Food Research 3 (2) : 96 - 101 (April 2019)
Journal homepage: http://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Determination of selected engineering properties of *Moringa oleifera* seed

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Article history:
Received: 6 June 2018
Received in revised form: 15 September 2018
Accepted: 8 October 2018
Available Online: 6 November 2018

Keywords:
Engineering properties,
Moringa oleifera,
Moisture content,
Seed

DOI:
https://doi.org/10.26656/fr.2017.3(2).124

Abstract

Engineering properties of agricultural products are very important in the design and manufacturing of processing machines. The methods adopted in the study were standard laboratory procedures for the determination of the engineering properties selected. In this research, the dimensional, gravimetric and frictional properties of *Moringa oleifera* seeds were determined as design parameters for the development of post-harvest equipment. The selected properties were: length, width, thickness, arithmetic and geometric diameters, surface areas, sphericity, moisture content, bulk and true densities, porosity, one thousand and unit seed weights, angle of repose and coefficient of static friction. The moisture contents used in the study were 7.82% and 15.82% dry basis (db). The mean seed length of 9.217±1.407 mm, width of 8.012±1.349 mm and thickness of 5.443±1.382 mm was found at moisture contents of 7.82% (db) respectively. While the mean seed length of 11.460±1.106 mm, width of 10.079±1.065 mm and thickness of 7.377±1.079 mm were obtained at moisture content of 15.82% (db) respectively. The mean arithmetic diameter, geometric mean diameter, sphericity and surface area at moisture content of 7.82% (db) were 7.557±1.3407 mm, 7.366±1.374 mm, 0.7964±0.048 mm, 176.185±64.416 mm^2 respectively. Also, the mean arithmetic diameter, geometric mean diameter, sphericity and surface area at moisture content of 15.82% (db) were 9.639±1.049 mm, 9.475±1.065 mm, 0.826±0.030 mm, 285.476±65.753 mm^2 respectively. The mean true density, bulk density, average porosity, unit mass and thousand seed mass at 7.82% (db) moisture content were found to be 0.5100±0.025 gcm^{-3}, 0.247±0.0580 gcm^3; 58.86%, 0.339±0.061 g, and 272.051±11.827 g respectively. Also, the average true density, bulk density, average porosity, unit mass and thousand seed mass at 15.82% (db) moisture content were 0.610±0.030 gcm^{-3}, 0.253±0.005 gcm^{-3}, 58.52%, 0.350±0.055 g, and 273.396±8.079 g respectively. The mean angle of repose, average static coefficient of friction on three different surfaces that include: glass, galvanized steel, and plywood at 7.82% (db) moisture content was found to be 17.834±0.350^o, 0.437±0.003, 0.481±0.002, and 0.569±0.003 respectively. Also, the mean angle of repose, average static coefficient of friction on three different surfaces that include: glass, galvanized steel, and plywood at 15.82% (db) moisture content were found to be 19.345±0.409^o, 0.471±0.002, 0.570±0.002, and 0.612±0.013 respectively. These parameters would serve as inputs for the efficient design of post-harvest equipment for *M. oleifera* seeds.

1. Introduction

Moringa oleifera is native to some parts of Africa and Asia and it is the sole genus in the flowering plant family *Moringaceae* (Zaku *et al.,* 2015). *M. oleifera* has been in use for many centuries in traditional alternative medicine to heal or prevent hundreds of diseases (Aremu and Akintola, 2014), and because of its numerous healing and nutritional properties, it is called “Miracle Tree”, “Mother’s Best Friend” and “Never Die”. The other common names of *M. oleifera* include “horseradish tree” and “drumstick tree”. The history of *M. oleifera* according to Zaku *et al.* (2015) dates back to 150 B.C when ancient kings and queens used *M. oleifera* leaves and fruit in their diet to maintain mental alertness and healthy skin. A mature *M. oleifera* grows up to a height of 6-7 m and is a drought-resistant and fast growing plant (Ramachandran *et al.,* 1980; Fuglie, 1999). There are thirteen varieties of *moringa* trees in the family, according to Aremu and Akintola (2014) which includes:

