ENGINEERING PROPERTIES OF MORINGA OLEIFERA SEEDS RELATED TO AN OIL EXPELLER DESIGN

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ABSTRACT

The aim of this research was to investigate some engineering properties of Moringa Oleifera seeds cultivated in Egypt. The properties were determined at a moisture content of seed 9.45 % (d. b.). Firstly the physical properties, the results showed that the mean values of the percentages by weight of seed parts to whole seed were 21.4 ± 2.4 and 78.6 ± 2.4 %, for kernels and husks respectively. The average values of length, width, thickness, arithmetic, and geometric mean diameter, sphericity, mass of individual seed, thousand seed mass, true density, bulk density, porosity, surface area and projected area were as follow: 13.8, 10.6, 10.3, 11.55, 11.45 mm, 84.9 %, 0.31 g, 290 g, 0.88 g/cm^3, 0.65 g/cm^3, 26.1%, 393 mm^2, and 91 mm^2 respectively. Secondly the mechanical properties, the results showed that the mean value of the angle of repose was 22.65^o ± 1.1^o, the coefficient of static friction for the stainless steel (304) structural surface had the lowest value (1.14) while the rubber structural surface had the highest value (2.05). The highest values of the rupture force, deformation ratio, hardness and the energy needed for rupture force were 67.5 N, 0.05, 89.75 N/mm and 36.5 N.mm while the lowest values were 35.2 N, 0.045, 58.51 N/mm and 25.9 N.mm, respectively.

keywords: *Moringa Oleifera, oil extraction design, engineering properties.*

INTRODUCTION

Among the gifts of Almighty Creator is the tree (Moringa Oleifera) where it is called the herb of life because of its many benefits of living organisms. Moringa tree (Moringa Oleifera, Family: Moringaceae) is a native to northern India, but today it is common throughout the tropical and sub-tropical regions of Asia, Africa, and Latin America. The Moringa Oleifera tree grows on different soil types including sandy and coralline sandy, grey loam, red lateritic, stony and rocky, quartzite clay and loamy clay soils **(CALM, 2007)**.

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It grows best where the average maximum daily temperature range is 25-35 °C, but also can survive summer temperature up to 48 °C for a limited period, and can tolerate frosts in winter **(Price, 2000).** The leaves and seeds of M. Oleifera are good sources of protein, vitamins A, B, C and minerals such as calcium and iron **(Dahot, 1988).** The seeds contain about 38 - 42% oil **(Anwar et al., 2006).** Moringa Oleifera seeds can also be used as an antiseptic in the treatment of drinking water **(Obioma and Adikwu, 1997)** All parts and components derived from this plant have been used for alleviating various ailments in traditional medicine for centuries in many cultures around the world **(Fahey, 2005**). The National Charity for Organic Growing has studied the efficacy of M. Oleifera seeds as a medical treatment and found that they provide legitimate relief for many medical problems. These include rheumatism, gout, sexually transmitted diseases, urinary infections, boils, and even epilepsy. When used as medicine, the seeds are pounded and mixed with coconut oil. Often, seed oil derived from the M. Oleifera seeds will be used in place of the mashed seed (**Sampson, 2005).** Moringa Oleifera seeds are eaten like green peas. The seeds offer concentrated nutrients including amino acids, proteins and a wide range of vitamins and minerals, making them an outstanding supplement for stressed and hurried individuals and a solid source of nutrition for undernourished populations around the world. The nuts can be served fresh or dried and often are pressed to remove the oil they contain, which is useful for cooking and can be added to other dishes to boost their nutrient content as well (**ECHO, 1996).** The Moringa Oleifera seed powder is much more economical, and arguably, safer than aluminum sulfate and other chemicals traditionally used in water purification. When crushed and added to turbid water, moringa seeds can serve to purify it for drinking and other uses. This cleansing property is the result of the coagulating nature of the Moringa seed, which can speed water clarification and allow water to settle and become safe to drink much more quickly. The use of M. seeds in water purification is expected to provide healthier, safer drinking water for many areas of the world in which technologically advanced methods are not available **(Folkard and Sutherland, 1996).** In order to design equipment for handling, conveying, separation, drying, aeration, storing, and processing of M. Oleifera seeds, it is necessary to determine their physical properties. The application of physical properties such as shape is an important parameter in the developing of sizing and grading machines and for analytical predictions of its drying behavior **(Esref and Halil, 2007).** It has been reported that it is essential to determine the physical properties of oilseeds for the proper design of equipment for handling, conveying, separation, dehulling, drying, aeration and mechanical expression of oil from these seeds (**Kachru, et al. 1994). (Ajav and Fakayode, 2013)** emphasized that the values of the dimensions of the Moringa seeds are useful in the calculation of the number of seeds that will be crushed at the feed end portion of the machine. It also assists in determining the total force that will be required to express the oil based on the number of seeds to be processed per batch. Based on the above, research has established that moringa leaves fed to livestock as feed on daily basis or as supplements increase the wellbeing and health conditions of the animals such as increased carcass weight, increased nutritional diets like proteins and minerals and increased economic returns to farmers. Moringa Oleifera seed is also rich in some substances which make it possible for the seeds to be used for water purification particularly in the rural communities. Consequently, studying the engineering properties of the seed is of paramount importance for oil producers, researchers, designers of agricultural machinery where the engineering properties play an important role for determining the dimensions of storage containers, seed hopper of handling equipment and transport operations also select range of clearance or apertures size in the shelling machines of seeds.

