trend of variation was detected for sunflower kernels.
5- Mass of 1000 seeds and seeds porosity increased linearly with the increasing of seeds moisture content. While, the bulk and true densities decreased with the increasing of moisture content for all studied crops.
6- Projection area of seeds generally increased with the increasing of moisture content for all studied crops.

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الخصائص الطبيعية لبعض المحاصيل المنتجة للزيت

أحمد محمود معتوق ، صلاح مصطفى عبد اللطيف و أحمد ثروت
قسم الهندسة الزراعية – كلية الزراعه – جامعة المنصورة.

تم تعيين بعض الخصائص الطبيعية مثل (الأبعاد الرئيسية والخصائص المرتبطة بها – كتلة الألف بذرة – مساحة الإسقاط الضوئي – الكثافة الظاهرية والكثافة الحقيقية – المسامية) لثلاثة من المحاصيل المنتجة للزيت وهي عباد الشمس صنف جيزة 102 وفول الصويا صنف جيزة 111 والكانولا صنف سرو 55 عند خمس مستويات مختلفة من المحتوى الرطوبي.

ولقد أوضحت النتائج المتحصل عليها زيادة قيم كل من الأبعاد الرئيسية والخصائص المرتبطة بها كالقطر الهندسي والقطر الحسابي والحجم الحقيقي والمحسوب ومعامل الشكل (K) والمساحة السطحية (A_s) والمساحة المحيطية (A_{ss}) ومعامل التلامس السطحي (C.C.) والنسب بين كل من (الطول والعرض – الطول والسمك – العرض والسمك) وكتلة الألف بذرة ومسامية البذور ومساحة الإسقاط الضوئي لكل من بذور وأنوية عباد الشمس وبذور فول الصويا وبذور الكانولا خطياً مع زيادة المحتوى الرطوبي للبذور في حين انخفضت قيم كل من معامل الشكل ومعامل التلامس السطحي والنسب المحسوبة بين الثلاث أبعاد الرئيسية لأنوية عباد الشمس خطياً بزيادة المحتوى الرطوبي للبذور. كما انخفضت أيضاً قيم كل من نسبة الكروية لبذور عباد الشمس وفول الصويا والكثافة الالظاهرية والحقيقية لبذور المحاصيل موضع الدراسة بزيادة المحتوى الرطوبي للبذور.

وأخيراً تم تطوير بعض العلاقات الرياضية والتي تصف طبيعة التغير في قيم الخصائص الطبيعية المختلفة تبعاً للتغير في المحتوى الرطوبي لبذور المحاصيل موضع الدراسة.