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M. stenopetala, M. doughardii. M. arborea, M. borziana, M. longituba, M. rivae, M. pygmaea, M. ruspoliana, M. hildebrandtii, M. ovalifolia, M. concanensis, M. oleifera and M. peregrina. However, *M. oleifera* is the most widely known variety. It is also a readily available diet used to help prevent malnutrition in children, pregnant women and nursing mothers (Ndubuaku *et al.,* 2014). The leaves and seeds have been found to be highly nutritious and medicinal. The seeds yield edible oil that is clear and odorless. It burns without smoke and will not turn rancid. The seeds are 35% oil and the remaining seed cake can be used as fertilizer or to purify water (Abdullah *et al.,* 2013). *M. oleifera* seeds contain a significant amount of oil that is commercially known as "Ben oil" or "Behen oil" due to the fact that oil contains high amounts of behenic acid which is used in many products for its ability to smooth the skin and condition hair. It could also be used in cooking, cosmetics, fuel and lubrication among others.

The characteristics of *M. oleifera* seed oil can be highly desirable especially with the current trend of replacing polyunsaturated vegetable oils with those containing high amounts of monounsaturated acids (Corbett, 2003). In recent times, increased attention has been focused on the utilization of under-exploited locally available agricultural products and by-products for food/ fibre processing in developing countries. Obviously, such utilization would help these countries, especially African countries that are currently facing adverse economic problems. Due to the facts that *M. oleifera* is harvested and collected manually by handpicking, there are always unwanted materials in all the harvested seeds which necessitates the need for the cleaning of the seeds. For further processing of the harvested seeds, there is a need for the determination of engineering properties, such as physical, chemical and oil properties among others. The knowledge of these properties is highly relevant to agricultural engineers due to the increasing economic importance of food materials, together with the complexity of modern technology for their production, handling, storage, processing, preservation, value addition and utilization (Adebayo and Nwankwo, 2013).

A rational approach to the design of agricultural machinery, equipment and facilities involve the knowledge of the properties of the agricultural product concerned. The need for comprehensive information on its properties is of importance, as these properties influence the design and evaluation of the processing/ handling of the product. Considering this, the knowledge of the engineering properties of agricultural seed materials are important in designing the equipment for harvest, transport, storage, processing, cleaning, hulling and milling (Niveditha *et al.,* 2013). Also Adejumo and Abayomi (2012) conducted a study on the effect of moisture content on some physical properties of shelled and unshelled *M. oleifera* seed at 6.8%, 10%, 15% moisture content (wet basis) and obtained the following results: the mean values of the physical properties of the seeds were determined as length 8.3-8.7 mm and 12.7-13.4 mm, width 7.4-7.6 mm and 10.3-11.0 mm, thickness 6.5-7.3 mm and 10.4-10.9 mm, geometric mean diameter 133.1-160.1 mm and 453.5-535.6 mm, sphericity 16.0-18.4 mm and 35.7-40.0 mm, thousand seed mass 316.8-326.7 g and 318.3-329.3 g, bulk density 0.031-0.032 g/cm and 0.041-0.047 g/cm³, true density 0.221-0.632 g/cm³ and 0.300-0.289 g/cm³, porosity 85.9-94.9% and 86.3-83.7%, surface area 3.19-2.21 cm³ and 3.56-5.32 cm³ for shelled and unshelled seeds respectively. Also, Oloyede *et al.* (2015) measured some engineering properties necessary to design drumstick *M. oleifera L.* pod sheller. The basic dimensions (length, width, and thickness) of *moringa* pods and seeds were found to increase linearly from 311.15 to 371.45 mm, 22.79 to 31.22 mm, and 22.24 to 29.88 mm, respectively, in the moisture range of 12 to 49.5% db. The coefficient of friction for both pods and seeds increased linearly with an increase in moisture content on all the surfaces used. The highest value was recorded on mild steel, with 0.581 for pods and 0.3533 for seeds, and the lowest on glass for pods, with a value of 0.501, and of 0.2933 for seeds on galvanized steel. These properties influence the design and evaluation of the processing of the seed. In this research, the dimensional, gravimetric and frictional properties of *M. oleifera* seeds were determined and presented as design parameters for the development of post-harvest equipment.