MATERIALS AND METHODS

The source of the seeds used in this research was from the horticulture Research Institute, ARC, Egypt, Giza. The samples were selected, cleaned and shelled manually for separating of seeds. The measurements and tests were carried out in the Fac. of Agri. Eng., Al-Azhar U., Assiut.

1. Physical properties of Moringa Oleifera seeds:

1. 1. Moisture content.

The moisture content of the whole dry seeds was determined by using an oven drying at 105 ± 1°C for 24 hours according to, ***Ozarslan, (2002)***.

This test was repeated six times. The moisture content was determined by using the following equation according to, ***Kabutey, et al. (2015).***

$M_C = (m_b - m_a)/m_a$ ………………………..……………………..(1)

Where:

$\boldsymbol{M_C}$: is the moisture content of the sample, (%, d. b.).

$\boldsymbol{M_b}$: is the mass of the sample before heat treatment, (g).

$\boldsymbol{M_a}$: is the mass of the sample after heat treatment, (g).

1. 2. Percentages of the seed parts.

100 seeds were randomly selected and masses of individual seeds were determined using a digital electrical balance with an accuracy of 0.001g. The kernels of seeds were separated manually and weighed to determine the percentage of seed parts (%, by wt.) from kernels and husks to whole seed as shown in the following equations:

$$\text{Kernels, (\%, wt.)} = (\text{Mass of kerne})/(\text{Mass of seed}) \times 100 \ \ldots.\ldots..(2)$$

$$\text{Husks, (\%, wt.)} = \frac{\text{Mass of seed} - \text{Mass of kernel}}{\text{Mass of seed}} \times 100 \ldots \ldots.\ldots\ldots(3)$$

1. 3. Three axial dimensions of the seed.

The basic dimensions (length, width, and thickness) of Moringa Oleifera seed were determined according to, ***Oloyede, et al. (2015)***. A digital Vernier-caliper with an accuracy of 0.01 mm was used to measure the three axial dimensions (L, W, and T) of 100 seeds selected randomly.

1. 4. Average diameter.

The average diameter was calculated by the arithmetic mean and geometric mean methods of the three axial dimensions. The arithmetic mean diameter (“D_a”, in mm.) and geometric mean diameter (“D_g”, in mm.) were calculated using the following equations according to**,** ***Mohsenin, (1986):***

$$D_a = (L + W + T)/3..\ldots....(4) \qquad D_g = (L \times W \times T)^{\frac{1}{3}} \ \ldots.\ldots....(5)$$

1. 5. Sphericity of the seeds.

The shapes of seeds and fruits are usually expressed in terms of their sphericity according to ***Sahin and Sumnu,* (2006).** So, the sphericity (“Ø”,%) was calculated by using the values of the geometric mean diameter and length according to the following equation, ***Mohsenin, (1986)*:**

$$\emptyset = D_g / L \times 100 \quad \ldots \ldots (6)$$

1. 6. Mass of the seeds.

To determine the mass of individual seed ("M_s", g) a 100 was randomly selected and weighed separately using a digital electrical balance with an accuracy of 0.001g. The thousand seeds weight was measured by weighing 100 seeds and multiplying by 10 to calculate the mass of 1000 seeds according to, ***Oloyede, et al. (2015)***.

1. 7. True and bulk density.

The volume and true density of the seeds were determined by the toluene displacement method according to, ***Mohsenin, (1992)***. A known weight of samples was poured into a 500 cm^3 fractionally graduated measuring cylinder containing 250 cm^3 toluene. The rise in toluene indicated the true volume of the seeds. The ratio of weight of seeds to the volume of displaced toluene is the true density. The bulk density of samples was determined by using a regular container of known mass. The container was filled to the brim with the samples and was gently vibrated ten times for the samples to consolidate. The weights of the samples were recorded and the volume of the container was estimated by filling with water, which was then poured into 500 cm^3 fractionally graduated measuring cylinders to determine the volume. The bulk density was calculated from the following relation:

$$\text{Bulk density } (\rho_b, kg/m^3) = W_S / V_S \quad \ldots \ldots (7)$$

Where:

$\boldsymbol{W_s}$: is the weight of the seeds, kg.

$\boldsymbol{V_s}$: is the volume occupied by the sample, m^3.

1. 8. Porosity.

Porosity ("ε", %) of the seeds was calculated from values of bulk and true densities by the following equation according to, ***Mohsenin (1986):***

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad \ldots \ldots (8)$$

1. 9. Surface area.

According to ***Oje and Ugbor, (1991) & Adejumo and Abayomi, (2012)***, the surface area was determined by first coating the surface of the seed with paint and coupled with printing on a light flexible paper. The surface edge was traced out with a very sharp thin pencil on a graph paper. The area was measured by counting the number of squares within the traced marks.

1. 10. Projected area.

50 of the seeds were randomly selected and were scanned using a scanner (HP LaserJet Professional M1132 MFP) to capture the image of seeds at the natural flat position, then; the pictures of seeds were exported to AutoCAD 2012 program to calculate the projected area of the seeds.

2. Mechanical properties of Moringa Oleifera seeds:

2. 1. Angle of repose.

The angle of repose was calculated from the measurements of the height (*h*) of the free surface and diameter (*d*) of the cone pile formed by using the following relationship according to, ***Garnayak et al. (2008)***:

$$\theta = \sin^{-1}(2h/d) \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where: h = the height of the free surface of the seeds (mm).

d = diameter of the pile formed (mm).

2. 2. Coefficient of static friction.

Static coefficient of friction of the seed was determined with respect to each of the following five structural materials, namely, stainless steel, glass, aluminum, plywood with grains parallel to the direction of motion and rubber. A four-sided plywood container with dimensions of 150 × 100 × 40 mm open at both the top and bottom was filled with the seeds and placed on an adjustable tilting surface. The structural surface with the box on its top was gradually raised by means of a screw device until the box just started to slide down. The angle of inclination was read from a graduated scale and the coefficient of friction was taken as the tangent of this angle***, Adejumo (2003)***. The same procedure was repeated for other materials.

$$\mu = \tan\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where: μ = Static coefficient of friction. β = angle of inclination.

2. 3. Rupture force, deformation ratio at rupture point, hardness and energy used for rupture.

The rupture force is the minimum force required to break the seed. It was determined using a digital universal material tester. Specifications of the device were as follows: Model No: MT 20 21, range of the measurement is 0 to 20000 N and its accuracy is 0.1 N. The rupture force measured at three axial dimensions (length, width, and thickness) of the seed. The output data from the device was represented in a chart on the computer by the software of the device. The chart is a relationship between the rupture force (N) and deformation (mm). The deformation ratio (D_R) is the axial strain at rupture point and it was computed by dividing the deformation at rupture point (*d*, mm.) on the length, width or thickness of seed, (*D*, mm) as shown in the following equation:

$$D_R = d/D \quad \text{(11)}$$

The hardness (H, N/mm) is the ratio of the rupture force and deformation at rupture point and it was computed using the following equation:

$$H = R_F/d \quad \text{(12)}$$

Where R_F: is the rupture force at rapture point, (N).

The energy used for rupture of the seed (E, N.mm) is equivalent to the area under the curve between the initial point and the rupture point. The area was computed by a spreadsheet software program namely Microsoft Excel using some different coordinates along with the curve from the origin point to rupture point.