2. Materials and methods

2.1 Sample preparation

The dry seeds of *M. oleifera* were obtained from Kano station of Forestry Research Institute of Nigeria (FRIN) and used for all the experiments in the study. The seeds were cleaned manually to remove all foreign matter such as dirt, stones and chaff as well as immature and broken seeds. It was then sealed and kept in a polyethylene bag for 78 hrs to equilibrate the moisture content of the seed. Seed samples were randomly taken to determine the initial moisture content by drying in an air ventilated oven at 103°C for 24 hrs (Ahmadi, 2009) and the average values obtained was recorded.

The remaining seed mass was divided into two sets. One set of the seed samples was reconstituted in addition to the initial moisture content of the sample by adding a calculated amount of distilled water and sealed in a polyethylene bag and stored in a refrigerator at 5°C for five days to enable the moisture to distribute uniformly throughout the seed sample (Ahmadi, 2009). The amount of water added to the sample in order to achieve the desired moisture was calculated using equation (1) as given by Solomon and Zewdu (2009):

$$Q = \frac{W_s(M_f - M_i)}{100 - M_f} \quad (1)$$

Where Q = Quantity of water to be added, g; M_i = initial moisture content; %, M_f = required moisture content; %, W_s = weight of samples, g.

Before starting a test, the required quantity of the seed was taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 hrs (Singh and Goswami, 1996) and after which the reconstituted samples were checked for the moisture content using the method described by Adesina *et al.* (2014). All analysis was carried out in the Department of Agricultural and Environmental Engineering's Laboratory, Faculty of Engineering Bayero University, Kano, Nigeria.

2.2 Determination of moisture content

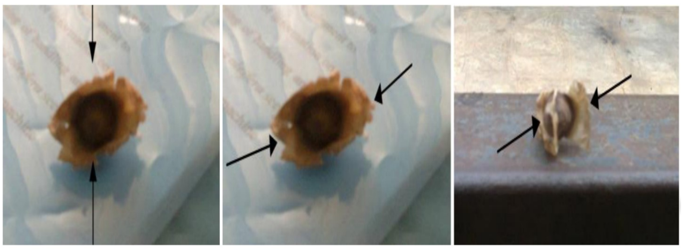
The initial moisture content dry basis of the seed samples was determined using the relationship obtained from Adesina *et al.* (2014)

$$M_{db} = \left(\frac{W_i - W_f}{W_f}\right) \times 100 \quad (2)$$

Where M_{db} = dry basis moisture content; W_i =initial weight of the seeds in grams; W_f = final weight of the seeds in grams

2.3 Dimensional measurement

The physical dimensions of the seed were determined by taking 25 seeds randomly and measured the length, width and thickness at the different moisture contents using a micrometer screw gauge (with 0.01 mm accuracy and 0-25 mm main reading (Model GMC- 20). The seed length was defined as the longest dimension. Width is the longest dimension perpendicular to length. Thickness is the longest dimension perpendicular to the length by width plane Adesina *et al.* (2014) (Figure 1).



(a) Length (L) (b) Width (W) (c) Thickness (T)

Figure 1. Measurement of dimensional axes

The arithmetic mean diameter, and geometric mean diameter was calculated using equation (3) and (4) respectively as used by Adesina *et al.* (2014):

$$Da = \frac{T \pm W \pm L}{3} \quad (3)$$

$$Dg = (LWT)^{\frac{1}{3}} \quad (4)$$

Where L is the length in mm; W is the width in mm; T is the thickness in mm; *Da* and *Dg* are arithmetic and geometric mean diameters, respectively

2.3.1 Determination of sphericity (φ)

Sphericity was obtained using the equation (5) below as given by Adesina *et al.* (2014)

$$\varphi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (5)$$

Where φ = Sphericity; L is the length in mm; W is the width in mm; and T is the thickness in mm.