RESULTS AND DISCUSSION

1. Physical properties of the seeds:

Results summary of the physical properties is presented in Table (1).

1. 1. Moisture content.

The average moisture content of the whole Moringa Oleifera seeds was determined as a 9.75 % dry basis. All the measurements were conducted under this content of moisture. It is worth mentioning that the moisture content is very important as it influences the engineering properties of Moringa Oleifera seeds; which in turn affecting on transporting and separating processes in addition to oil expeller design.

1. 2. Percentages of seed parts.

Fig. (1) and Table (1) show the values of seed parts to whole seed, (%, wt.). Percentage of kernels and husks ranged from 17.9 to 24.5 and 73.6 to 82.2 % and the mean values were 21.4 ± 2.4 and 78.6 ± 2.4 %, respectively. These results may help for determining the mass of kernels in seeds using the following equation:

$$M_K = 0.214\ M_S \quad \text{(13)}$$

Where: M_K is the mass of kernels and M_S is the mass of seeds.

Fig. (1): The parts of Moringa Oleifera seeds after the separation process.

1. 3. Three axial dimensions.

From Table (1), the values of length (L) ranged from 11 to 17 mm with a mean value of 13.8 ± 1.74 mm. The values of width (W) ranged from 8.8 to 12.4 mm with a mean value of 10.6 ± 1.3 mm. The values of the thickness (T) ranged from 8.7 to 12.1 mm with a mean value of 10.3 ± 1.18 mm.

Table (1): Physical properties of M. Oleifera seeds (Sample size 100 seeds).

Properties		**Min.**	**Max.**	**Mean**	**SD**	**CV %**
percentage of seed parts, (%, by wt.)	Kernels	17.9	24.5	21.4	2.4	11.21
	Husks	73.6	82.2	78.6	2.4	3.05
Axial dimensions, (mm)	L	11	17	13.8	1.74	12.6
	W	8.8	12.4	10.6	1.3	12.3
	T	8.7	12.1	10.3	1.18	11.5
Average diameter, (mm)	Da	9.60	13.60	11.55	1.08	9.35
	D_g	9.40	13.30	11.45	1.06	9.26
Sphericity, (%)	Ø	78.7	94	84.9	7.3	8.8
Mass, (g)	M_s	0.22	0.41	0.31	0.07	21.16
	M_{1000}	275	301	290	9.8	3.38
Density, (g/cm^3)	ρ_t	0.78	0.98	0.88	0.05	5.78
	ρ_b	0.63	0.67	0.65	0.01	2.25
Porosity (%)	ε	19.2	31.6	26.1	3.49	13.6
Surface area, (mm^2)	S	316	446	393	48.2	12.3
Projected area, (mm^2)	A_p	70.3	117	91	12.9	14.1

Fig. (2) shows the frequency distribution curves of three axial dimensions of M. Oleifera seeds (L, W, and T). The highest frequencies of L, W and T were 26 % at (13 – 14 mm), 56 % at (9 – 11 mm) and 31% at (9 – 10 mm), respectively. The shapes of curves are semi-normal distribution for length and width, normal distribution for thickness.