2.3.2 Determination of surface area (S)

The surface area, (S) in mm^2 was calculated by using equation (6) below as given by Niveditha *et al.* (2013).

$$S = \pi {D_g}^2 \quad (6)$$

Where; S = surface area; and Dg = geometric mean diameter.

2.4 Gravimetric Measurement

2.4.1 Determination of unit and one thousand seed mass

Mass of 1000 seeds of *M. oleifera* was determined by counting 100 seeds randomly and measured using an electrical digital balance (Model MP1001, gallen kamp) with maximum capacity of 600 g and accuracy 0.01 g and then was multiplied by 10 to give the mass of 1000 seeds and divided by 100 to give the unit mass (Adesina *et al.*, 2014). The test was done in ten replicates and mean value was taken.

2.4.2 Determination of solid density

The true or solid density can be defined as the ratio of a given mass of sample to its volume and was determined by using water displacement method. The solid density was calculated using equation (7) below as given by Adesina *et al.* (2014). The test was done in ten replicates and the mean value was taken:

$$\text{True density (g/cm3)} = \frac{\text{weight of the sample(g)}}{\text{Volume of distilled water displaced(cm}^3\text{)}} \quad (7)$$

2.4.3 Determination of bulk density

Bulk density was determined by weighing the grains packed in a container of known volume. The equation (8) below as given by Aviara *et al.* (2017) was used to determine the bulk density of the grain sample.

eISSN: 2550-2166

$$\rho_b = \frac{M_b}{V_b} \quad (8)$$

Where ρ_b = Bulk density of the seeds (g/cm^3); M_b= mass of seeds in the beaker (g); and V_b= volume of beaker (cm^3).

2.4.4 Determination of porosity

The porosity of the seeds was calculated using equation (9) as utilized by Aviara *et al.* (2017).

$$\text{Porosity} = \left(1 - \frac{\rho_b}{\rho_s} \times 100\right) \quad (9)$$

Where ρ_b = bulk density (g/cm^3); and = ρ_s solid density (g/cm^3).

2.5 Frictional properties

2.5.1 Determination of Angle of repose

The angle of repose of the *M. oleifera* seeds was determined using the cylindrical pipe method. A topless and bottomless cylinder was filled with grains and slowly raised on a surface until it leaves the seeds forming a cone, and the radius of the base and height of the cone that was formed by the grains were used to calculate the angle of repose. Equation (10) below was used to determine the angle of repose as given by Zewdu and Solomon (2007). The test was done in ten replicates and mean value was taken.

$$\Theta = \tan^{-1}\left(\frac{h}{r}\right) \quad (10)$$

Where Θ = angle of repose (°); h = height of piled seed (cm); and r = radius of base of cone (cm)

2.5.2 Determination of coefficient of static friction

Coefficient of static friction (μ) was determined on three different surfaces (plywood, galvanized steel and glass), which are commonly used for the construction of processing and handling machine (Niveditha *et al.*, 2013). A plastic cylinder of 100 mm, diameter and 50 mm height as described by Adesina *et al.* (2014) was used. The cylinder was filled with seed and placed on an adjustable inclined surface. The plastic cylinder was raised slightly so that its open bottom edge did not touch the inclined surface only the seed samples were touching the surface. All three surfaces were raised slowly until the cylinder filled with seeds started to slide down. At that point, the angle of tilt, (θ) was recorded. Coefficient of static friction (μ) was calculated using the equation (11) below. The test was done in ten replicates and mean value was taken.

$$\mu = \tan\theta \quad (11)$$

3. Results and discussion

The results obtained were subjected to statistical analysis using Microsoft Excel 2007 (Microsoft Corp., USA). Tukey's test at a significance level of $p<0.05$ was used to compare means of all the parameters calculated at the initial moisture content of 7.82% (db) to that measured at 8% increase in moisture content of 15.82% (db).

3.1 Seed axial dimensional

The results of *M. oleifera* seed axial dimensions obtained at two different moisture content levels are presented in Table 1. The Table shows that the three axial dimensions of the seed increased with moisture content in the moisture of 7.82% and 15.82% (db.), the major axis (length) increased from (9.217±1.407) mm to (11.460±1.106) mm, the intermediate axis (width) from (8.012±1.349) mm to (10.078±1.065) mm, and the minor axis (thickness) from (5.443±1.382) mm to (7.377±1.079) mm. This was in agreement with the work

Table 1. Statistical value of the measured and calculated axial dimensional of the *M. oleifera* seed

Parameters and Unit	Moisture content (db)	N	Mean±SD	Std. Err.	t-value	95% Conf. Interval	
						Lower	Upper
Length (mm)	7.82%	25	9.217±1.407	0.281	-6.268	8.636	9.798
	15.82%	25	11.460±1.106	0.221	-6.268	11.003	11.916
Width (mm)	7.82%	25	8.012±1.349	0.270	-6.012	7.456	8.569
	15.82%	25	10.079±1.065	0.213	-6.012	9.639	10.518
Thickness (mm)	7.82%	25	5.443±1.382	0.276	-5.517	4.872	6.013
	15.82%	25	7.377±1.079	0.216	-5.517	6.932	7.823
Arithmetic diameter (mm)	7.82%	25	7.557±1.3407	0.268	-6.117	7.004	8.110
	15.82%	25	9.639±1.409	0.210	-6.117	9.206	10.071
Geometric diameter (mm)	7.82%	25	7.366±1.374	0.275	-6.064	6.799	7.933
	15.82%	25	9.475±1.065	0.213	-6.064	9.035	9.914
Sphericity (mm)	7.82%	25	0.7964±0.048	0.010	-2.611	0.777	0.816
	15.82%	25	0.836±0.030	0.006	-2.611	0.814	0.839
Surface area (mm^2)	7.82%	25	176.185±64.416	12.883	-5.937	149.596	202.775
	15.82%	25	285.476±65.753	13.151	-5.937	258.335	312.617

eISSN: 2550-2166

of Aja and Fakoyode (2013), who measured some engineering properties of *M. oleifera* and found to have increased of 8.45±0.976 mm, 7.82±0.922 mm and 6.41±1.092 mm respectively. The increasing trend in axial dimensions, this gained in moisture content, might be due to the filling of voids upon absorption of moisture and subsequent swelling. The arithmetic mean diameter had higher mean values of (7.557±1.340 mm to 9.639±1.049 mm) than the geometric (7.366±1.374) mm to (9.475±1.065) mm, sphericity (0.796±0.048 mm to 0.826±0.0302 mm) and the surface area (176.185±64.416 mm^2 to 285.476±65.753 mm^2) of the seed. These could be of important consideration in the theoretical determination of the *M. oleifera* seed volume at different moisture contents. Moreover, assessment of the mean geometric diameter is useful in the evaluation of the projected area of a particle moving in the turbulent or near-turbulent area of an air stream.

The null hypothesis was tested on the assumption that seeds exposed to 7.82% and 15.82% moisture contents have the same effect on the dimensional properties of the seed, i.e. the difference in the means of the treatments (moisture content) is zero. This indicates that the null hypothesis was rejected out-rightly and means that there was a significant difference between the means of the axial dimension at 5% level of significance.