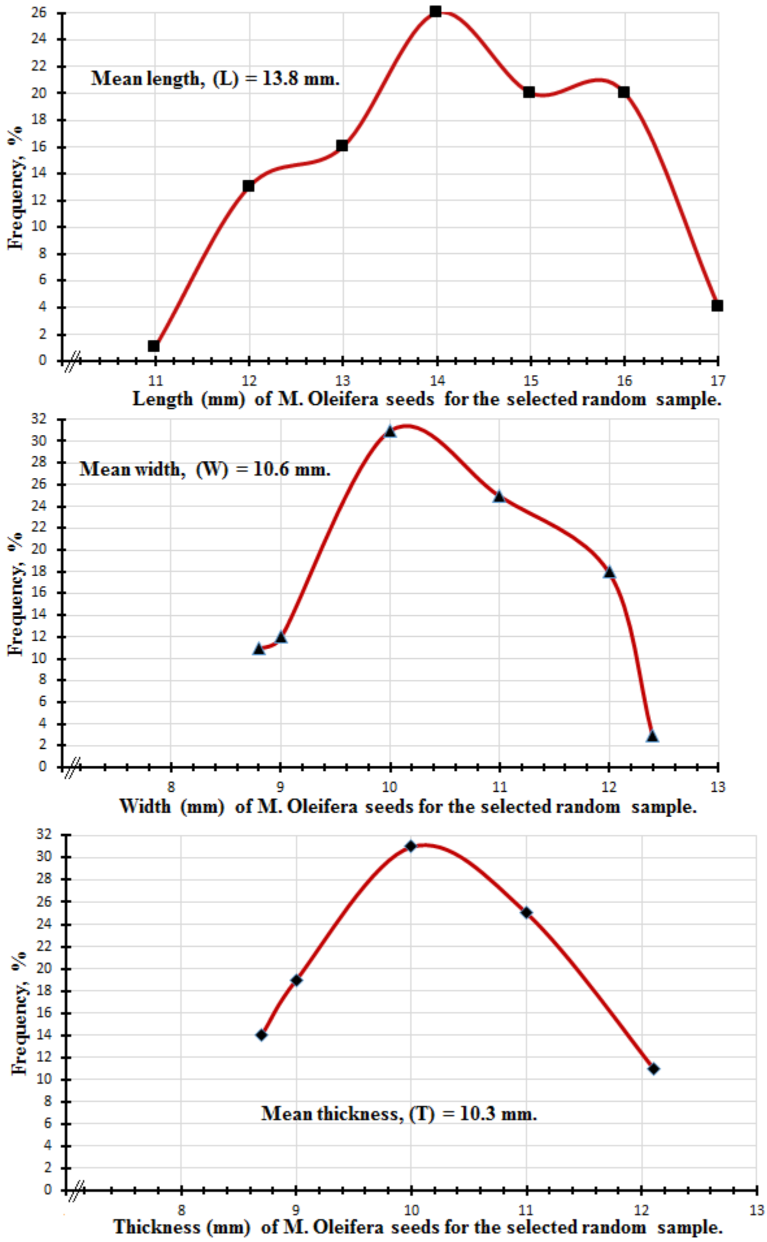

Fig. (2): Frequency distribution curves of the three axial dimensions.

1. 4. Average diameter.

From Table (1), the values of arithmetic mean diameter (Da) ranged from 9.60 to 13.60 mm with a mean value of 11.55 ± 1.08 mm. While the values of the geometric mean diameter "Dg" ranged from 9.40 to 13.30 mm with a mean value of 11.45 ± 1.06 mm.

1. 5. Sphericity of the seeds.

Fig. (3) and Table (1) show the values of sphericity ranged from 78.7 to 94 % with a mean value of 84.9 ± 7.3 %. The sphericity was determined to express the shape of the seed. ***Garnayak et al. (2008)*** considered any grain, fruit, and seeds as spherical when the sphericity value is above 70 %. Accordingly, these results indicated that the frequent percent (100 %) of Moringa Oleifera seeds in the sample was spherical (sphericity > 70 %).

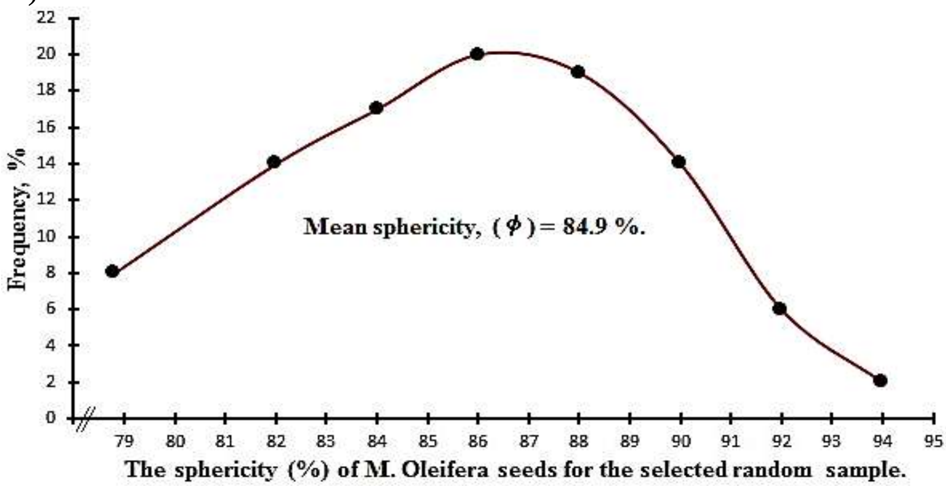

Fig. (3): Frequency distribution curves of the sphericity, %.