3.2 Seed gravimetric properties

The mean true and bulk densities were found to be 0.600±0.025 gcm^{-3}, 0.247±006 gcm^{-3} and 0.610±030 gcm^{-3}and 0.253±0.005 gcm^{-3} at 7.82% and 15.82% moisture levels respectively. The porosity was computed from the values of the true and bulk densities as 58.86% and 58.52% at 7.82% and 15.82% moisture contents respectively. The true density of the *M. oleifera* seeds shows that the seeds were slightly less dense than water (1.00 g/cm^3) and therefore will float on water. It was noticed also that all the gravimetric properties increased with increase in moisture content (Table 2). The unit mass increased from 0.339±0.061 g/cm^3 at 7.82% moisture content to 0.350±0.055 g/cm^3 at 15.82% moisture content. The 1000 seeds mass also increased from 272.051±11.827 gcm^{-3} at 7.82% moisture content to 273.396±8.079 gcm^{-3}. Based on the gravimetric analysis of the seed, result shown that the different moisture contents (7.8% and 15.82%) have the same effect on the true density, unit mass and thousand seed weight of the seed, except the bulk density of the seed in which there was a significant difference in their mean effects.

3.3 Frictional properties of *M. oleifera* seed

The average coefficients of friction on three different surfaces viz glass, galvanized steel and plywood were found to be 0.437±0.003, 0.481±0.002 and 0.569±0.003 respectively at 7.82% moisture content (Table 3). The average values for glass, galvanized steel and plywood at 15.82% moisture content was found to increase to 0.470±0.002, 0.570±0.002 and 0.612±0.013. It was observed that the static coefficient of friction was highest on plywood and lowest on glass. The mean angle of repose was found to be 17.834±0.351° at 7.82% moisture content and 19.345±0.409^{0}at 15.82% moisture content.

Table 2. Statistical values of the measured and calculated gravitational properties of the *M. oleifera* seed

Parameters and Unit	Moisture content (db)	N	Mean±SD	Std. Err.	t-value	95% Conf. Interval	
						Lower	Upper
True density (g/cm^3)	7.82%	10	0.510±0.025	0.008	-0.812	0.582	0.618
	15.82%	10	0.610±0.030	0.009	-0.812	0.589	0.631
Bulk density (g/cm^3)	7.82%	10	0.247±0.058	0.002	-2.506	0.243	0.251
	15.82%	10	0.253±0.005	0.002	-2.506	0.249	0.257
Unit mass (g)	7.82%	10	0.339±0.061	0.0019	-0.400	0.296	0.383
	15.82%	10	0.350±0.055	0.017	-0.400	0.310	0.389
Thousand seed mass (g)	7.82%	10	272.051±11.827	3.740	-0.297	263.590	280.512
	15.82%	10	273.396±8.079	2.555	-0.297	267.617	279.175

Table 3. Statistical values of the measured and calculated frictional properties of the *M. oleifera* seed

Parameters and Unit	Moisture content (db)	N	Mean±SD	Std. Err.	t-value	95% Conf. Interval	
						Lower	Upper
Coefficient of static friction on glass	7.82%	1	0.437±0.003	0.000867	-34.589	0.435	0.439
	15.82%	0	0.471±0.002	0.000482	-34.589	0.470	0.472
Coefficient of static friction on galvanized steel	7.82%	1	0.481±0.002	0.000593	-104.050	0.480	0.482
	15.82%	0	0.570±0.002	0.000616	-104.050	0.568	0.571
Coefficient of static friction on plywood	7.82%	1	0.569±0.003	0.000971	-9.989	0.567	0.571
	15.82%	0	0.612±0.013	0.004142	-9.989	0.602	0.620
Angle of repose	7.82%	1	17.834±0.351	0.110857	-8.871	17.785	18.085
	15.82%	0	19.345±0.409	0.129300	-8.871	19.053	19.638

eISSN: 2550-2166

4. Conclusion

The determination of selected engineering properties of *M. oleifera* seeds at two moisture content 7.82% (db) and 15.82% (db) show that the higher the moisture content present in the seed the higher the value of its length, width and thickness. This study also shows that a significant change in the moisture content will also lead to a significant change in the physical properties of the seed.

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eISSN: 2550-2166