1. 6. Mass.

From Table (1), these results showed that the values of individual seeds masses ranged from 0.22 to 0.41 g with a mean value of 0.31 ± 0.07 g. Also; the results indicated that the values of the mass of one thousand seed ranged from 275 to 301 g with a mean value of 290 ± 9.8 g.

1. 7. Density and porosity.

Table (1) shows the values of true densities ranged from 0.78 to 0.98 g/cm^3 with mean value of 0.88 ± 0.05 g/cm^3. Also; the values of bulk densities ranged from 0.63 to 0.67 g/cm^3 with a mean value of 0.65 ± 0.01

g/cm^3. Therefore; the percentages of porosity ranged from 19.2 to 31.6 % with a mean value of 26.1 ± 3.49 %.

1. 8. Surface and projected area.

The results in Table (1) indicated that the values of the surface area ranged from 316 to 446 mm^2 with a mean value of 393 ± 48.2 mm^2 while the values of the projected area ranged from 70.3 to 117 mm^2 with a mean value of 91 ± 12.9 mm^2.

2. Mechanical properties of the seeds:

Results summary of the mechanical properties is presented in Table (2).

2. 1. Angle of repose.

Table (2) shows the values of the dynamic angle of repose on a wooden surface. The angle of repose ranged from 21.75° to 24.1° with mean value 22.65° ± 1.1°. This result can be used to design the side inclination of seed hopper of handling machines, silos and storage containers to allow easy sliding.

Table (2): Mechanical properties of Moringa Oleifera seeds.

Properties		Min.	Max.	Mean	SD	CV %
Angle of repose, (Degree)		21.75	24.1	22.65	1.1	9.14
Coefficient of static friction	Aluminum	1.13	1.5	1.28	0.11	8.79
	S.S. (304)	1.01	1.3	1.14	0.09	7.93
	Glass	0.98	1.4	1.23	0.12	9.51
	Plywood	1.51	2.01	1.75	0.16	9.01
	Rubber	1.81	2.33	2.05	0.17	8.02
Rupture force, (N)	L	46.9	73.3	67.5	2.6	11.88
	W	33.1	39.3	35.2	1.89	9.25
	T	40.1	44.6	43.4	1.11	7.13
Deformation ratio	L	0.02	0.08	0.05	0.02	2.11
	W	0.03	0.06	0.045	0.01	5.25
	T	0.02	0.07	0.045	0.01	3.21
Hardness, (N/mm)	L	68.91	98.65	89.75	12.1	16.8
	W	56.22	61.25	58.51	9.7	9.6
	T	62.13	70.5	69.65	6.5	11.3
Energy of rupture, (N.mm)	L	13.2	52.9	36.5	3.5	4.9
	W	8.9	35.7	25.9	4.7	9.9
	T	12.6	45.5	32.6	6.9	10.3

2. 2. Coefficient of static friction.

Table (2) and Fig. (4) show the values of the coefficient of static friction ranged from 1.01 to 1.3, 0.98 to 1.4, 1.13 to 1.5, 1.51 to 2.01 and 1.81 to 2.33 with mean values of 1.14 ± 0.09, 1.23 ± 0.12, 1.28 ± 0.11, 1.75 ± 0.16 and 2.05 ± 0.17 for the five different structural surfaces: stainless steel, glass, aluminum, plywood, and rubber respectively.

The results in Fig. (4) indicated that the stainless steel (304) structural surface had the lowest value of the coefficient of static friction while the rubber structural surface had the highest value of the coefficient of static friction.

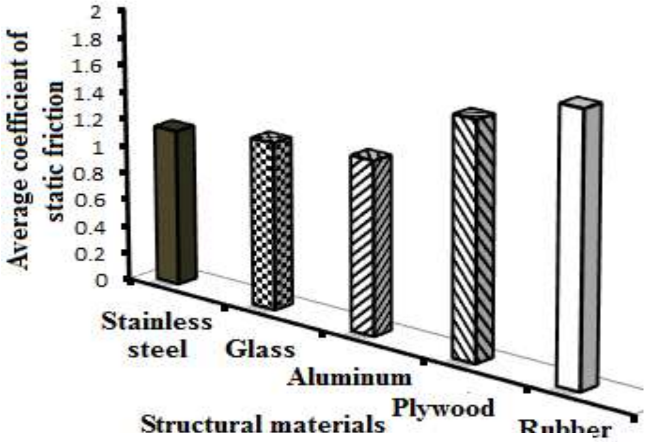

Fig. (4): Coefficient of static friction.

2. 3. Rupture force and deformation ratio.

Table (2) and Fig. (5) show the mean values of the relationship between the rupture force and the deformation ratio at three axial dimensions of the seed. The results showed that the rupture force ranged from 46.9 to73.3, 33.1 to 39.3 and 40.1 to 44.6 N with mean values of 67.5 ± 2.6, 35.2 ± 1.89 and 43.4 ± 1.11 N for length, width and thickness of seed, respectively. The deformation ratio at the rupture point ranged from 0.02 to 0.08, 0.03 to 0.06 and 0.02 to 0.07 with mean values of 0.05 ± 0.02, 0.045 ± 0.01 and 0.045 ± 0.01 for length, width and thickness, respectively.

2. 4. Hardness and energy used for rupture.

The results indicated that the hardness ranged from 68.91 to 98.65, 56.22 to 61.25 and 62.13 to 70.5 N/mm with mean values of 89.75 ± 12.1, 58.51 ± 9.7 and 69.65 ± 6.5 N/mm for length, width, and thickness, respectively. Accordingly, the Energy used for rupture force ranged from 13.2 to 52.9, 8.9 to 35.7 and 12.6 to 45.5 N.mm with mean values of 36.5

± 3.5, 25.9 ± 4.7 and 32.6 ± 6.9 N.mm for length, width, and thickness, respectively.

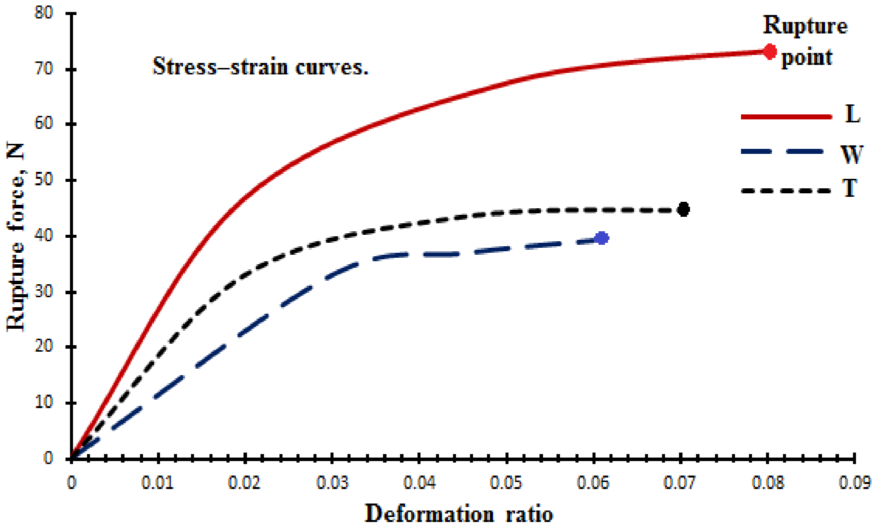

Fig. (5): The mean values of the relationship between the rupture force and the deformation ratio at three axial dimensions of the seed.

CONCLUSION

The following conclusions can be made from this study:

1. Firstly, the physical properties of Moringa Oleifera seeds:
2. The mean values of kernels and husks were 21.4 ± 2.4 and 78.6 ± 2.4 %, by wt., respectively. The equation ($M_K = 0.214\ M_S$) used to calculate the mass of kernels in seeds.
3. The mean values of length, width and thickness are 13.8 ± 1.74, 10.6 ± 1.3 and 10.3 ± 1.18 mm respectively. The mean values of arithmetic mean diameter and the geometric mean diameter were 11.55 and 11.45 mm., respectively. The average values of sphericity was 84.9 ± 7.3.
4. The average value of individual seed mass was 0.31 ± 0.07 g. The mean value of the mass of one thousand seed was 290 ± 9.8 g.
5. The average values of true densities, bulk densities, percentages of porosity, the surface area and the projected area were 0.88 g/cm^3, 0.65 g/cm^3 26.1 %, 393 ± 48.2 mm^2 and 91 ± 12.9 mm^2 respectively.
6. Secondly, the mechanical properties of Moringa Oleifera seeds:

7. The angle of repose ranged from 21.75^{o} to 24.1^{o} with mean value $22.65^{o} \pm 1.1^{o}$.
8. The coefficient of static friction for the stainless steel (304) structural surface had the lowest value (1.14) while the rubber structural surface had the highest value (2.05).
9. The highest values of the rupture force, deformation ratio, hardness and the energy needed for rupture force were 67.5 N, 0.05, 89.75 N/mm and 36.5 N.mm while; The lowest values were 35.2 N, 0.045, 58.51 N/mm and 25.9 N.mm, respectively.

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الملخص العربى

الخصائص الهندســية لبذور المورينجــا المرتبطة بتصميم طارد الزيت

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يعرف نبات المورينجا بعشبة الحياة أو النبات المعجزة لما لها من فوائد لا تعد ولا تحصى فى العديد من المجالات الطبية و الغذائية، كما تحتوى البذور على نسبة عالية من الزيت ذو القيمة الغذائية العالية التى قد تفوق زيت الزيتون، ويهدف هذا البحث إلى الحصول على قاعدة بيانات تتعلق بتصميم آلات التداول وطارد الزيت وفصل البذور وصوامع التخزين وعمليات النقل وذلك من خلال تحديد الخصائص الطبيعية و الميكانيكية لبذور المورينجا المنزرعة بمصر. بذور المورينجا أوليفيرا المستخدمة فى هذا البحث من معهد بحوث البساتين، مركز البحوث الزراعية، تم اختيار عينات عشوائية للقرون وتنظيفها يدوياً لفصل البذور، وقد تمت التجارب عند محتوى رطوبى للبذور ٩.٤٥ ٪ على أساس الوزن الجاف، وتم الحصول على النتائج التالية:

أولاً: الخصائص الطبيعية.

١- متوسط نسبة وزن لب البذرة و القشرة بالنسبة لوزن البذرة كاملة كانت ٢١,٤ و ٧٨,٦ ٪ على التوالى.

٢- متوسط الابعاد المحورية (الطول و العرض و السمك) للبذرة كانت ١٣,٨ و ١٠,٦ و ١٠,٣ مم على التوالى ومتوسط القطر الحسابى والقطر الهندسى كانت ١١,٥٥ و ١١,٤٥ مم. أما متوسط نسبة الكرية فكانت ٨٤,٩ ٪.

٣- متوسط كتلة البذرة، كتلة الألف بذرة، الكثافة الحقيقية، الكثافة الظاهرية ونسبة المسامية كانت ٠,٣١ جرام، ٢٩٠ جرام، ٠,٨٨ جرام/سم^{٣}، ٠,٦٥ جرام/سم^{٣} و ٢٦,١ ٪ على التوالى.

٤- متوســــــط المساحة الســطحية والمساحة المعرضه كانت ٣٩٣ مم^{٢} و ٩١ مم^{٢} على التوالى.

ثانياً: الخصائص الميكانيكية.

١- متوسط زاوية المكوث كانت ٢٢,٦٥ درجة.

٢- متوسطات معامل الإحتكاك الاستاتيكى مع أسطح الألومنيوم ، الصلب المقاوم للصدأ (الاستانلس ستيل ٣٠٤) ، الزجاج ، الخشب و المطاط كانت ١,٢٨ ، ١,١٤ ، ١,٢٣ ، ١,٧٥ و ٢,٠٥ على التوالى.

٣- أعلى متوسط للقوة اللازمة لكسر البذرة ، نسبة التشوه عند نقطة الكسر ، و الصلادة و الطاقة المطلوبة للكسر كانت ٦٧,٥ نيوتن، ٠,٠٥، ٨٩,٧٥ نيوتن/مم و٣٦,٥ نيوتن.م بينما كانت أقل قيم ٣٥,٢ نيوتن، ٠,٠٤٥ ، ٥٨,٥١ نيوتن/مم و ٢٥,٩ نيوتن.م على التوالى.

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(١) و(٢) مدرس الهندسة الزراعية بكلية الهندسة الزراعية جامعة الأزهر فرع أسيوط.